THE

GENESIS OF ORE-DEPOSITS.

BY

PROFESSOR FRANZ POŠEPNÝ.

Reprinted, together with the Discussion Thereof, from
Volumes XXIII. and XXIV. of the Transactions of
the American Institute of Mining Engineers.

SECOND EDITION.

Containing also a Biographical Notice of Professor Pošepný, and Numerous Additional Papers and Discussions by American and European Authors, Reprinted from Volumes xxx. and xxxi.
of the Same Transactions.

NEW YORK CITY
PUBLISHED BY THE INSTITUTE
At the Office of the Secretary.
1902.

FC

GENERAL TABLE OF CONTENTS.

PREFACE TO THE SECOND EDITION.

THE first edition of this volume, issued in 1895, and containing only the famous treatise of Posepny and the discussions directly based upon it, was exhausted by an unexpectedly large demand from students, teachers and mining engineers in practice. The Council of the Institute authorized the publication of a new edition, which was at first designed to be a simple reproduction of the former one, with the addition of the Biographical Notice of the distinguished author. But the presentation of certain notable papers on this subject at the Washington meeting in February, 1900, led to the decision that these papers, with the discussions thereof, should be included in the new edition.

In the execution of this plan, it was found impossible to include papers of recognized importance, published prior to 1900, or papers on cognate subjects, such as classifications of ore-deposits, descriptions of special deposits, etc., published since. The Secretary's Note, constituting the Appendix to this volume, gives ample proof that the valuable material of these classes contained in the *Transactions* of the Institute far exceeds the capacity of a single book. Indeed, the publication of the present collection is not intended to render unnecessary the consultation of many papers not contained in it, by any one who would gain a comprehensive notion of the science to which it relates. Among such papers, it would be easy to point out not a few, equal in value to those which are here reproduced. With regard to all these, the Secretary can only express his regret that they could not be included, and his pride, nevertheless, that the material thus necessarily omitted is so abundant and so important.

R. W. RAYMOND.

DECEMBER, 1901.

PREFACE TO THE FIRST EDITION.

THE name of Franz Posepny appears in the first volume of the *Transactions* of the Institute as one of its foreign members. At the Boston Meeting of February, 1888, he was elected an honorary member, in recognition of his numerous and valuable contributions to the literature of economic geology, and particularly to the science of ore-deposits, which has borne in Germany, at least, since the days of the brilliant Cotta, the name of *Erzlagerstättenlehre.* The views of Cotta and his associates, sometimes called, for convenience, "the Freiberg school," dominated for a generation the current theories and classifications of mining engineers. This is particularly true of the United States, where the excellent translation of Cotta's text-book by Prof. Frederick Prime, one of his pupils, and one of the original members of the Institute, was for many years the controlling, and, indeed, the only easily available authority on this subject in the English language.

As a personal friend, diligent student and hearty admirer of Bernhard Cotta, and no less as professional critic of his views, I feel myself bound to say that his theories, as stated more than thirty years ago, are still, to a surprising degree, valid and comprehensive. There is scarcely a single modern modification of them for which he did not, with intuitive prescience, leave a place. On the other hand, it is a fair criticism of the whole "Freiberg school," that it gave too much prominence and attributed too much typical importance to fissure-veins of the class represented in the *Erzgebirge.* Such writers as Groddeck and Grimm have undoubtedly aided to modify this disproportionate emphasis. But it has not ceased to influence the conceptions entertained by miners, and even by legislators, as the United States mining law (evidently based on the "true fissure-vein" as a general type) abundantly demonstrates.

Posepny had contributed to the subject numerous monographs, throwing much-needed light upon it from the detailed study of special mining districts. He had been for many years devoted to this particular branch of geology, and had occupied for ten years a chair as professor in the Przibram Mining Academy, dealing exclusively with the theory of ore-deposits. When I urged him to contribute, for the International Meeting of the Institute in 1895, a paper on that subject, I did not venture to expect so generous a response as I received, in the free dedication to the Institute of a treatise comprising a summary of the views and observations of the distinguished author, and covering the whole field of his specialty. Besides its wealth of details, this treatise presents a most interesting and suggestive attempt at a genetic classification—a feature confessedly absent from most earlier systems.

The translation of Prof. Posepny's work was to me a labor both instructive and delightful; and I take pleasure in acknowledging here that my task was greatly lightened in that regard by the marvellous accuracy and beauty of the German manuscript, the whole of which came to me in the exquisite handwriting of Madame Posepná. Her husband was for some months unable to write, by reason of an injury to his hand. Probably he regarded this accident as a misfortune; but I trust he will not be offended if I say that his American translator had reason to take, with gratitude, a different view of it.*

My translation of the paper itself has received the author's approval; but the translation of his later communication, which appears in this volume in the course of the discussion, goes to press without final revision on his part. I can only infer, from his omission to return with corrections the copy sent him several months ago, that he has not found serious errors in it.

The presentation of this paper at the Chicago Meeting of 1893 was the signal for a lively and interesting discussion on the part of American geologists. That discussion has by no means come to an end; and it is likely that the impulse thus given to a renewed study of this important subject will continue to operate for a long time to come. It was, however, necessary to stop somewhere, in preparing the present volume for the convenient use of readers; and the line has been drawn at the end of Vol. XXIV. of the *Transactions* of the Institute, so as to include, with a complete analytical index, for ready reference, both the original paper and all the discussions of it contained in Vols. XXIII. and XXIV.

R. W. RAYMOND.

---

* See further remarks in the Biographical Notice of Posepny, in this volume.

BIOGRAPHICAL NOTICE OF FRANZ POŠEPNÝ.

BY R. W. RAYMOND, NEW YORK CITY.

(Atlanta Meeting, October, 1895.)

On the 27th day of March last, the day on which the Florida sessions of the last meeting of the Institute began in Ocala, occurred the death of one of its most distinguished honorary members, Bergrath Franz Posepny, of Vienna, formerly professor of the science of ore-deposits in the mining school at Przibram, Bohemia. Prof. Posepny had greatly increased his fame among American mining engineers, besides laying the Institute under special obligations of gratitude, by the elaborate, brilliant and suggestive treatise on "The Genesis of Ore-Deposits," which he contributed to the International meeting, held at Chicago, in 1893. This essay, constituting the first complete publication of the substance of his course of lectures at Przibram, enriched and perfected by the matured results of his investigation and reflection down to the date of its completion, was a free gift of almost unprecedented value to the society which had distinguished him by honorary membership. In estimating the generosity of the author, it must be borne in mind that the copyright of such a work, the fruit of years of study and of practice as an instructor, is of no little value to a European professor, and constitutes one of the legitimate rewards of his (otherwise not highly-paid) labor.

Moreover, Prof. Posepny performed under peculiar difficulties his promise to contribute this treatise. Apart from his failing health, an accidental fall had so crippled his hand that he was for months unable to write; and the whole of the voluminous German manuscript had to be dictated to his wife, in whose exquisitely clear and beautiful handwriting it came to me for translation and publication. That interesting labor, willingly performed, was greatly lessened by this circumstance; and I did not hesitate to confess to Prof. Posepny that my personal regret for his accident was considerably mitigated by the indirect gain thus occasioned to his translator.

I trust that I do not transgress propriety by saying in this place a few words concerning Madame Clotilde Posepná, who accompanied her distinguished husband in his visit to the United States in 1876 (as on so many of his other journeys and expeditions), and with whom so many members of the Institute had the pleasure of becoming acquainted at that time. With the exception, perhaps, of Sir Charles and Lady Lyell, I can recall to mind no other husband and wife so highly accomplished, so thoroughly united and so mutually complementary in scientific work. In the matter of languages, for instance, I remember hearing one of them say that, drawing a meridian through eastern Europe, they had divided the map between them; he assuming for his province the tongues east of that line, while she took care of those to the west, including all the European languages and literatures that we commonly regard as required for linguistic accomplishment. German, of course, was common ground to both. The inestimable value of such a colleague to Prof. Posepny is indicated abundantly in his treatise, already mentioned, which exhibits, on the one hand, the results of much original investigation in Eastern Europe, and, on the other hand, a wide acquaintance with the technical literature of western nations. That treatise aroused so much interest among mining engineers in this country, and gave rise to so much suggestive discussion, that a separate volume, containing the original paper, the criticisms which it elicited, and Prof. Posepny's reply thereto, carefully indexed for convenient consultation, has been issued by the Institute, to accommodate instructors and students. It was just as this edition was leaving the press that I received the news of Prof. Posepny's death; and in view of the part which his wife had taken in his service to the Institute and to science, I inserted at the beginning of the book these words,* which I here repeat, not doubting that they will be heartily adopted by every one who shall read them:

---

* This dedication, and the frontispiece-portrait of Posepny, have been omitted from the present volume.

TO

MADAME CLOTILDE POŠEPNÁ,

WIFE, COMRADE AND COLLEAGUE

OF THE DISTINGUISHED AND LAMENTED

AUTHOR OF THIS TREATISE,

THE PRESENT VOLUME IS INSCRIBED

IN WITNESS OF GRATITUDE FOR HER CO-OPERATION,

AND SYMPATHY WITH HER BEREAVEMENT.

In attempting to sketch the career of Franz Posepny, I shall make free use of the appreciative obituary notice written by his friend and colleague, Oberbergrath Ritter C. von Ernst, one of the editors of the *Oest. Zeitsch. für Berg- und Hüttenwesen*, and published in that journal April 27, 1895.

Born March 30, 1836, at Starkenbach, in Bohemia, Posepny, after preliminary courses in various Bohemian schools, entered, in 1852, the Polytechnic School at Prague, with the special purpose of pursuing the natural sciences, for which he had a native inclination. In addition to the prescribed curriculum, he zealously frequented the lectures and practical exercises in botany, mineralogy, geology, palæontology, chemistry, technology, metallurgy, etc. In order to utilize in the department of mining his knowledge of geology, he went, in 1857, to the mining school at Przibram, where he was specially interested in the lectures of Director Grimm on the science of ore-deposits. It was from Grimm (says his German biographer, on the authority of Posepny's own notes) that he heard for the first time the view that ore-deposits are characteristically confined to decomposed rocks—a doctrine which guided and influenced him for many years after. After finishing his mining course, he entered (1859) the State service, and was first assigned, without pay, to the government bureau at Nagybánya, and thence (1860), at a salary of less than 50 cents a day, to Ohlalaposbánya, in Transylvania. This region, with its complicated mine-workings and vein-phenomena, was peculiarly interesting and stimulating to an ardent young mining engineer and investigator; but he was condemned to the prosaic drudgery of auditing the old accounts of mines which had been destroyed in the rebellion of 1848, and his superior official discouraged his studies underground, telling him that he had "much more important things to attend to than going down into old mines, which could show him only rubbish and dirt." He was obliged, therefore, to pursue his favorite studies in secret until a more favorable position was assigned to him as the director (at about 60 cents per day!) of certain explorations for lignite in the district of Kovar. Here he distinguished himself by the execution of a topographical and geological map of the district, determining, on palæontological evidence, the age of the coal-deposits. This led to a recognition of his peculiar qualifications for the study of problems in economic geology; and in 1862 he was designated (at the increased salary of 75 cents per day!) to make an investigation of the ore-deposits and almost abandoned mines of Rodna, in Transylvania. This work, in which he at first received assistance from the *Geologische Reichsanstalt* at Vienna, was subsequently somewhat peremptorily and prematurely terminated, and, late in 1865, Posepny was ordered to make a similar study of the gold-mines of Verespatak. This occupied him until 1869, when he was recalled to Vienna, and directed to examine and report upon the mines of Raibl, in Carinthia. This work consumed a good deal of time, and the authorities were, perhaps, inconsiderate in their repeated demands for a hasty completion of it. Posepny was still, after 11 years of service, only an "expectant," without title and with scanty pay; and in justifiable dissatisfaction with this treatment, he accepted, in 1870, the offer of an independent position—specially created for him—as economic geologist for Hungary, with a salary and allowances amounting to something like $1000 per annum. This he occupied for two years, executing during that period many investigations of value to the Hungarian mining industry. In 1872 he returned to Raibl; finished and presented, in 1873, his official report on that district, and then went back to Hungary, to continue his study of the Schemnitz region. But by this time his services were required in a wider field; and he resigned his position in Hungary to accept that of Vice-Secretary in the Royal-Imperial Ministry of Agriculture (including mining) of Austria. In this capacity, from 1873 to 1879, he carried out in Tyrol and Salzburg a series of investigations (published in the first volume of his *Archiv für Praktische Geologie*), and also made journeys to various countries, including an extended tour in the United States.

But he was not satisfied with this achievement of official position and its sphere of usefulness. His conviction of the importance to the mining industry of the scientific study of mineral deposits had been expressed incessantly in publications, urging the introduction of special lectures on this subject in mining schools; and in 1879, the ministry with which he was connected succeeding in obtaining from the Emperor authority to establish, at the academies of Leoben and Przibram, separate chairs devoted to that department, the professorship at Przibram, together with the title of Bergrath, was given to Posepny, and occupied by him until, in 1888, he retired from public service, receiving in recognition of his merit the order of the Iron Crown.

In some respects, his labors at Przibram were the most fruitful of his life. Besides discharging the duties of the class-room, which served, no doubt, to consolidate and systematize the knowledge gathered in practice, he added to that knowledge by a diligent and minute study of the geology and vein-relations of the extensive and productive Przibram mines. This really great investigation was carried through by Professor Posepny with wonderful persistency, at great personal expense, and without assistance. Its results are to be published in the second volume of his *Archiv für Praktische Geologie*, which was in press at the time of his death.

After resigning his professorship and retiring from active service, he established himself, with his inseparable helpmate, in a pleasant cottage home in the suburbs of Vienna, where he devoted himself more exclusively than ever to his favorite studies, making journeys of observation to Transylvania, Germany, Switzerland, the Ural, France, England, Sweden, Norway, Italy, Sardinia, and finally, in the spring of 1894, to Greece and the Orient, as far as Jerusalem. His principal attention in these journeys was given to the geology and the mining (present, historical or pre-historical) of the countries he visited. That he could appreciate, however, other sentiments and associations, I have touching proof in a note which he sent me from Jerusalem, enclosing a leaf plucked on the Mount of Olives. It should be mentioned also that, in addition to his main specialty, he was an enthusiastic student, and no mean authority, in anthropology and numismatics.

During this closing period of his intensely active life, his industry might fairly be called desperate; for the increase of a long-standing pulmonary weakness, to which in these latter years a disease of the heart was added, produced in him the abiding conviction, not only that his days were numbered, but that they might at any moment suddenly end. What he accomplished with failing strength and under such a depressing consciousness, is truly amazing. Yet, in his letters to me, he never alluded to the shadow of such an apprehension; and I did not dream that his magnificent contribution to the Institute was the bequest of a dying man, and the last important work of his life. I take the liberty of translating portions of a private letter from his wife, which, although not intended for publication, are calculated to give, better than words of mine could do, a pathetic and inspiring picture of his heroic devotion:

> "Although for many months I had necessarily foreseen the sad termination of his sufferings, I could not help clinging to occasional momentary gleams of hope; and the end seemed, after all, awfully sudden.
>
> "Only with the utmost exertion did we two succeed in so far completing the proof-reading of the second volume of the *Archiv*, that nothing will now prevent its early publication.
>
> "With the kind assistance promised by his professional colleagues, I may also hope to bring out, in a year or two, a third volume. It is a purpose dear to me to publish all that he left behind. Much will, of course, appear in fragmentary form, but it will at least stimulate thought and discussion.
>
> "It is almost incredible how hard he worked, giving himself in later years no rest, because he continually looked for death. Outwardly he appeared so full of life and pleasure in life (*so lebensfroh*), and seemed to be in perfect health. But I knew better; and he himself used to be annoyed when people spoke of his good looks, for, as he said, he was always 'only a handsomely turfed grave!'"

I am unable to give at this time a complete list—still less a critical account—of the published reports and treatises of Prof. Posepny, between one and two hundred in number. This will be done, I understand, in the introduction to the second volume of his *Archiv*, now in press. Nevertheless, I may venture to express some general reflections concerning his career and his position in scientific literature.

1. Even from the bare outline of his life which I have given,

it is evident that he trod no easy path to eminence and fame. For many years he was utilized without being adequately appreciated; ordered from place to place; scantily paid and arbitrarily overruled; his far-reaching plans thwarted by shortsighted officialism, intent upon more immediate practical results. For this the government bureaus are not necessarily to be blamed. Posepny was, heart and soul, not a government official, but the lover and slave of science. And governments do not exist for the promotion of science. The utmost which they can legitimately do in that direction is to assist the progress of science on grounds of political economy; that is, as an element in the industrial prosperity of the commonwealth, and an incident of the intelligent administration of its resources. European states have gone further in theory than our own Federal government (though few have been so loosely liberal in practice) in the range of application given to this principle. But, under any government, immediate administrative necessities may often take precedence of purely scientific investigations, and the subordinates of a bureau may be commanded to devote themselves to barren routine when they would rather be "exploring the unknown."

2. Moreover, not everybody who burns with ambition to distinguish himself by increasing the sum of permanently valuable human knowledge should, on that account, be enabled, either by public or by private aid, to pursue his supposed mission at the expense of other people. Some peculiar fitness must first be demonstrated; and, on the whole, there is perhaps no better test than that of patient and obedient service, even under unwelcome restraint. The man who, like Posepny, in spite of, and in addition to, his routine duties, continues with ardor his scientific investigations, is the best man to be subsequently intrusted with such higher work.

3. But this is not all. The best training, even for a specialty, does not consist in simply encouraging the inclination of genius in one direction. We hear a good deal about education as being ideally, as it is etymologically, the "drawing-out" of what is already in the pupil. This is true enough, if we add that the best work of education is the drawing-out of faculties which the pupil does not know or believe to be in him, and that its least important function is the assistance of those domi-

nant powers and purposes which need little help. It is often in the branch for which the schoolboy shows no taste or capacity that he should be most rigorously drilled, not merely for the moral, but also for the mental, discipline thus secured. And there is nothing that contributes more potently to success in the larger school of life than the subjection of young men to work which they do not like, and in the knowledge of which they are, consequently, deficient. I say "consequently," but the consequence may be often the cause. The dormant capacity once developed by practice, many a man ends by liking a work which he understands, who began by disliking it because he did not understand it.

4. In the case of Posepny, I am not at all sure that the disappointment and drudgery of his early career were not the best things that could have happened to him. Incidentally, they gave him a much wider experience than he would have obtained by rapid promotion—which might have made of him either a conservative official, calmly contemptuous of youthful ambitions, or a library-theorist, learnedly discoursing of nature at second-hand; of both of which classes the world has enough already. They are useful in their way; but it would have been a pity to waste Posepny, in order to increase either.

The result, in his case, of the irksome discipline of fiery, unconquerable genius, was to reinforce the knowledge of literature and theory with an extensive and intimate direct knowledge of nature, and, above all, to make the chemist and geologist also a practical miner and mining engineer. The latter circumstance adds exceptional and characteristic weight to his scientific generalizations. I may add that, in my judgment, the nature of his early labors not improbably bred or deepened in him that sense of the vital importance to science of the minute observation, and purely "objective" description, of single groups of phenomena, which is so prominent in all his writings. In accordance with it, his works are mainly detailed accounts and discussions of single mining districts. In other words, he continued to the end the method of investigation which was forced upon him in the beginning by superior authority. The difference between such monographs, produced by the patient labor of months in each locality, and the sketchy results of hasty visits by expert tourists, such as constitute much of the literature of this class, requires no comment.

5. I have emphasized at some length this feature of Posepny's work, because I think it carries an important lesson for American mining engineers and geologists. We are making rapid progress in science; but we do it in a tumultuous and irregular fashion, accumulating a goodly stock of untrustworthy data and of premature theories as we go. Our young investigators are often in a hurry to promulgate generalizations; and, on the other hand, our practicing mining engineers are often too busy to observe and record facts. The two classes could aid each other more than they do; and especially those who are confined by their duties to one locality might learn from the example of Posepny that the thorough study of one locality is the most valuable contribution that can be made to general science. On the other hand, the authors of theories may profitably note that Posepny himself, as the result of wider observation, was obliged to change the views he had expressed, under the influence of preconceived impressions, in early years.

6. In my brief preface to the separate edition of "The Genesis of Ore-Deposits," issued by the Institute, I have used the following language, which I here repeat, as an introduction to some further observations upon Posepny's work:

"The views of Cotta and his associates, sometimes called for convenience 'the Freiberg school,' dominated for a generation the current theories and classifications of mining engineers. This is particularly true of the United States, where the excellent translation of Cotta's text-book by Prof. Frederick Prime, Jr., one of his pupils, was for many years the controlling, and indeed the only easily available, authority on this subject in the English language.

"As a personal friend, diligent student and hearty admirer of Bernhard Cotta, and no less as professional critic of his views, I feel myself bound to say that his theories, as stated more than thirty years ago, are still, to a surprising degree, valid and comprehensive. There is scarcely a single modern modification of them for which he did not, with intuitive prescience, leave a place. On the other hand, it is a fair criticism of the whole 'Freiberg school,' that it gave too much prominence and attributed too much typical importance to fissure-veins of the class represented in the *Erzgebirge.* Such writers as Groddeck and Grimm have undoubtedly aided to modify this disproportionate emphasis. But it has not ceased to influence the conceptions entertained by miners, and even by legislators, as the United States mining law (evidently based on the true 'fissure-vein' as a general type) abundantly demonstrates."

Of the two authorities named in the above extract, as aiding to modify the views of the "Freiberg school," Bergrath Dr. Albrecht von Groddeck, whose treatise appeared in 1879, was the director of the Prussian Mining Academy at Clausthal. His treatment of the science of ore-deposits was chiefly characterized by the recognition of numerous "types," and the citation of leading examples under each type. Oberbergrath Johann Grimm, whose treatise appeared in 1869, was director of the Austrian Mining Academy at Przibram, in Bohemia; and it was in Grimm's lecture-room, from 1857 to 1859, that Posepny received his first working-theory of the nature and origin of mineral deposits. I must confess that I cannot find in Grimm's book, published ten years later, the sweeping generalization to which, on Posepny's authority, Ritter von Ernst (as quoted by me above) alludes; and I am led to suppose that the veteran instructor had seen cause, before 1869, to modify his views. However that may be, it was as a disciple of Grimm that Posepny began his work; and it was only after years of patient study of facts in the field, that he promulgated any comprehensive system of his own.

7. That system, his matured statement of which is found in "The Genesis of Ore-Deposits," cannot be said to involve any appeal to newly-discovered causes, or any denial of accepted principles in geology. The same is true of all systems proposed since the exclusive agency of plutonic action on the one hand, or of aqueous action on the other, was recognized as untenable. They have all been simple attempts to classify the observed facts for fruitful study, and to estimate the relative importance of the several natural agencies which were universally recognized as factors. For the purpose of classification, the chief distinctive characters have always been: (1) The time-relations of a mineral deposit, as formed simultaneously with

the enclosing rock, or as a regular member of a series of rocks, or as a later segregation or intrusion; (2) its form; (3) the manner and agencies of its origin; and (4) its contents. Of these characters, sometimes one and sometimes another has been treated as the primary distinction. Gold-, silver-, lead-, and copper-mines, etc., may have been the leading classes in a system designed for convenient use in practice; veins, stockworks and impregnations may have been separated as groups of independent significance in another practical system; original deposits may have been combined with deposits of subsequent formation, if both were supposed to have originated through the same processes, etc. For the purposes of science, it will probably be admitted that a genetic classification is to be preferred; and such a classification Posepny proposed. That it was not final or complete he acknowledged, not only expressly in words, but tacitly by his preliminary division of minerals as "idiogenous" and "xenogenous," and the practical confinement of his genetic classification to the latter. It is, of course, plain that the idiogenous minerals must likewise have had a genesis, and that a complete genetic classification would include them, not as a separate primary group, but as parts of other groups, determined by the conditions and agencies of their origin. Posepny's system, beginning as it does with the rocks already formed, and ignoring their prior genetic history, is, to that extent, an avowed compromise. But it is on that basis to be judged, and not by comparison with something more ambitious and comprehensive, at which the author did not pretend to aim. My views on this subject have been sufficiently set forth elsewhere; and the position of Posepny has been so clearly and fully stated by himself as to render further exposition needless.

8. In fact, the present state of the science of mineral deposits is such as to render any man's system of classification a matter of subordinate pedagogic importance. The declared purpose of Professor Posepny, in the presentation to the Institute of what he at first entitled "Subjective Views of the Origin of Ore-Deposits,"* was to invite criticism and discussion. This purpose was unquestionably realized in a discussion (not

---

* See my remarks, *Trans.* xxiv., 980, and in the present volume, p. 233.

yet ended) of great interest and value. And the remarkably stimulating effect of that treatise seems to me typical of the chief permanent effect of the author's whole work, in the field in which he became pre-eminent. I believe it will be the verdict of his successors, as of his contemporaries:

a. That he furnished an example of unselfish and unqualified devotion to science, which will be an inspiration forever.

b. That he contributed to science, in his special department, an immense amount of careful and accurate fundamental work, which can be confidently relied upon as trustworthy material for future study, being guaranteed, not only by his eminence in general science, but also by his familiarity, as a mining engineer, with operations and observations underground.

c. That, on the basis of his wide observation, coupled with his extensive knowledge of technical literature, he exerted a potent influence in promoting the scientific study of ore-deposits and in correcting extreme theories and tendencies which have tended to bias and distort that science.

9. In the last proposition, I have in mind more particularly the controversy which Posepny and his friend, the late Prof. Stelzner, of Freiberg, waged against the lateral-secretion theory of Prof. Sandberger. In this debate Posepny no doubt assumed to some extent the attitude of a partisan; and, perhaps, in some respects, his controversial utterances may have gone beyond a judicial impartiality. This has been pointed out more than once by his critics, and particularly in the discussion of his recent treatise in the *Transactions* of the Institute. As I have elsewhere declared, I think he was right in his general view and argument, and I will here do no more than call attention to the circumstance that those of his statements which have been seriously contested by American authorities were mainly based upon the publications of others, not upon his own observation. Many such publications are affected with "subjective" opinions; many of them are unaccompanied with accurate drawings; and many of them lack precision in description, and are, therefore, liable to misinterpretation. It is no wonder that in single cases Posepny may have mistaken the intended meaning of an author or accepted too hastily an assertion too hastily made. But it must be confessed that, as a whole, his survey of the literature of his subject was singularly comprehensive, intelligent and fair.

10. As I have observed already, Posepny's final work was not offered as the last word of science in that field. We now know, what he knew when he wrote it, that it was *his* last word—the utterance of one who was about to turn over to others the results of a life-labor still incomplete, and surpassing in fruitful suggestion even its illustrious record of accomplished achievement. The loss of such a man at any time is deplorable; but doubly so when he departs in the prime of years, just prepared for the ripest and richest harvest of all his planting. Posepny's views will still incite and reward discussion; but we shall sorely miss the ablest of expositors and critics in Posepny himself.

It has been my endeavor in the foregoing sketch to preserve the standpoint of disinterested justice; but I cannot deny that, while I have been thus coldly analyzing and estimating the scientific leader, there has been constantly present with me a vision of the splendid presence of my own dear friend. I never saw him but once—at the time of his visit to this country in 1876. But that meeting confirmed the personal attraction already exercised upon me by his works; and our subsequent intercourse by correspondence made the charm perpetual and indissoluble. A few such friends I may still count in foreign lands, unseen, yet ever present; and it sometimes seems to me that these relations of mind and heart, which defy separation in space, are the best types of the relation which defies death also. At all events, I find that he and I, who could be together, though confined to the Old and the New World respectively, are not less mutually near, now that one of us has entered the World which lies so close to both.

THE GENESIS OF ORE-DEPOSITS.

By Prof. Franz Posepny, Vienna, Austria.

CONTENTS.

Introduction.

Part I.—General Facts and Theories.

INTRODUCTION.

ALL serious investigators of this problem have recognized its complex character, and the difficulty of solving it definitely in the present state of our knowledge. Single and simple occurrences are at present clearly understood; but the more complicated phenomena give rise to discordant and often totally contradictory views, showing that we are still far from the truth upon this subject. The study of it has been the labor of my life; yet I must confess that the little I have here and there accomplished bears no proportion to the great range of inquiry. I collect, nevertheless, in this paper, some of the personal views to which I have been led, chiefly in order that they may be submitted for consideration and discussion to my American colleagues.

Looking upon a single, somewhat complicated ore-deposit, we must confess that a superficial, tourist's examination of it could not give satisfactory results. Yet the literature of this subject refers us to such materials chiefly. Even treatises based upon the profound studies of years do not exhaust the subject; for they are affected by the existing stage of development of the auxiliary sciences, by the existing degree of exploration and exposure of the deposits described, and by the personal views of their authors.

Mining, indeed, constantly furnishes fresh evidences in new openings, but it destroys the old at the same time; and if these are not preserved for science before it is too late, they are lost forever. The whole mining industry is in its nature transitory; but the nation, which intrusts to the miner, upon certain conditions, the extraction of its mineral wealth, has a right to demand that the knowledge thus gained at the cost of a part of the national resources shall not be lost to science.

PART I.

GENERAL FACTS AND THEORIES.

1. Systems of Classification Employed Hitherto.

Studies of individual deposits naturally involve speculations concerning their genesis, and many such monographs contain valuable data, which, for the more thoroughly examined mining districts, are so well established and so comprehensive as to invite a systematic arrangement and a genetic explanation. At first, only the form of the ore-deposit was considered in such classifications; afterwards the barren surrounding medium was included. From this standpoint, unfortunately still taken by some purely empirical experts, the earth's crust is primarily divided into ore-bearing and barren rocks.

It was especially the *true veins*, at one time the principal objects of mining, which gave rise to speculations and discussions, having now only a historic interest.* A. Werner was the first to frame a scientific theory. He distinguished between ore-deposits contemporaneous in origin with the enclosing rocks and those of subsequent formation, and proved once for all that veins are fissures filled with ore, thus furnishing the most important characteristic for the recognition of primary and secondary formations. As to the manner in which fissures have been filled, Werner's theory, based upon a comparatively limited field of observation, has, like many of his neptunistic views, failed to maintain itself; and this question remains still without a final answer.

Curiously enough, many systematizers reproached Werner for having introduced into his system a genetic principle, which they sought to eliminate, confining themselves to the form of deposit as a guide. Thus Waldenstein (*op. cit.*, p. 5) distinguished (*a*) tabular deposits (beds and veins); (*b*) stock-deposits, flat-lying or steeply inclined; and (*c*) scattered masses, such as nests and pockets.

Even Cotta, otherwise an earnest advocate of geological principles, classified ore-deposits according to their form and kind as beds, veins and masses, adding a new and somewhat indefinite group of "impregnations." J. Grimm† also followed in the main the old principles of classification; included in his system the eruptive ore-breccias which he had personally examined and the tabular segregations of ore, and pronounced not only ore-beds (*Erzlager*), but also certain bed-masses (*Lagerstöcke*) to be sedimentary formations. Dr. A. von Groddeck‡ followed genetic principles already acquiring predominance. He distinguished: (*a*) original deposits, and (*b*) deposits of débris. The former he subdivided into (1) those formed contemporaneously with the country-rock, and stratified (ore-beds, segregated beds, etc.) or massive; (2) those formed later (cavity-fillings, veins, cave-deposits, metamorphic deposits). He pronounced ore-beds (*Erzlager*) to be sedimentary, and included in his sys-

---

* The period 1556 to 1791, that is, from G. Agricola to A. Werner, is an illustration. See also *Die Besonderen Lagerstätten der Mineralien*, by J. Waldauf von Waldenstein, Vienna, 1824, p. 164, etc.; *Die Lehre von den Erzlagerstätten*, by B. von Cotta, 2d ed., Freiberg, 1859, p. 85, and the English translation by F. Prime; and J. A. Phillips' *Treatise on Ore-Deposits*, London, 1884, p. 74, etc.

† *Die Lagerstätten der nutzbaren Mineralien*, Prague, 1869.

‡ *Die Lehre von den Lagerstätten der Erze. Ein Zweig der Geologie*, Leipzig, 1879.

tem the cave-deposits and metamorphic deposits without describing their occurrence in detail. He declared that his system, like all others, had only the purpose of arranging the material of observation conveniently for comprehensive study, and that the manifold products of nature could not be forced into a system of classification.

Groddeck's description of the series of forms of deposits is highly original. He presents a number of types, mainly characterized by the varying material of the deposits and its manifold combinations and transitions. Evidently there was before him the ideal of combining in a systematic representation the different standpoints from which the subject was to be viewed. At least, if I correctly understood his personal, oral communication of his views, he hoped to represent one standpoint by abscissæ and the other by ordinates, so that the intersection would determine the type of the deposit. This is true enough; but it presupposes an exhaustive knowledge from both standpoints, which we unfortunately do not possess. My way of looking at the subject was, as appears from his expressions in a later publication, incomprehensible to him.* It seemed to him a sort of heresy to doubt the contemporaneous deposition of the ore of the Mannsfeld copper-schists with the rock, although I assured him that this doubt need only continue until the chemical and physical possibility of such a deposition should be shown.

Groddeck's system comprises, it is true, the metamorphic deposits, but without special definition or illustrative examples. In answer to a criticism of A. Stelzner's† on this point, he replies that he has included in this class those deposits also which have been formed through alteration of the rock-material by the process which Stelzner had proposed to call metasomasis, but that the ore-bearing masses thus originated cannot be regarded as separate deposits, because they are only incidental phenomena of the filling of cavities. In other words,

---

* "Bemerkungen zur Classifikation der Erzlagerstätten," *Oesterr. Zeitschr.*, 1885; *Rev. Univ. des Mines*, 1886, xix.; *Gornoj Jour.*, 1886, iii., p. 430. "Unverständlich ist es mir, dass Pošepný, der sich so grosse Verdienste um die Kenntnisse der Erzlagerstätten erworben hat, das Vorkommen sedimentärer Erze ganz ignorirt," etc.

† Cited in *Das neue Jahrbuch für Mineralogie*, ii., 1880, p. 50.

he grants but subordinate rank to one of the clearest and most important genetic aids to classification, furnished by the occurrence of rocks transformed into ore. After conceding that deposits of dêbris should probably be included among stratified deposits, he restricts his system to four chief classes: 1. Stratified or sedimentary deposits; 2. Massive or eruptive deposits; 3. Cavity-fillings; 4. Metamorphic and metasomatic deposits. This brings him essentially nearer to my view, which groups the first two classes together, as contemporaneous with the country-rock in origin, with the reservation, however, that the contemporaneity indicated by the stratigraphy should be verified by other evidence.

While the work of J. Grimm comprises all useful deposits, that of Groddeck is confined to ore-deposits, although it would be practicable to classify salt, coal and other beds under his system.

In England and America the subject has been variously viewed, considerations of practice being predominant, and stratification being regarded as the specially decisive factor. This conception appears first, so far as I know, in the writings of J. D. Whitney,* who divides mineral deposits primarily into (1) superficial, (2) stratified and (3) unstratified. The stratified deposits are divided into (*a*) those in which the valuable mineral constitutes the mass of a bed, (*b*) those in which it is disseminated through sedimentary beds, and (*c*) those originally deposited from aqueous solution, but since metamorphosed. The unstratified deposits are again divided as irregular [subdivided into (*a*) masses of eruptive origin (*b*) disseminated in eruptive rocks; (*c*) stock-work deposits; (*d*) contact deposits; (*e*) fahlbands] and regular [subdivided as (*f*) segregated veins; (*g*) gash-veins; (*h*) true or fissure-veins].

We find here an explanation of the term "gash-veins," unfamiliar in Europe. Whitney says (*op. cit.*, p. 225):

> "Segregated veins, which are peculiar to the altered crystalline, stratified or metamorphic rocks, are usually parallel with the stratification and not to be depended on in depth. Gash-veins may cross the formation at any angle, but are peculiar to the unaltered sedimentary rocks. True veins are aggregations of mineral matter, accompanied by metalliferous ores, within a crevice or fissure,

---

* *Report of a Geological Survey of the Mississippi Lead Region*, Albany, 1868, p. 224, and *The Metallic Wealth of the United States*, Philadelphia, 1854, p. 34.

which had its origin in some deep-seated cause, and which may be presumed to extend for an indefinite distance downwards."

Somewhat different is the classification of R. Pumpelly,[*] who distinguishes: I. *Surface-deposits* [(1) residuary, (2) stream-, (3) lake- and bog-deposits]. II. *Forms due to the texture of the enclosing rock or to its mineral constitution, or to both* [(1) disseminated concentrations, further subdivided as (*a*) impregnations and (*b*) fahlbands; (2) aggregated concentrations, comprising (*a*) lenticular, (*b*) irregular masses or "stocks," (*c*) reticulated veins or "stock-works," (*d*) contact-deposits]. III. *Forms due chiefly to pre-existing cavities or open fissures* [(1) cave-deposits; (2) gash-veins; (3) fissure-veins].

Dr. R. W. Raymond,[†] who followed, in the main, the classification of Lottner,[‡] distinguished: I. *Superficial Deposits* [(1) Deposits of débris (placers); (2) surface-formations in place (bog-ore, etc.)]. II. *Inclosed deposits* [(1) sheet-formed or tabular, divided into (*a*) lodes or veins, and (*b*) beds and seams; (2) mass-deposits, divided into (*a*) masses, and (*b*) impregnations, etc.; and (3) other irregular deposits, such as (*a*) pockets distributed in large deposits, (*b*) isolated segregations, gash-veins, etc.].

Prof. J. S. Newberry[§] adheres mainly to the classification of J. D. Whitney, with some new matter of his own, the value of which has been justly estimated by Raymond.[||]

An analogous line of thought is followed by J. A. Phillips.[¶] He declares that a careful study of the origin, structure, and composition of ore-deposits, appears to justify their division into the following groups: 1. *Superficial* [(*a*) formed by the mechanical action of waters, (*b*) resulting from chemical action]; 2. *Stratified* [(*a*) constituting the bulk of metalliferous beds formed by precipitation from aqueous solutions, (*b*) beds

---

[*] Not possessing the original work, I quote from the monograph of S. F. Emmons, *Geology and Mining Industry of Leadville*, Washington, 1886, p. 373.

[†] *Report of the Commissioner of Mining Statistics*, Washington, 1871, and the reprint, *Mines and Mining of the Rocky Mountains*, New York, 1871, p. 373.

[‡] *Bergbaukunde*, Berlin, 1878.

[§] "The Origin and Classification of Ore-Deposits," *School of Mines Quarterly*, New York, March, 1880; also, *Eng. and Min. Journal*, New York, vol. xxix., 1880, pp. 421 and 437.

[||] *Eng. and Min. Journal*, vol. xxx., 1880, p. 1.

[¶] "A Treatise on Ore-Deposits," London, 1884, p. 3.

originally deposited from solution, but subsequently altered by metamorphism, (*c*) ores disseminated through sedimentary beds in which they have been chemically deposited]; 3. *Unstratified* [(*a*) true veins, (*b*) segregated veins, (*c*) gash-veins, (*d*) impregnation, (*e*) stock-works, (*f*) fahlbands, (*g*) contact-deposits, (*h*) chambers or pockets].

In France, comparatively little has been done in framing such systems, higher importance being attached to the synthesis of the minerals, the explanation by experiment of geological processes, and the attempt to confirm by the study of mineral-deposits in other countries the theories thus supported. Observations have been made in many cases, not to furnish material for new conclusions, but to prove the truth of existing theories, as, for instance, Elie de Beaumont's theory of "pentagonal symmetry" in the relation between mineral veins and the courses of mountain ranges, etc.

In recent times, the chemical standpoint has become dominant with the French school, and in the treatise of De Launay,* which has just appeared, the attempt is, in fact, made to base a system of ore-deposits upon a purely chemical view of the subject. He distinguishes: 1, *Gîtes d'inclusions* (ores as primitive constituents of eruptive rocks); 2, *Gîtes filoniens* (containing ores deposited, no matter how, in pre-existing cavities in the rocks); and, 3, *Gîtes sédimentaires* (where metallic substances have been laid down, either as sediments or as precipitates, in marine- or fresh-water basins). In another place I will say something of this view, which, in some respects, corresponds with my own.

It is evident from the foregoing mere enumeration of the names of groups and classes of the several systems that, as a general rule, every new observation, considered important by the observer, has been added to the established traditional conception, which, however, was primarily based upon distinctions of form and kind, to which genetic principles, if recognized at all, were secondary. I may refer, in illustration, to the class of "pipe-veins," and the exhaustive paper of Dr. Raymond† demolishing it. I myself once thought a new

---

* "Formations des Gîtes Metallifères," *Encyclopédie Scientifique, des Aide-memoires publiée sous la direction de M. Léauté*, Paris, 1893.

† *Trans. A. I. M. E.*, vi., 1887, p. 393.

group to be warranted by conclusive observations, namely, *typhonic* deposits,* in which the ores occur cementing together the fragments of a brecciated mass. But I soon became convinced by the observation of other occurrences, equally difficult to fit into the existing system, that the whole system must be transformed before it could assimilate, without destruction to itself, the new facts observed in the course of time.

But a stable and complete system could only be framed, when all the controlling facts—in other words, all the ore-deposits—were accurately known. This is not likely ever to be the case. New observations are constantly made in mining operations, which, moreover, often obliterate the old ones, so that they cannot be verified and compared.

It is, however, absolutely necessary, in a field so complicated as that of ore-deposits, to have some general understanding, some sort of system, comprising what is known. And evidently, in framing a system, the characters of form, being the most obvious and the most familiar to the miner, would be naturally emphasized, while genetic characters were left in the background. But this ought not to check genetic investigation, or the advancing recognition of real relations. A genetic system must, indeed, involve hypotheses, and may not, for a while, be practically useful; but in time it will, like every other cultivated branch of geology, assume more permanent forms.

At the Przibram Mining Academy there was established, in 1879, a new chair of "The Geology of Mineral Deposits," which I occupied for about ten years. As the title indicates, it was neither intended merely for instruction in the usual "science of mineral deposits," nor as a geological course, appended to the technical course in mining, as might be inferred from a title like "*Montangeologie*," or "Mining Geology." The leading subject in view was the genesis of the useful mineral deposits. In the present paper I purpose to give a brief statement of the substance of my lectures, which, apart from a few extracts, have never been published.

---

* "Ueber typhonische Gesteinsmassen," *Verh. d. k. k. geol. Reichsaust.*, 1871, p. 94.

2. Standpoint and View of the Present Paper.

The principal genetic distinction is doubtless between deposits contemporaneous with the country-rock, and those subsequently formed in it.

The earth's crust consists of rock-elements, chiefly individualized as mineral species. Two or three dozen of them—the rock-forming minerals—constitute by far the larger part of the solid earth as known to us. The remainder, much greater in number and variety, ornament our mineral cabinets, but form an insignificant portion of the rocks. The greater part of this group is made up of the legion of minerals occurring in ore-deposits; and most of these have undoubtedly had a secondary origin in the rocks—for instance, all the cavity-fillings, which of course could only be deposited after the rocks were formed. The secondary origin of some minerals which do not occur in cavity-fillings is less evident. But they occur sometimes in company with those which clearly have this character; so that we may consider these numerous minerals, occurring in comparatively small quantities, as secondary.

We have two main groups of mineral aggregates: that of the *rocks*, and that which we will call comprehensively *the mineral deposits*. The minerals of the first group belong to it as native and original; those of the second are foreigners to the rocks in which they occur. The two groups may therefore be designed (from ἴδιος, one's own, and ξένος, strange) as *Idiogenous* and *Xenogenous* respectively.

It is not necessary here to consider the various origins of rocks, since we take as our starting-point the rocks already formed. The clearly sedimentary rocks consist of the débris of older formations—idiogenous as well as xenogenous; and we must distinguish in them, besides mechanical sediments, chemical precipitates and organic products.

The sediment of a basin is the detritus carried into it from the land and deposited in the form of a flat wide cone. Successive conical envelopes should therefore strictly be the form of such sedimentary beds, though frequently they present apparently level parallel strata. The deposition of a precipitate, on the other hand, takes place throughout the liquid in the basin, and its form more completely represents the ideal *stratum*. In both sediments and precipitates, we find sometimes, besides organic remains, finely divided organic substances, forming the bituminous portions of the rocks. But the great masses of vegetable matter forming the coal-beds were, according to the most widely held opinion, deposited in swampy bottoms, and are therefore neither sediments nor precipitates. Several coal-beds, one above another, indicate a slow sinking of the basin, and its periodical filling-up with detritus from the rivers to such an extent that vegetation could again take root.

A coal-basin with several beds becomes on this view the measure of the sinking which is doubtless the cause of every large basin, but which only becomes strikingly evident when the basin contains coal-seams.

The foregoing points are mentioned because they indicate original discordances in stratification among the sedimentary layers themselves, and between these and the precipitates and organic formations.

If we find in the midst of these formations ores lying exactly between two strata, this relation is not conclusive proof of their sedimentary or precipitative origin. This must be proved in every given case; for in the present state of our knowledge we cannot understand how the metallic sulphides so characteristic of ore-deposits could be formed in that way.

As to the eruptive rocks, we do not know what they once were, as we study them only from the moment of cooling. But we observe at once that iron—a metal widely distributed in ore-deposits and in nature generally, occurs primitive in these rocks, in the form of magnetite, a mineral of striking metallic appearance.

This idiogenite of the eruptive rocks can be detected without chemical aid; but with such aid we find traces of other metals besides iron; and this leads us to surmise that the eruptives have brought a whole series of heavy metals up from the "barysphere" into our "lithosphere," and that it looks as if the metals of our ore-deposits originally belonged to the barysphere. This surmise De Launay regards as already proved. He derives, as it were, *a priori*, all the heavy metals of our ore-deposits from the eruptive rocks, and erects upon this hypothesis an entire system.

3. The Xenogenites in General.

With relation to the xenogenites or mineral deposits, the first question concerns the space which every secondary mineral or mineral-aggregate requires to establish its existence. It must either have found this space waiting for it, or it must have made room by driving out an original mineral.

Although we shall chiefly consider cavities formed in rocks after the formation of the rocks themselves, we must not forget that some may have been primitive in the rocks. We know that in substances of the greatest apparent density small cavities or pores must exist, since we can, for instance, by adequate pressure, force quicksilver through them. Moreover, we encounter in the eruptive rocks larger cavities, suited to receive considerable mineral-aggregates—the so-called blow-holes. These phenomena must certainly be considered, although the cavities of secondary origin will first be the subject of attention.

With regard to the filling, I observe, first, that the mineral deposits upon the walls of cavities, from liquids circulating within them, usually have a characteristic structure, for which I propose the name "crustification," as a companion to "stratification." (Single crusts were formerly called mineral shells or scales; and Groddeck introduced the word "crust," which is comprehensible in most languages.)

Most frequently mineral crusts occur concentrically in regular succession, and fill the whole cavity (except the central druse), thus forming a symmetrical crustification. They cover, however, not only the cavity-walls, but the surface of every foreign body in the cavity, thus forming crusted kernels which greatly complicate the phenomenon. We shall see, however, that a geode-cavity serves much better than a fissure-cavity to explain the relations of crustification, and that the crusted kernels will give us no trouble in that regard.

Sometimes mineral crusts have undergone a secondary alteration (carbonates are replaced with silica, etc.). The crustification is thus made less distinct, or even obliterated. As a general rule, however, *crustification is a characteristic feature of cavity-filling.*

The cavities are formed either by mechanical or by chemical forces; and these two classes must be sharply distinguished, in view of the important rôle of each. The former may be the effect of exterior and foreign forces, or of such as are interior, residing in the rock itself. Formerly I called such spaces (with reference mainly to the accompanying fault-phenomena) "Spaces of Dislocation;" but I believe the term "Spaces of Discission" (from *scindere*, to tear apart) would be more suitable. The latter class I formerly called "Spaces of Corrosion" (with reference to the effect of the leaching and attacking liquids); but I would now substitute the more self-explanatory name "Spaces of Dissolution."

Spaces of dissolution naturally occur in soluble rocks, especially limestone, and show, with wonderful clearness, the irregular course often followed by underground waters. At and near the surface, we often find the cavity-formations at the contact of soluble with insoluble rocks; and we may infer that this relation affects also the subterranean circulation. Solution seldom extends to the whole mass of the soluble rock. Usually it affects a part only, in which it forms more or less irregular chains of cavities, sometimes so large that pieces of roof fall in, and thus spaces of discission are locally produced. A cavity filled with secondary mineral, however irregular its form may be, and even though it cuts across the stratification, usually shows a predominant course, which we are thus led to recognize as the channel of circulation of the liquid to which we owe the mineral deposit.

As I shall show later, we must assume that the liquid which formed the space of dissolution also performed the filling; in fact, that both processes were almost contemporaneous. Nevertheless, they must not be confounded with the metamorphic processes where the idiogenite is expelled, atom by atom, by the xenogenite; for the deposits in spaces of dissolution show always a distinct crustification, and hence every single crust, at least, must have found free space waiting for it.

Concerning the origin of spaces of discission, so much has been written that it cannot even be stated in abstract here. Two groups of these are distinguished. Those of the first group do not extend beyond one rock, and the force which produced them probably has its seat in that rock. In the eruptives, they are usually deemed fissures of contraction; in limes and dolomites, J. D. Whitney called them gash-veins.

The cavities of the second group extend out of one rock into another. The force which produced them resided outside of the formation. Considerable movements of one wall along the other are often evident, whence the common name, "fissures of dislocation."

In a paper upon this subject*, about twenty years ago, I attempted to show that every fissure, in whatever material, must properly be a fissure of dislocation; that the tendency to dislocation (namely, an unequal tension in the rock) precedes the formation of fissures; and that whenever the condition of the rock permits, a dislocation of the fissure-walls can be always traced, even in fissures of contraction.

As to the filling of spaces of discission, it must not be supposed that they represent throughout their entire length open spaces of uniform width. The original fissure was sometimes closed, wholly or partially, by the detritus originating in the friction of the walls, or by the movement or "swelling" of the country-rock, or by other causes. Only the places remaining open would permit an active circulation of solutions and a regular deposition from them. At points obstructed there would be no circulation, or a very sluggish one. When high pressure was present, and the rock contained interstices, the liquid doubtless penetrated from the fissure into the rock, impregnating it with mineral; or a soluble rock was attacked, and spaces of dissolution were formed, to be filled in like manner as the fissure itself.

This explains the fact that, on the same vein-plane, rich deposits alternate with poor or barren spots, and that the miner, seeking a bonanza, persistently follows the barren traces of the vein, according to a well-known, fundamental law of prospecting.

From the genetic standpoint, the richer portions are interesting as sometimes occupying more or less regular belts in the vein-plane, called "channels," "shoots," "chimneys," etc. These names evidently designate the main channels through which the mineral solutions passed; and the occurrence of such forms in most kinds of deposits tends to prove that, notwithstanding other differences, they were all formed in a similar way.

---

* "Geol. Betrachtungen über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, xxii., Vienna, 1874.

The *primitive* rock-cavities (pores and blow-holes) may also be filled with secondary minerals. In the former, there results a finely disseminated mineral substance, constituting such a deposit as Cotta denominated *impregnation.* Blow-holes are very often filled with minerals of the quartz family (opal, chalcedony, etc.), and we are often able to infer from the structure of such geodes the process by which they were filled.

Where the mineral solutions found no cavity already prepared, they must have conquered the necessary place by expelling a corresponding part of the original material. When one mineral individual was replaced by another, as in cases of pseudomorphs, the nature of the process can often be inferred from a comparison of the composition of the two; and the laws thus discovered may frequently be applied to the problems of the origin of mineral aggregates. Many phenomena, however, even in the formation of pseudomorphs, are hard to explain,—the fact, for instance, that in some minerals the change commences within the mass and progresses outward, etc.

Where the original material was expelled, there must have been first an access for the liquids which began and executed this effect. Such may be furnished by original minute rock-cavities, or by secondary cavities.

The original substance of the greater part of the pseudomorphs known to us was composed of soluble minerals, such as carbonates, sulphates, and chlorides, which also occur as the elements of rocks. Hence it may be inferred that metamorphous or metasomatic deposits will be especially frequent in soluble rocks like limestone, dolomite, etc., and that we may also expect such deposits to occur frequently in company with those which fill spaces of dissolution.

Pseudomorphs show us one substance in the crystal-form of another. This indication is lacking for the recognition of metasomatic deposits; yet sometimes the original rock was characterized by peculiar structure, such as lamination or jointing—as, for instance, the cellular structure of the *Rauchwacke* (*Cargneule*), which is reproduced in the cellular calamine which has replaced it. Moreover, the original rock may have contained fossils, which have been replaced, with the rest, by the new mineral, retaining their form; for instance, the bivalves and mollusks of the Bleiberg limestone in Carinthia and at

Wiesloch in Baden, reproduced in galena and calamine; the brachiopods of the Silurian iron-ores of central Bohemia, etc.

Most important for the study of the process are transitional forms between the earlier and the later material; for instance, coatings of the latter upon kernels of the former, such as limonite upon siderite or ankerite; and likewise important is the occurrence of regular pseudomorphs, replacing one element in a heterogeneous rock, like those of cassiterite after feldspar in the granite of Cornwall.

After the expulsion, atom by atom, of the original material, the resulting deposit must be massive, showing no crustification.

Frequently, however, there are only negative indications of the metamorphosis. It can be seen merely that the deposit is not an original rock; that it has not been deposited in preexisting primitive or secondary cavities; and hence, that it must have been formed by replacement.

In general, two kinds of metamorphous deposits may be distinguished. In the first, the new material has replaced the more soluble ingredients of a heterogeneous rock, and the result resembles the description of an impregnation, in which the new material occupies the original interstices of the rock. In the second, a part or the whole of a homogeneous rock has suffered metamorphosis, and the deposit will bear a certain resemblance to filled cavities of dissolution.

As I have shown above, and will illustrate further on with some examples, we may thus establish certain types of deposits entirely without reference to form. Some of these may coincide with groups in earlier systems, but others appear together in one and the same group. This seems at first not to favor the practical usefulness of the above principles, but, as I have said, we do not yet know enough to frame a final system. That must be the aim of future studies, and it is obvious that our purely genetical factors will be more helpful than the arbitrary characters based upon the exterior form of deposits. We distinguish, then, *Idiogenites*, or deposits contemporaneous in origin with the rock, from *Xenogenites*, the deposits of later origin, including not merely those of ores, but mineral deposits in general; and to these we may add, in harmony with some older systems, the deposits of débris as a third class, *Hysterogenites*, or latest formations.

The *Xenogenites* we divide into such as penetrated pre-existing cavities (filling primitive cavitives, spaces of discission, or spaces of dissolution), and the metamorphic or metasomatic deposits, which made room for themselves by the expulsion of an earlier material.

The form of all these deposits is not fixed, but depends upon various geological relations of the country-rock. The mention, under former systems, of regular forms of deposit, contemplated rather the ideal of the system itself. In reality, the ore-bodies in "veins" and "beds" are irregular, and form masses for which the most various names exist in all countries.

We must now speak more particularly concerning the method of formation of the different deposits. Probably no one doubts at the present day that they are predominantly the result of humid processes of solution and deposition. But such generalities are not enough. The processes alleged must be put upon the basis of actual causes, still operative, and capable of being proposed and discussed in explanation of geological phenomena. It is, therefore, necessary to introduce, at this point, the theoretical chapter which follows.

4. The Subterranean Water-Circulation.

In treating of the genesis of mineral deposits, this department cannot well be so lightly handled as it is in most text-books of general geology. Prof. A. Daubrée, in an authoritative discussion of the subject,* ascribes the mineral deposits, among other effects, directly to the liquids circulating underground. It is my desire, with the aid of personal observations incidental to my continuous study of such deposits, to present a somewhat closer view than that of Prof. Daubrée.

Surface phenomena exhibit clearly a constant circulation of liquids, and corresponding phenomena, so far as they are observable underground, indicate the persistence of this condition, so that we must infer a subterranean circulation connected with that of the surface. We have then to consider, first, the surface-phenomena, so far as they concern our purpose, and, second, the underground phenomena.

As to the former, we know that it is chiefly the solar energy

---

* *Les eaux souterraines a l'époque actuelle*, etc., vols. i. and ii., Paris, 1887; and *Les eaux souterraines aux époques anciennes*, etc., Paris, 1887.

which initiates the circulation by lifting above the land the water of the sea, and thereby imparting to it the potential energy which is variously exhibited in its return to the sea. The mechanical effects of flowing water* in erosion, transportation and sedimentation need not occupy us here. As to the chemical effects, we know that the mineral constituents of the rocks, dissolved through this circulation, chiefly find their way in the rivers to the sea. In regions without drainage to the ocean, the dissolved minerals are concentrated by evaporation, which may lead to precipitation. I would remark, however, that in my opinion small proportions of salts are mechanically taken up in the evaporation of sea-water,† as careful analyses of rain-water have proved, and that this fact leads to the explanation of the salt and salt lakes in regions without drainage, etc.

A. *The Vadose Underground Circulation.*

In connection with the underground phenomena, the *ground-water* has for us a special interest. As is well-known, a portion of the atmospheric precipitate sinks, through open fissures or through the pores of permeable masses, into the rocks, and fills them up to a certain level. When in a given terrain, by wells or other openings, the ground-water (that is, the water-level, *Grundwasserspiegel, nappe d'eau*) has been reached at several points, it is found that these points are in a gently inclined plane, dipping towards the deepest point of the surface of the region, or towards a point where an impermeable rock outcrops. The ground-water is not stagnant, but moves, though with relative slowness, according to the difference in height and the size of the interstitial spaces, down the plane mentioned, and finds its way, in the first instance, directly into the nearest surface-stream, or, in the second instance, forms a spring, which takes indirectly a similar course. Thus stated, free from all complications, the phenomenon exhibits clearly the law of circulation. The atmospheric moisture evidently descends; and even the movement of the upper layer of the ground-water is only apparently lateral, but really downwards,

---

* *Die Wasserfälle des Niagara und ihre geologische Bedeutung*, by F. Pošepný, Vienna, 1879.

† "Zur Genesis der Salzablagerungen, besonders Jener im Amerikanischen Westen," *Sitz. Ber. der k. k. Acad. d. W. im Wien*, 1877.

and is determined (for equal sectional areas of the rock-interstices) by the difference in height between the water-level and the surface-outlet.

For that part of the subterranean circulation, bounded by the water-level, and called the vadose or shallow underground circulation, the law of a descending movement holds good in all cases, even in those complicated ones which show ascending currents in parts. The total difference in altitude between the water-level and the surface-outlet is always the controlling factor.

When these two controlling levels are artificially changed, as often happens in mining, the law still operates. In sinking a shaft through permeable ground, it is of course necessary to lift continuously the ground-water. The water-level thus acquires an inclination towards the shaft, which may thus receive not only the flow of the immediate vicinity but even also that of neighboring valley-systems. A shaft imparts to the previously plane water-level a depression, giving it the form of an inverted conoid with parabolic generatrix. An adit produces a prismatic depression in the water-level; and so on for other excavations. On the other hand, a bore-hole, from which the water is not removed, does not affect the water-level.

Atmospheric waters falling upon impermeable rocks at the surface cannot penetrate them, but must join the existing surface-circulation. The rocks are usually covered with more or less detritus, in the interstices of which the ground-water can move; and the water-level is in most cases at the boundary between the permeable surface-formation and the impermeable rock below.

These relations are complicated by the occurrence of fissures (which the ground-water of course fills), and by the communication of such fissures in depth with permeable formations, which come to the surface somewhere at a lower level, though at great distance. In such cases, as is well known, a siphon-action is set up, and the ground-water of one region may find an outlet far away, even beyond a mountain range.

Peculiar conditions are created by the occurrence of relatively soluble rocks, such as rock-salt, gypsum, limestone and dolomite, in which, by the penetration of meteoric waters and the circulation of the ground-water, connected cavities are formed, constituting complete channels for the vadose circulation.

It is often possible to observe directly, not only the formation but also the filling of these cavities, and thus to obtain valuable material for the explanation of the origin of xenogenites outside the vadose circulation, and not observable in the stages of formation.

It is for our purpose a most valuable fact, that the phenomena of leaching indicate the path of the circulating liquids through soluble rocks, so that we can study the process in its several stages. The water flowing at the bottom of a cave in limestone is unquestionably ground-water; and it follows that the whole complex group of cavities has been eaten out by it. If in another limestone cave we see no flowing water, the current must have found some lower outlet; and the cave represents for us an ancient ground-water channel.

The many and various phenomena of the Karst region are well known: the *Dolins*, *Ponors* and *Katravons*—points where a surface-stream sinks into the earth; vertical openings, at the bottom of which flow subterranean streams; and caves out of which streams issue—illustrating the whole series of the entrance, the course and the exit of subterranean waters.

In 1864, I had opportunity to observe, at Máros Ujvár, in Transylvania, a very instructive illustration of this kind, which is shown in Fig. 1. Here the rock-salt comes to the surface with steep zigzag stratification, and is covered only with detritus, to the depth of a few meters.* Mining is carried on in great parallelopiped-shaped chambers, by means first of levels run horizontally from a shaft, and winzes sunk vertically from these. The workings were at that time 125 meters or 409 feet deep. A great difficulty in the extraction was the entrance of saturated brine from that side of the mine where the Máros river flowed by. Until the mine had been protected by an adit of semi-circular course in the impermeable rock, surrounding the salt-body, the water annually raised and delivered without utilization into the river contained 84,000 tons of salt, or more than twice the weight of the rock-salt mined.

---

* "Studien aus dem Salinargebiete Siebenbürgens," by F. Posepny, *Jahrb. der k. k. geol. Reichsanst.*, 1867, xviii., p. 506–516.

Various investigations have proved that the water of the river passes through the overlying detritus to the salt-body, which it penetrates at the boundary of the impermeable rock of the hanging-wall, finding its way through separate channels to appear as saturated brine, at the deepest point of the mine-workings. These channels had most frequently a cylindrical shape, smooth walls, and sometimes so great a diameter that a man could crawl in. There were always several to be seen, of which, of course, only the lowest in position brought the brine.

The explanation is simple. The water from the river, reaching the salt-body through the detritus cover, acted at the border of the salt, where the principal depressions in the surface were located, and the saturated brine thus formed filled all interstices in the adjoining salt-body. By the leaching of such solutions into each deeper level opened in the mine, a line of maximum activity of circulation was gradually formed, which was followed also by solutions not yet saturated, with additional leaching and the final creation of open channels as the result.

An example on a large scale of such a channel in rock-salt, created, however, without the aid of mining operations, was recently described by H. Winklehner,* who found among other striking phenomena of lixiviation in the rock-salt of the islands of the Persian Gulf, a horizontal natural channel or adit, on the island of Larak, which he was able to follow for about 1½ kilom. (1 mile). It expanded in places to caverns 12 m. (39 feet) high, without ever extending outside of the salt.

In precisely the same way were formed the channels in other less soluble rocks, such as limestone, when, the level of the entrance being above that of the exit of the ground-water, a line of maximum activity of circulation was established between the two points. This line, and the cavities developed along it, would not, indeed, always have the regular parabolic course, but would be dependent upon various influences of the stratification, the presence of rocks of unequal solubility, or even an intermixture of impermeable rocks. A mass of the latter, oc-

---

* "Salzvorkommen in Süd-Persien," *Oesterr. Z. für Berg-und Hüttenwesen*, 1892 xl., p. 581.

curring on the line connecting the two points named, might cause the channel to bend up and down, or even in places to assume an upward inclination.

Figs. 2 and 3 illustrate these conditions. S is the soluble, I the impermeable rock; *a*, the entrance-point and *z* the outlet-point of the ground-water; *a b c z*, the line along which approximately a channel might be made, if the impermeable rock were not present. In its presence, the dissolving current must take another road, *a d z*, following more or less the contact between S and I, and in Fig. 2, descending to a depth proportioned to the relation between the original rock-interstices and the hydrostatic head, while in Fig. 3 it first surmounts the dam formed by the impermeable rock, and then plunges towards the outlet *z*. We see that in this way various channels may originate at the contact of permeable and impermeable rocks, as indeed we find them often in nature.

But when to these factors fissures are added, the conditions are essentially changed, for the circulation follows in preference the open fissures, and, if they pass through soluble rocks, enlarges them by solution.

Sometimes the position and the level of the outlet are altered —as, for instance, in the progressive erosion of valleys; and it may then easily happen that the new channel, representing the new conditions, will take a totally different direction, crossing the line of the old one.

Siphon-action is to be observed in soluble, much more frequently than in permeable rocks, as the frequency of intermittent springs in limestone indicates. Such springs presuppose the existence of a siphon-like channel, through which the ground-water cannot flow to escape from the lower leg until the water-level has risen to the top of the bend of the siphon.

We have seen that the ground-water may traverse deep fissures leading to soluble or permeable rocks, and may follow such rocks for considerable distances. When the ground-water, warmed in depth, has an opportunity to reach the surface, such as is given in Fig. 6 by the difference, H, in level, a thermal spring is the result—a so-called *acrotherm*, if its water is not highly charged with minerals, and not unlike the ground-water of the place.

Artesian wells present an analogous case, also explained hitherto by the principle of hydrostatic pressure (see Fig. 7). The outcrop of the permeable layer has been assumed to be necessarily higher than the mouth of the well, in order to account for the rising of the water above the latter level. The cause has been conceived as the operation of communicating pipes, the drill hole being one leg, and the permeable layer the other, and it has been overlooked, that the latter is no open pipe, but a congeries of rock-interstices, in which the water has to overcome a great resistance, and that, perhaps, in level regions no hydrostatic head at all can be demonstrated. Certainly the powerful factor of the higher temperature, and in some cases the gaseous contents, of the ascending water, were omitted from the calculation.

It would be a matter of surprise to me, if the purely hydrostatic and strictly mathematical views heretofore current on this subject had not led to disappointment. I introduce Fig. 7, the conventional diagram of an artesian well, for the purpose of stimulating further thought on the matter.

The Filling of the Open Spaces Formed by the Vadose Circulation.—This is very important genetically, since it is a matter subject to current and direct observation, and capable of furnishing conclusions applicable to inaccessible subterranean occurrences.

We can observe spaces on the bottom of which, frequently, the ground-water which excavated them is still flowing, and which are therefore filled for the most part with air. Liquids carrying various minerals drip into these spaces and leave a part of their contents on the walls; the cause of deposition being, on the one hand, the evaporation of a part of the liquid, or, on the other hand, such changes as the loss of carbonic acid, precipitating as carbonate the soluble bicarbonate of lime; the oxidation of soluble ferrous to insoluble ferric oxide; the reduction of ferrous sulphate by organic matter to sulphide, etc. The form and structure of these precipitates vary at different parts of the walls. On the roof occur the *stalactites*, and on the floor (if it be not covered with water) the corresponding *stalagmites*. The wall-deposits have characteristic forms likewise; so that we can recognize by the appearance of any piece of the deposited mineral the place where it was formed. But from water covering the bottom of the cavity only horizontal deposits can orginate. Sometimes the cavity is contracted, so that its whole cross-section is occupied by the liquid. If it is accessible to observation, we can then see that the deposits from the circulating liquid cover the walls uniformly.

This can be much more clearly observed in artifical conduits, where precipitation occurs. We find, for instance, in the pipes which convey concentrated brine, the walls uniformly covered with a deposit, mostly of gypsum. But if air or gas is admitted into the pipes, the deposit occurs only at the bottom. We may thence infer that so long as the circulating liquid fills the whole cavity the attraction of the walls for the precipitated particles is controlling; but that when gas enters, gravity becomes predominant and draws these particles to the bottom.

In opal and chalcedony geodes we can often see both forms of precipitate: the crust uniformly covering the walls, and the horizontal deposit. Fig. 4 represents a geode of iron-opal, from Dreiwasser, in Hungary, in which, besides the crustification and horizontal deposit, stalactitic and stalagmitic forms also appear. A thin crust of translucent hyalite covers all parts of the wall, including the floor. The cylindrical stalactites are also of hyalite. Some of them extend to the bottom, and are perhaps joined to stalagmites rising from the crust there. The remaining space is half filled with a milk-white, opaque, opaline substance, in which occurs a thin layer of translucent hyalite. On the same specimen several other less regular cavities are visible. All of them were lined with the hyalite crust, and some have also the opaline layers. These layers are parallel in all the cavities; and it cannot be doubted that they were horizontally deposited. The stalagmites stand at right angles to them, and were unquestionably vertical when formed. The geode certainly occupied, therefore, at the place of formation, the position shown in Fig. 4.

I must resist the temptation to describe the manifold forms of deposit in limestone caves. Fig. 5, an ideal diagram, showing a wall-accretion, and stalactites and stalagmites, separate and grown together, is given, not to illustrate the variety of the phenomena, but to indicate their analogy with those of the little geode in the iron-opal of Fig. 4. It is easy to conceive, that, under some circumstances, particularly in old cavities, lying above the water-level and not subject to further enlargement, the formation of stalactites, etc., might ultimately fill the whole space.

The floor of caves often shows deposits colored with ferric oxide, the explanation of which is obvious. Sometimes we find in the upper caves traces of sediments also; and, in one instance I found in an outlet-cave pebbles of very hard rocks, which certainly came from the surface.* The chemical reaction of the formation and filling of these caves are so simple as to need no discussion here.

Much more various observations, however, can be made in the *artificial caves*, formed by mine-workings. Here we have conditions analogous to those of the natural caves, but much greater variety, since the most widely different substances come into play. The mine-workings are situated at an artificially depressed water-level, and will show, in general, processes analogous to those observed in limestone caves, particularly the formation of stalactites. From calcareous rocks, from mineral deposits, and from the mine-masonry, crusts, stalactites and sinter are formed, analogous to those which occur in cavities at the natural water-level. Processes of oxidation will here also play the leading part, although reduction may also be effected through the more abundant organic matter in the mine-waters. Thus stalactites of pyrites, evidently reduced from ferrous sulphate by organic matter, are often found in metal-mines. A respectably large number of observations already illustrates the processes which are going on under our eyes in mines, and from which we can draw conclusions as to the destruction and creation of many minerals by circulating under-ground solutions. But we must not forget that these proofs apply only to the conditions of the shallow or vadose circulation, and that, for the explanation of the formation of the more ancient deposits, we must look to the rock-regions below the water-level.

In order to give at least one American example, I refer to the observation of Raymond, who found in an old Spanish mine, in the Cerillos range of New Mexico, an iron pick-axe, the eye of which was filled with beautifully crystallized galena,

---

* "Geol. mont. Studie der Erzlagerstätten von Rézbánya in S. O. Ungarn," von F. Posepny, *Ung. geol. Gesellsch.*, 1874, p. 48.

evidently a reduction of lead sulphate by the decaying wood of the handle of the pick.*

It may be said, in general, that the results of the processes of oxidation, chlorination, and reduction, observed in those regions of ore-deposits which lie above water-level, have come to pass under conditions analogous to those just described; so that we are able to adduce extended series of proofs, not only as to formations now going on, but also as to similar formations long since finished.

B. *The Deep Underground Circulation.*

Thus far, we have considered only such processes as take place in the region above water-level, and are still, in some cases, open to our observation. As we descend to a deeper region, there is less hope of encountering formative processes still active. When we penetrate by mining into the depths, we artificially depress the water-level, and create conditions unlike those which attended the formation of the deposits.

But, if we compare the deposits formed below water-level, under proportionally greater pressure and at higher temperature, with those of the upper region, it appears beyond doubt that the former also must have been produced by deposition from fluid solutions.

When we compare the low solubility of certain ingredients of the deposits with the spaces in which they occur, often in large quantity, it is impossible to assume that they could have been precipitated from solutions existing in these spaces only. We must concede that immense volumes of solutions must have flowed through the spaces—in other words, that the deposits were precipitated from liquids circulating in these channels.

The formation of these cavities has been already discussed, and referred to mechanical and chemical causes. It remains to consider the manner of their filling. We have seen that the uppermost layer of the ground-water has an apparently lateral, but really descending movement; and it is very natural to imagine that this top layer slides, as it were, upon a lower mass, which is apparently stagnant. According to this con-

---

* *Trans. A. I. M. E.*, 1883, xi., p. 120.

ception, the deep region would be comparable to a vessel filled with various permeable, impermeable, and soluble materials, over which water is continually passed, so that, from the moment when all the interstices have been once filled, only the uppermost water-layer has any movement.

But, with increase of depth, the pressure of the water-column increases, as does the temperature. The warm water certainly tends to rise, if not prevented by interstitial friction, as is, no doubt, generally the case. But where the warmed water finds a half-opened channel communicating with the upper region, it will experience much less friction on the walls, and must evidently ascend. It might thus be conceived that the ground-water descends by capillarity through the rock-interstices over large areas, in order to mount again through open channels at a few points.

This subject was viewed by A. Daubrée in a much wider significance, and extended to cover the origin of volcanic phenomena.* He propounded the inquiry, whether the enormous quantities of steam which are daily liberated from the deeper region are continually replaced from the surface, and if so, how? He pointed out that this water-supply could not take place through open fissures, in which the liquid water descended at one time and the steam ascended at another, but he showed that the descent could be effected through the porosity and capillarity of the rocks. Jamin's experiments have taught us the influence of capillarity upon the conditions of the equilibrium established by means of a porous body introduced between two opposing columns. Daubrée constructed an apparatus in which the temperature in one part of the capillary passage was so high that the liquid must assume the form of steam, and thus escape the operation of the laws governing its infiltration. This apparatus comprised a sandstone slab, with water above and a chamber below, the latter provided with a manometer for measuring the pressure of the steam collected in it. The whole was exposed to a temperature of about 160° C. (320° F.), and steam collected in the chamber of 68 cm. mercury-column, indicating about 13 pounds over the atmospheric pressure in the manometer, or a total pressure of about 1.9 at-

---

* *Synthetische Studien zur Experimentalgeologie*, by A. Daubrée; German translation, by Dr. A. Gurlt, Brunswick, 1880, p. 180.

mosphere. This steam could only come from the water above the sandstone through which, in spite of the pressure, a capillary filtration took place.

> "The difference in pressure on the two sides of the stone not only did not drive the liquid back, but permitted it to filter quickly from the colder side (100° C. = 212° F.) to the hotter (160° C. = 320° F.), and favored the rapid evaporation and the drying of the hot stone surface" (*op. cit.*, p. 184).
>
> "According to these experiments, therefore, water may be found by capillarity, operating in the same direction as gravity, against a strong interior counter-pressure, to descend from the shallower and cooler regions to deeper and hotter ones, where, by reason of acquired temperature and tension, it is capable of producing great mechanical and chemical effects" (*op. cit.*, p. 186).

Daubrée's experiment confirms our view that the portion of the ground-water lying below water-level is not stagnant, but descends by capillarity, and since it cannot be simply consumed in depth, receives there through a higher temperature a tendency to return towards the surface, which tendency is most easily satisfied through open channels. Stated summarily:* The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and, reaching these, it ascends through them to the surface.

The solvent power of the water increases with temperature and pressure, and also with the duration of its underground journeying. Hence, while it is descending, it can dissolve or precipitate only the more soluble substances. But the ascending current in the open conduits is undoubtedly loaded more heavily and with less soluble substances, which, as the conditions of their solubility (temperature and pressure) gradually disappear in the ascent, must be deposited in the channels themselves.

The open channels, in which the solutions ascend, are not the deductions of theoretical speculation. They really exist, as we can prove by induction from appropriate observations.

The Ascending Waters Encountered in Mines.—A number of such phenomena are adduced by H. Müller.† For instance, in

---

* *Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten*, von F. Posepny. *Extrait du compte rendu de la 3me. session du Congrès géologique international.* Berlin, 1885, p. 71.

† "Ueber die Beziehungen zwischen Mineralquellen und Erzgängen." Cotta's *Gangstudien*, vol. iii., 1860, p. 261.

the Gottes Geschick mine, near Schwarzenbach, in the Erzgebirge, at the depth of 110 m. (360 feet) an acid spring containing CO_2 and H_2S emerges from a nickel- and cobaltiferous-silver ore-vein (*op. cit.*, p. 286). At the Wolkenstein Bad, an acid spring comes from the druses of an ore-vein containing a crust of barytes and amethyst. In the Alte Hoffnung Erbstollen mine, near Mitweida, bad air and exhalations of carbonic acid led, in 1835, to an analysis of the ground-water, which proved to be weakly acid. In the Churprinz mine at Freiberg a warm (25° C. = 77° F.) acid spring was struck on the Ludwig Spat vein at the depth of about 160 m. (525 feet). Besides these, Müller names a number of mineral springs occurring in Bohemia and Saxony at the outcrops of mineral veins never opened by mining. In spite of the great reserve which he exhibits, he summarizes his view as follows (*op. cit.*, p. 307):

> "Mineral veins and mineral springs are certainly adapted to complement each other in genetic theory. On the one hand, the ore-veins, as extended, indefinitely deep fissures, gradually filled, indicate a very profound origin for the mineral springs, and suggest variations caused by time and circumstances in the amount and mutual reactions of their contents, solid or volatile; and, on the other hand, the present relations of mineral springs explain the mode of ingress and deposit of the constituents filling the veins."

Soon after this publication (I think in 1864), a thermal spring of 23° C. (73° F.) was struck at a depth of 533 m. (1748 feet) in the Einigkeit shaft, at Joachimsthal, and in the same mine at two other points similar mineral springs, rising with strong pressure, were exposed. They prevented further increase in depth of that part of the mine, and were plugged as far as practicable. The analysis made in 1882 showed that they were acid springs containing considerable silica (33 grammes per ton). In one of them arsenic was also proved to the extent of 22 grammes per ton.*

The mineral waters of the Joachimsthal mines are said to come in contact, near the place where they were encountered, with basalt-like rocks (called *Wacken*), which traverse the ore-veins, and are, therefore, of later origin. In general, most of

---

* Since the metric ton of 1000 kilo., or the weight of $m.^3$ (1 cubic meter) of water, is a rational unit of weight, I refer all tenors to it, and state them in grammes or milligrammes to avoid decimals. Thus 22 grammes per ton represents 0.022 per thousand, or 0.0022 per cent.

the ore-deposits of the Erzgebirge appear to have a decidedly recent origin, but even from this standpoint the mineral springs found in mining are to be regarded as nothing else than the continuation of those ascending liquids which have filled the ore-veins. Mining depresses the water-level, so that mineral waters circulating in the neighborhood are forced to those points in the mine where there is only atmospheric pressure.

This "neighborhood" may, indeed, extend to a comparatively long distance. For instance, the thermal spring at Carlsbad, which is the nearest to Joachimsthal, is 17 kilom. (10.5 miles) away and 380 m. (1246 feet) above sea-level, while the spring in the Einigkeit shaft at Joachimsthal was struck at 206 m. (675 feet) above sea-level, that is, 174 m. (571 feet) lower than Carlsbad. The irruption of the thermal waters of Teplitz in Bohemia into the lignite-mine of Dux, 7 kilom. (4 miles) away, which took place first in 1879, and has occurred recently since, shows plainly that subterranean communications may thus be established for long distances by mining,*

Additional data for the study of these relations are furnished by the miners on the Comstock lode, where, with the advancing depth of operations, ascending thermal waters were unexpectedly encountered, the abundance and high temperature of which presented extraordinary obstacles to mining. The great richness of the deposit was the reason that the hope of going deeper was not abandoned, as in Joachimsthal, where the only effort was to dam out the waters from existing workings; but that, on the contrary, the struggle was accepted against the waters themselves and the enormous heat which they caused in the mines.

As is well known, the upper workings on the Comstock, before any ascending waters had been encountered, were not specially hot, though warmer (21° to 24° C., or 70° to 75° F.) than other mine-workings in similar positions. Dr. F. Baron v. Richthofen noticed no abnormal mine-temperature, although he ascribed the Comstock to earlier solfataric action.†

---

* "Einige, die Wassereinbrüche in die Duxer Kohlenbergbaue betreffende, geologische Betrachtungen," von F. Posepny. *Oesterr. Zeitsch. f. Berg-u. Hüttenw.*, 1888, xxxvi., pp. 39–54.

† *The Comstock Lode, Its Character and Probable Mode of Continuance in Depth*, San Francisco, 1866, p. 54.

At a later period, upon the cutting through of clay-partings in the rock, the hot-water repeatedly broke into the workings with great force, as, for instance, in the North Ophir mine, when, according to Clarence King,* the workmen had scarcely time to escape. The water is said to have had a temperature of 40° C. (104° F.), and filled the workings immediately to a height of 30 m. (100 feet). In another case the water broke into the 2200-foot level of the Savage mine, and filled the large spaces both of that mine and of the Hale and Norcross up to the 1750-foot level, or to a height of 137 m. (450 feet). Gas was continually but not violently evolved; and although Prof. J. A. Church† reports it to have been under a pressure of 200 pounds per square inch, he believes that this was not a gaseous, but a hydrostatic pressure.

The water which in 1880 flooded the Gold Hill mines came from a bore-hole in the Yellow Jacket shaft, at a depth of 939 m. (3080 feet); had, according to George F. Becker,‡ a temperature of 77° C. (170° F.); and was heavily charged with hydrogen sulphide. In the upper levels of the mine, Becker says there is evidence of the presence of carbonic acid, and on the 2700-foot level where the temperature was 66° C. (150° F.) a deposit of sinter was found, consisting mainly of carbonates. Church (p. 206) remarks that it was at first believed that the repeated irruptions of water came from chains of cavities existing in the rock, but that at the time of his visit the conviction was that they came through shattered and decomposed seams, parallel with the lode, and sometimes of great thickness.

Systematic and long-continued temperature-observations in several Comstock mines enabled Becker to represent comprehensively for different lines the increase of temperature with depth; and it thus appeared that this increase was greatest in the vicinity of the lode, diminishing with the distance from the lode; that the vehicle of heat was the water; and hence that it was through the lode itself that communication with the hot depths took place, and the phenomenon denominated "solfataric action" by Richthofen was caused.

---

* *U. S. Geol. Expl. of the 40th Parallel*, vol. iii. *Mining Industry*, Washington, 1870, p. 87.

† *The Comstock Lode, Its Formation and History*, New York, 1879, p. 207.

‡ "Geology of the Comstock Lode," etc., *U. S. Geol. Survey*, Washington, 1882, pp, 230, 386.

The chemical constitution of these intruding waters will be considered further on, after certain phenomena occurring nearer to the surface have received attention.

Related Phenomena Near the Surface.—A sort of transition to the corresponding phenomena on the surface itself is illustrated by the mines at Sulphur Bank, Cal., which have furnished some of the most important data contributed by America to the study of the genesis of ore-deposits.

This is a once rich, but now (apparently) practically exhausted quicksilver-mine, in the working of which not only thermal waters but gaseous emanations were encountered as obstacles. At the time of my visit in 1876 an open-cut exploitation was in progress, the terraces of which had extended in some places about 5 m. (16 feet) below the natural surface. Sulphur, as well as quicksilver, was won; but it subsequently appeared that the sulphur-deposit was confined to the uppermost zone, while the quicksilver (or cinnabar) extended in considerable proportions to deeper regions.

At that time I found sulphur and cinnabar in a decomposed basalt, partly as the filling of irregular fissures, traversing the rock in all directions, partly as impregnations in the rock itself, which had often been reduced to a porous mass. The process of decomposition proceeded unquestionably from the fissures, which, moreover, gave forth hot mineral waters and gases. The odor alone was sufficient proof that the gases contained H_2S, to the oxidation of which into SH_2O_4 the acid reaction of the rock and its moisture was to be ascribed. The miners (mostly Chinese) chiefly followed in extraction the fissures (partly because it was the easiest way to make rapid progress; partly because the richest ores were there concentrated); and, as a result, large round blocks, often several meters in diameter, were left standing. These had a distinct shaly structure, but were so loosely held together that a kick would reduce them to ruins. In the interior of the larger, light-gray blocks, was often found a nucleus of solid, dark, undecomposed rock. (Some of these *nuclei* I have added to the collection of the Przibram Mining Academy.)

The cracks were filled chiefly with an opaline mass in which a white, opaque ingredient was variously kneaded, as it were, with a gray to black one, translucent at the edges. The specimens taken fell into irregular pieces, bounded by fissures, evidently the result of loss of volume or loss of moisture by the opaline mass.

The cinnabar formed either distinct mineral crusts in the crevices or impregnations of the porous neighboring rock. This was true of the sulphur also; only, the latter appeared, as a rule, in crystalline aggregates upon the cinnabar crusts—an indication of its later origin. Occasionally the cinnabar was deposited in beautiful crystals on the fissure-walls, but these were generally so loosely attached that it was difficult to secure a specimen.

The pyrites, mostly disseminated in the rock, tended so strongly to decomposition, evidently by reason of its saturation with sulphuric acid, that specimens containing it soon fell to pieces.

These observations suffice to show that in this case hot mineral-waters ascend through fissures containing ore-crusts and opaline deposits; and when it is considered that the deposit of amorphous, hydrated silica is unquestionably the work of the mineral water which decomposed the rock, and, also, that the cinnabar occurs in the interior of the opaline mass, the two phenomena cannot well be separated, and it must be assumed that a metallic sulphide has here been deposited from an ascending spring. Fig. 10 represents the exposure as sketched in my note-book.

Later developments exhibit these relations still more clearly. Le Conte and Becker* found a shaft 50 m. (164 feet) from the basalt, about 92 m. (302 feet) deep in sandstone, from which drifts had been run northward at different levels under the outcrops of the deposit. It is to be regretted that their reports are not accompanied with precise descriptions of the mine-workings. In the third level (64 m. = 209 feet below the surface) the drift was 70 m. (230 feet) long, "cutting through the ore-body and reaching only barren rock on the

---

* "The Phenomena of Metalliferous Vein-Formation, Now in Progress at Sulphur Bank," by J. Le Conte and W. B. Rising, *Am. Jour. of Sci.*, xxv., p. 424.

"On Mineral Veins, Now in Progress at Steamboat Springs, Compared with the same at Sulphur Bank," by J. Le Conte, *Am. Jour. of Sci.*, xxv, p. 424.

"Geology of the Quicksilver-Deposits of the Pacific Slope," by G. F. Becker, *Monograph U. S. Geol. Surv.*, Washington, 1888, p. 251.

other side. The fourth level has been pushed 31 m. (101 feet), and has reached the ore-body." From these data it is hardly possible to form an idea of the position of the ore-body traversed.

The data given concerning the interior structure of the deposits are, however, important. Sandstones and slates are here broken up by fissures in such a way as often to form a breccia. Whether the fragments belong together, and whether they present the relation which I have denominated typhonic, is not stated; but it may be inferred from the sketch of an ore-specimen from this place that the fragments do not belong together, and that their condition has been brought about by more extreme dislocations. The subject is highly important for us; and I have attempted in Fig. 11, although the original is not before me, to represent it according to Le Conte's sketch, so as to place it side by side with other phenomena thoroughly familiar to me.

The fragments of slate and sandstone have somewhat rounded edges, and leave varied interspaces, which are filled, partly with a still soft or already indurated paste, containing finely disseminated metallic sulphides, partly with cinnabar, for the most part in coherent crusts. A part of the space is usually empty, exhibiting what I call a central druse. Sometimes, it is said, the rock-fragments are cemented together with massive cinnabar, and kernels of rock crusted with cinnabar occur frequently.

Hot mineral water and gases carrying H_2S force their way through the interstices of the deposit, as was the case observed in the upper zones. The silica deposits are found in all stages of consolidation, from a gelatinous mass to chalcedony and (Leconte, *op. cit.*, p. 29) alternate with layers (crusts) of metallic sulphides (cinnabar and pyrites). Becker examined the whole neighborhood, and extended his studies to similar ore-deposits of the region. He does not consider the basalt of Sulphur Bank, as do G. Rolland* and Le Conte, to be a lava-stream, but takes it to be an eruptive rock, originating on the spot, which has overflowed a fresh-water formation of recent age. The bottom proper is a Cretaceous sandstone. The ore-bearing character extends from the basalt (about 16m.=52 feet thick)

---

* "Les Gisements de Mercure de Californie," *Annales des Mines*, 1878, p. 26.

through the fresh-water layers in to the Cretaceous sandstone. Concerning its relations in the middle layer we have no data, which is unfortunate, since the effects of the acid waters upon this calcareous material must have been considerable, and it is not unlikely that the deposit had in this region a totally different character. Fresh-water formations adjoining the deposit have preserved to a remarkable degree plant-roots, etc., transformed into lime carbonate; and it would be very instructive to study their forms as metamorphosed by the mineral water.

Concerning the chemical constitution of the warm (80° C.= 176° F.) water, I shall speak further. According to Becker's analysis (*op. cit.*, p. 259), it is extraordinarily rich in chlorides, borax and sodium carbonate. The gas liberated from it often proved to be ammoniacal, and consisted in 1000 parts of 893 parts CO_2, 2 parts H_2S, 79 parts CH_4 (marsh gas) and 25 parts nitrogen.

As to the presence of other metals besides mercury, it is worthy of mention that Dr. Melville found small amounts of gold and copper in the marcasite accompanying the cinnabar, and that G. Becker found in the efflorescence from the mine-workings, besides the substances detected in the mineral water, traces of cobalt and nickel.

As will be seen, this deposit furnishes genetic data, concerning not only the ores of quicksilver, but also those of other metals. An ascending mineral spring here passes from the deep into the shallow region, and suffers, besides the reduction of pressure and temperature, the oxidation of its H_2S, from which result a strong acid and the deposition of sulphur nearest the surface.

In depth no sulphur is found, but sulphides of quicksilver and iron, upon or within deposits of silica, both being in distinct alternating mineral crusts. It cannot be doubted that cinnabar and pyrites on the one hand, and silica, on the other, have been precipitated from the solution which still ascends in these channels. At most, it may be doubted whether this precipitation is still going on. Le Conte adduces in support of the probable continuance of the process the occurrence of silica sometimes gelatinous and soft, as if recently precipitated. Becker and Melville tried to obtain direct evidence of the presence of quicksilver dissolved in the ascending mineral water of to-day, but their careful investigations failed to find it. Although the water contains ingredients in which quicksilver is soluble, there is no quicksilver dissolved, and it must have been already precipitated by some agent—as they suggest, ammonia.

There are among geologists unbelieving Thomases enough, who will believe in the presence of quicksilver in the mineral solution only when it has been actually precipitated for them; but there are those, on the other hand, who are convinced by the evidence thus far gathered that the sulphide deposits of this locality proceeded from the ascending thermal spring, whether the process of precipitation is still going on or not.

Equally weighty data are furnished by Steamboat Springs in Nevada, to which Laur and J. A. Phillips first called attention, and which Le Conte and Becker investigated thoroughly.* In a valley surrounded with eruptive rocks, but underlain chiefly by Archæan rocks, thermal springs may be seen at several points emerging from north-and-south fissures. The action of these springs has covered the ground with a sinter-deposit, predominately of lime carbonates, about 15 m. (49 feet) thick. In this sinter may be traced many fissures, here and there still open, but mostly closed by the deposit of silica on their walls. According to a sketch given by Le Conte, these very clearly crustified deposits extend somewhat above the general level of the surface, forming single mounds or chains of mounds.

From some of them hot vapors and gases still issue, chiefly CO_2 containing H_2S. In others, such emanations have been so greatly diminished that only by listening can the liberation of vapor in depth be perceived. Some of the fissures are completely filled, and give forth neither mineral water, steam nor gas.

In the group, about 200 m. (656 feet) wide and 1 kilom. (0.6 mile) long, which lies nearest to the railway-track, these phenomena are most strikingly exhibited. Besides the principal

---

* M. Laur, "Sur le gisement et l'exploitation de l'or en Californie," *Annales des Mines*, 1863, iii., p. 423.

J. A. Phillips, *Phil. Mag.*, 1871, xlii., p. 401. Also *A Treatise on Ore-Deposits.* London, 1884, p. 70.

J. Le Conte, "On Mineral Veins now in Progress at Steamboat Springs Compared with the Same at Sulphur Bank," *Am. Jour. Sci.*, xxv., p. 424.

G. F. Becker, "Geology of the Quicksilver-Deposits of the Pacific Slope," *Monograph U. S. Geol. Survey*, Washington, 1888, pp. 331.

substances mentioned below in the table, Becker found in this mineral water also small amounts of metallic compounds, as, for instance, HgS, a trace of Na_2S, 1.0 gramme per ton of Na_2SbS_3, and 8.7 grammes per ton of Na_2AsS_3.

About 1½ kilom. (1 mile) to the west is a group of similar fissures, yielding some steam and CO_2, but no mineral water. In the mineral crusts of these, however, several metallic sulphides occur. In 1863, Laur declared that he had seen in them distinct traces of gold. In 1878, one of these fissures was opened by an adit, about 15 m. (49 feet) under the surface, and produced a vein-matter carrying cinnabar, which was mined for a while as quicksilver-ore. The temperature of this mine was not so high as to cause serious trouble to the workmen.

G. F. Becker carefully analyzed the filling of several fissures, and found, besides hydrated ferric oxide, considerable quantities of Sb, As, Pb, Cu, Hg sulphides and gold and silver, as well as traces of Zn, Mn, Co and Ni. Since from 1 to 3.5 kilog. (2.2 to 7.7 lbs.) of the vein-stuff were employed for each analysis, the results are specially trustworthy, and I give the records of three analyses here, expressing them in grammes per ton (1 ton = 1,000,000 grammes):

	I.	II.	III.
Sulphides of antimony and arsenic,	......	23,000.0	150.0
Ferric oxide,	......	2,500.0	......
Sulphide of mercury,	1.4	2.5	1.0
Lead,	88.0	21.0	......
Copper,	0.3	12.0	......
Gold,	0.9	1.0	......
Silver,	0.3	0.3	......

(Considering the gold and silver to be alloyed in the above proportions, we should have bullion 0.750 and 0.769 fine, which is the general grade of the so-called "free gold" of Transylvania.)

The careful study of the phenomena, particularly by G. F. Becker, leaves no doubt that in this case ascending mineral waters have deposited, besides the various forms of silica (from opal to crystalline quartz), different metallic sulphides, and that the fissure-fillings exhibit a very clear instance of crustification. It is, indeed, not proved that the process is now going on. But that is not the main point. We may be content to have the proof that it has taken place.

Mineral Springs at the Surface.—When we isolate a spring characterized by high temperature, a large quantity of gas or of matter in solution, we notice at once that its level is higher than that of the ground-water. The more thorough the isolation or walling-in, the more striking is this phenomenon, so clearly unlike that of the vadose or shallow circulation.

Isolation is usually performed by digging as deep as possible, so as to get at the spring below the loose surface-material in an impermeable rock, and then, by building a well-pit, to give it freer ascent. But since the circulation of the ground-water in the loose surface is very lively, the necessary depression of the water-level in such an excavation involves the lifting of large quantities of water. Moreover, the escape of the gas from the mineral spring often hinders the operation; so that there is, as a rule, little opportunity for thorough investigation. Cases in which accurate observations have been properly recorded for preservation are very rare.

The first good fissure encountered in the bed-rock is deemed to be the channel of the mineral spring, and the well is built over it. Complete isolation from the ground-water is probably seldom practicable. Nevertheless, the mineral spring, being under higher pressure than the ground-water, will tend to exclude it from the well. The imperfection of the isolation is shown, however, when we try for any reason to pump out the well. To lower the water-level, say 1 m. (3.28 feet), we have to raise many times the amount of water which the spring itself would normally furnish (even taking into account the decreased pressure, which affects the flow in the proportion of the square root of the head). The excess, generally surprisingly great, comes from the ground-water which finds its way into the well.

If we allow the mineral water to ascend again quietly in the well, the level rises at first rapidly, then slowly, and finally remains (in the absence of change in the height of the ground-water and in the barometric pressure) stationary at a certain height above the ground-water level. This difference of height represents the ascensional force of the mineral spring.

If the spring makes a deposit at its mouth (mostly of lime carbonate, hydrated ferric oxide, and silica) it may thus build a conduit, extending above the ground-water level and the surface to the height represented by its ascensional force. Thus, we find conical mounds from the top of which mineral springs flow. This phenomenon is shown in the highest degree by geysers, *i.e.*, thermal springs in which paroxysmal developments of steam and gas occur, often forcing the water to notable heights. Some of the magnificent geysers of the Yellowstone National Park have built chimney-like conduits of considerable size. Their structure has much similarity to that of stalactites; indeed, we may recognize generally, in the various deposits of ascending mineral springs (in other words, in the products of the deep circulation), many analogies with the vadose circulation. This circumstance indicates a relation between the phenomena of the two regions which is often entirely ignored or even denied.

While, for instance, the geysers have a temperature above boiling-point, some mineral springs rise but little above the mean local temperature of the surface or of the ground-water. This may be especially observed in the acid springs; yet, these are also ascending springs, and must have been formed in the deep region.

Within the vadose region we have, sometimes, ascending waters, which are, however, mostly to be explained by hydrostatic pressure. But, within the deep region, hydrostatic pressure can play no part; and here it is the higher temperature and the presence of gas which cause the ascension of mineral springs. The extreme instances of this kind, such as geysers, steaming springs, mud-volcanoes, petroleum springs, etc., nobody will undertake to explain by hydrostatic pressure, and more moderate results of the same factors can scarcely, with consistency, be so explained.

It is a striking circumstance that ascending springs occur chiefly in the neighborhood of the later eruptive rocks, such as trachyte, basalt, etc. This is emphatically the case throughout the zone which crosses Europe from west to east, in France, Germany, Bohemia, Hungary, and Transylvania. Here the warm springs and the acid springs occur thickly, while north and south of this zone they are only sporadic. Their connection in the zone with the eruptive rocks is evident, and they are often considered as the last echoes of the processes of eruption. The sporadic springs, in places where eruptive rocks play no part, must have come through deep fissures of dislocation. For example, the line of the fault along which the Alps sank below the Tertiary basin of Vienna is marked by a complete series of thermal springs.

This circumstance has another and far-reaching significance. For ore-deposits are similarly distributed. They are most numerous and most closely grouped in the neighborhood of eruptive rocks, especially extended zones of eruptive rocks, as in the American West, and in Hungary and Transylvania, while among other rocks they are fewer and more scattered.

Chemical Constitution of Mineral Waters.—Ascending mineral springs have widely varying composition; some, like the "aerotherms," representing strictly only warmed ground-water, while others are strongly mineralized, and carry some substances almost to saturation. The material bearing on this subject is too voluminous and heterogeneous to be fully cited and discussed here. I must be content with the exhibit of a few analyses, specially interesting for the present purpose.

The following is a list of the localities, etc., represented in the table below:

Waters Encountered in Mines.

No.	Locality.	Temperature.		Authority.
		°C.	°F.	
1	Gottesgeschick mine, Schwarzenberg,	11.	51.8	R. Richter.
2	Einigkeits shaft, Joachimsthal,	28.7	83.7	J. Seifert.
3	The "Sprudel," in Colliery at Brüx, Bohemia,			J. Gintl.
4	Comstock, Savage, 600-foot level,	28. ?	82.4	S. W. Johnson.
5	Comstock, Gould and Curry, 1700-foot level,	48. ?	118.4	S. W. Johnson.
6	Comstock, Gould and Curry, 1800-foot level,	50. ?	122.	S. W. Johnson.
7	Comstock, Hale and Norcross,	70. ?	158.	S. W. Johnson.
8	Comstock, Ophir,	21.1	70.	Attwood.

Water in Ore-bearing Fissures.

No.	Locality.	Temperature.		Authority.
		°C.	°F.	
9	Sulphur Bank, Herman shaft,	70. ?	158.	G. F. Becker.
10	Sulphur Bank, Parrot shaft,	70.	158.	G. F. Becker.
11	Steamboat Springs,	75.	167.	G. F. Becker.

Some Bohemian Thermal Springs.

No.	Locality.	Temperature.	
		°C.	°F.
12	Sprudel, Carlsbad,	64.	147.2
13	Kreuzbrunn, Marienbad,	12.	53.6
14	Wiesenquelle, Franzensbad,	13.	55.4
15	Urquelle, Teplitz,	50.	122.

Weak and Strong Mineral Springs.

No.	Locality.	Authority.
16	Ottoquelle, Giesshübel,	Dr. Novak Kratschmann.
17	Josephsquelle, Bilin (1875),	Dr. Ruppert.
18	Puits de l' Enclos des Celestins, Vichy,	Bunsen.
19	Rippoldsau, Josephsquelle (1875),	Bunsen.
20	Rippoldsau, Wenzelquelle (1875),	Bunsen.
21	Rippoldsau, Leopoldquelle (1875),	Bunsen.
22	Kissingen, Pandurquelle (1856),	Liebig.
23	Kissingen, Rákoczyquelle (1856),	Liebig.
24	Yellowstone, Cleopatra, Mammoth Hot Springs (1888),	F. H. Gooch.
25	Yellowstone, Grand Geyser,	T. E. Whitefield.

It is well known that analysts in combining their results do not follow the same rule. One supposes a certain acid to be united with an alkali; another gives the same acid to an earthy base, etc. What interests us in the comparison afforded by the table is the substances occurring in large proportions, the carbonates and sulphates of the alkalies and alkaline earths; the chlorides, the silica, and the quantity of organic matter (if it were determined by a uniform procedure).

I deem it most convenient to take 1 ton of 1000 kilogrammes (representing, for waters not too rich in mineral, the weight of 1 cubic meter), and to express the weights of the salts in grammes, to avoid decimals. In order to show the relations of the salts, one to another, it is well also to represent them on the basis of 1000 parts of the solid matter.

For the Comstock waters, the rationally-stated analysis of S. W. Johnson, from the 600-foot level of the Savage mine (C. King, *op. cit.*, p. 87), served me as a guide, according to which I have recalculated the figures (Church, *op. cit.*, p. 204) for other mines and levels.

These analyses show the irruptive waters on the Comstock to be poor in dissolved substances. According to the determination of solid residuum by E. S. Bristol (C. King, *l. c.*, p. 88), this would not be the case. He finds the mine-water of the 500-foot level to contain in the Savage north drift 2660 grammes, and in the Yellow Jacket west drift as much as 3271 grammes of solid material in one ton (1000 kilos). But it is a question whether these figures do not refer to ordinary mine-waters, as the term "west drift" seems to indicate.

The predominance of sulphates over carbonates is nothing unusual; but the decided predominance of lime, sulphate or

Analyses of Some Ascending Waters.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
One Thousand Kilogrammes of Mineral Water contain, in Grammes:																									
Alkal. carb...	1150	352	2297	145	110	449	460	70	1954	325	333	2356	167	1167	415	1312	3374	5437	.....	.....	.....	.....	.....	.....	378
Earthy "	510	55	729	51	.....	.....	.....	48	54	57	17	127	146	381	100	565	586	981	1257	1170	1653	1110	1087	625	9
Alkal. sulph..	82	12	37	.....	.....	.....	.....	57	.....	689	172	535	500	3339	23	34	954	314	1273	1105	917	.....	.....	145	39
Earthy "	.....	.....	6	535	246	286	386	222	23	.....	.....	.....	.....	.....	56	.....	.....	.....	299	240	37	978	892	559	0
Chlorides......	62	6	58	2	1	20	23	10	1150	1115	1612	1031	170	1213	63	30	381	534	85	69	44	6441	5998	304	619
Silica...........	.....	51	72	31	38	69	60	38	37	42	391*	73	8	61	48	59	43	65	57	97	86	13	4	52	303
Other subst...	.....	.....	6	.....	.....	.....	.....	5	1883†	2412†	325†	.....	120	34	13	5	1	84	5	17	20	15	9	46	42
Total......	1804	476	3205	764	395	824	929	450	5101	4640	2850	6126	1111	6195	718	2005	5339	7415	2976	2698	2757	8557	7990	1731	1390
One Thousand Grammes of Solid Residuum contain, in Grammes:																									
Alkal. carb...	632	739	717	118	278	545	495	156	383	70	117	384	150	188	577	655	631	735	.....	.....	.....	.....	.....	.....	273
Earthy "	288	115	227	67	.....	.....	.....	107	10	12	6	28	135	61	139	283	108	132	422	436	601	130	136	362	6
Alkal. sulph..	46	24	11	.....	.....	.....	.....	125	.....	148	60	409	450	539	32	17	183	42	427	412	332	.....	.....	84	28
Earthy "	.....	.....	2	699	623	347	415	492	5	.....	.....	.....	.....	.....	77	.....	.....	.....	100	88	13	114	111	323	.....
Chlorides......	34	12	17	2	2	24	25	23	225	242	569	166	153	195	87	15	70	72	28	22	16	754	751	175	445
Silica...........	.....	107	22	40	96	83	64	83	7	9	137	12	8	10	61	30	8	8	18	36	31	1	1	30	218
Other subst...	.....	23	14	74	1	1	1	14	370†	519†	111†	1	104	7	27	.....	.....	11	5	6	7	1	1	26	30
Total......	.....	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

* Sodium quadrisilicate, $Na_2Si_4O_9$.

† Mostly sodium biborate, $Na_2B_4O_7$.

gypsum in the Comstock waters is unique. This relation would still remain if we should reckon a part of the sulphuric acid as combined with the alkalies. The two most trustworthy analyses of Attwood and Johnson give 222 and 535 grammes of gypsum per ton of water, and 492 and 700 grammes per ton of dry residuum. Apart from their gypsum, the Comstock irruptive waters may be classed among the weak or acrothermal springs, like those of Teplitz in Bohemia.

The Sulphur Bank and Steamboat Springs waters are distinguished from all others in the table by a considerable proportion of sodium biborate, and resemble unmistakably certain Suffioni and Lagoni waters of Middle Italy. Their degree of impregnation and their large proportion of chlorides bring them near the waters of Carlsbad and Franzensbad, Bohemia. The proportion of sodium chloride is not surprising in the American West, in the neighborhood of undrained and therefore salt regions, but it is surprising in Bohemia, a country notoriously free from salt, in which no rock is known to contain these highly soluble substances. We must assume that they exist in the deeper region, in forms not yet decomposed, such as sodalite ($3Na_2Al_2Si_2O_8 + 2NaCl$) which must be chemically decomposed before its NaCl can be dissolved. The presence of quantities of salt smaller than those here under consideration can be attributed (as I at one time attempted to show)* to atmospheric precipitation. A. Bobierre found† by careful and continuous analysis of the rain-water falling in Nancy throughout the year 1863, 14 grammes of salt per ton or cubic meter; and G. Zoppe‡ has argued that the sometimes considerable contents of sodium chloride in the springs of the Iglesiente district, in the island of Sardinia, can only be explained by the transportation of salt from the sea by wind. (A stormy cloud-burst, March 7, 1886, showed as much as 387 grammes per ton or cubic meter.) The salt of the atmospheric precipitation is concentrated by evaporation. In Bohemia, for instance, only one-fourth of the rainfall escapes into the Elbe;

---

* "Zur Genesis der Salzablagerungen, besonders jener im nordamerikanischen. Westen," *k. k. Akad. d. Wissensch.*, Wein, 1877.

† *Compt. rend.*, lviii., p. 755. *Bullet. Soc. Chim.*, liv., p. 467.

‡ "Descrizione geologico-mineraria dell' Iglesiente," *Memorie descritt. della Carta geol. d'Italia*, iv., Roma, 1888, p. 119.

in more southern regions the whole evaporates. The descending ground-water is still further concentrated; so that in this way the salt normally found in the ascending waters may be accounted for.

But while the water of Steamboat Springs is rich in sodium chloride, the Comstock mine-water is poor, notwithstanding the comparatively near neighborhood of the two places. Both adjoin eruptive rocks, especially basaltic outflows; but the Steamboat Springs break out of crystalline rocks. May not the ascending waters have derived their abundant sodium chloride from minerals, like sodalite, which contain it chemically bound?

Hydrogen sulphide plays an important part in the ascending waters. Its presence seems to be the cause of a greater abundance of dissolved substances. It is attributed to the decomposition of sulphates through the organic matter, traces of which are found in most of the ascending waters. By reoxidation, it produces the sulphuric acid which transforms carbonates into sulphates. It is remarkable that in many mineral springs H_2S appears periodically in surprising excess, and often disappears again, almost without leaving a trace. It is probable that an alternation of the processes of oxidation and reduction would produce this phenomenon.

The most important geological factor in ascending waters is undoubtedly carbonic acid; for it is chiefly this compound which in the deep region, under high temperature and pressure, develops a greater solvent power for most of the elements of the rocks. The alkalies, earths and silica of our mineral springs have certainly been dissolved from the rocks by carbonic acid, and the carbonates thus formed usually predominate over the associated sulphates. The analyses do not give us the conditions in which they exist, because the statements of results depend largely upon the individual views of the analysts.

The general exhibit sketched above shows that in the Comstock waters the sulphates exceed the carbonates, and that the chemists have been led to connect the sulphuric acid preferably with the earths. They have simply found an excess of sulphuric over carbonic acid, as is the case also in the strong thermal springs of Bohemia. The relation between the two analyses of Sulphur Bank water is remarkable; one showing the sulphates, and the other carbonates, to be predominant. Apparently one sample was taken from water which had been for a considerable period in contact with the atmosphere, so that the liberated H_2S gas, oxidizing to H_2SO_4, expelled the CO_2 from a part of the carbonates. The three irruptive thermal waters, Nos. 1, 2 and 3 in the table, are acid, and also contain a notable quantity of free CO_2 in solution—which, indeed, determines their acid character. I have added for comparison Nos. 16 and 17, two favorite Bohemian acid springs. No. 18 is the famous Vichy spring in France; No. 16 is a weak water, esteemed for table-use; and No. 17 is the celebrated stronger water of Bilin. A few years ago, the quantity of the latter spring had seriously fallen off; and there is reason to surmise that a part of its water had found a way into the collieries of Brüx, where similar acid springs appear at several points. Fortunately for Bilin, an increased supply was obtained there by means of an adit and bore-hole. It is known that distilled water at normal barometric pressure and ordinary indoor temperature may contain in absorption an equal volume of carbonic acid, and that mineral water under the same conditions has a somewhat higher absorption-coefficient. The free CO_2, not held in bicarbonates, is mostly given by analysts in terms of weight. These, by the employment of the well-known volume of one gramme of CO_2, could be easily transferred into terms of volume, a more practical form for all cases, which is unfortunately not yet generally used.

Since in the deep regions the absorption-capacity of water for CO_2 is diminished by increased temperature, but, on the other hand, increased in much greater proportion by increase of pressure, a portion of the gas absorbed in depth is liberated in the higher region and contributes energy to the ascending current.

Thus far the substances present in mineral waters in the largest proportions have been chiefly considered. We must now study also those which occur in minute proportions, since these concern most nearly the question with which we are dealing.

Minute Metallic Admixtures in Mineral Waters.—Ordinary analyses show the presence of some metals, especially iron and manganese, which occur as easily oxidizable protoxides, giving rise to the precipitation of hydrated peroxides. Lime carbonate in solution as bicarbonate, is simultaneously precipitated by evaporation and the loss of CO_2; and silica is likewise thrown down under certain conditions. Such precipitates are called, according to their predominent ingredients, ocher, sinter, tufa, travertine, etc.

Minute metallic admixtures are found:

1. Dissolved in the mineral water itself.
2. In the ochers or sinters deposited at the mouths of springs, where they are concentrated in observable quantity, having been, without doubt, originally held in solution by the springs.
3. Moreover, there are found, in some places, at the mouths of springs, substances which were not originally in the solution, but have been subsequently dissolved and ultimately precipitated by the action of the mineral water upon various foreign bodies attacked by it.

The proportions of metallic ingredients found in ordinary spring-analyses were at first generally regarded with doubt, unless a chemist of the rank of Berzelius vouched for them. Fresenius and others admitted that such ingredients might be taken up from metallic conduits. But at last they were proved to exist in springs, excluding this hypothesis. Of course, "traces" are worthy of less confidence than ponderable quantities. According to Dr. Loschner,[*] Göttl found in the Geisshübl waters "traces" of copper, and even of gold. Of the fifty-nine chemical elements recognized in 1847, twenty-four were known to Elie de Beaumont[†] as occurring in mineral springs. Of these only six (Ur, Mn, Fe, Bi, Sb, As) were metals. G. Bischof[‡] doubled this list, and the knowledge of the subject has been greatly increased since by Liebig, Will, Fresenius, Rammelsberg, Wackenroder, Thenard and Chevalier. It is chiefly from the deposits of springs that we learn of the minute metallic substances once dissolved in them. The oxides of Cu, Sn, Co, Zn, Sb, Ni, etc., were precipitated together with the oxide of iron. Ochers are especially rich in arsenic. Tin is often found in the thermal deposits of Wiesbaden, Soden, Homburg, Rippoldsau, Alexisbad, Driburg, Bruckenau, Kissingen, etc.

---

[*] *Badeschrift über Giesshübl*, 3 Aufl. Prag., 1855.

[†] *Bulletin de la Soc. Geol. de France*, 2 Ser., iv., p. 1249, etc.

[‡] *Lehrb. d. Chem. Geologie*, Aufl., i., p. 2078.

Lead occurs in the springs of Rippoldsau (according to Will, 1.6 to 3.7 milligrammes per ton), Kissingen (10 to 13 mg. per ton), Alexisbad, Ems, Homburg, Carlsbad (in the Schlossbrunn, according to Göttl), Pyrmont, etc.* Copper has long been known to exist in acid mine-waters (*e.g.*, the cement-waters of Schmöllnitz, Herrengrund in Hungary, etc.), and is found also in ascending waters at Carlsbad (authority, Göttl), Aachen (Liebig), Bagnères de Luchon (Filhol), Bourbonne (Tomsier), Luxueil (Braconnot, Henry), Wiesbaden (Fresenius), Brückenau (Keller), Rippoldsau (Will), and in many other chalybeate waters.† Arsenic is, of course, often found in mineral waters. I will mention only the Magdalena spring of Mont-Doré (45 to 55 grammes per ton, says Thenard), St. Hectaire (6 to 8 per ton), Royat (35 g. per ton), and Bourbole (815 g. per ton). G. Bischof ‡ gives as follows the maxima found in mineral springs up to 1854:

	Milligrammes per Ton. Of Water.	Milligrammes per Ton. Of Ocher.
Arsenious acid,	1.5	38.460
Antimony oxide,	0.1	......
Zinc oxide (sulphate),	13.3	......
Lead oxide,	0.1	1.900
Copper oxide,	6.4	1.000
Tin oxide,	0.1	.50

I add, as illustration, the contents of the mineral waters of two important localities, as calculated from the contents of the ocher. The chief constituents of these waters are given in the table on page 42. The first three springs are at Rippoldsau.

Locality:	Rippoldsau (acc. to Will.)			Kissingen (acc. to Keller.)	
Springs:	Josef.	Wenzel.	Leopold.	Pandur.	Rákoczy.
Constituents.	Milligrammes per ton.				
Protoxide of tin	25	17	38	134	166
Antimony oxide	16	10	24	107	134
Copper oxide	104	69	156	128	150
Arsenious acid	600	400	900	1120	800

In discussing Steamboat Springs I have already mentioned

---

* Dr. B. M. Lersch, *Hydrochemie*, i., Berlin, 1879, p. 342.

† *Ibid.*, p. 438.

‡ Dr. H. Ludwig's *Die natürlichen Wässer*, Erlangen, 1862, p. 96. Compare J. Roth's *Allgemeine Chem. Geologie*, Berlin, 1879, p. 564, etc.

the metals found by G. F. Becker, among which are Hg, Au, and Ag.

I would only, in addition, call attention to the variations in the deposit of one and the same spring, for which purpose I select the Puits de l' Enclos des Celestins, at Vichy,* of which an analysis is given in the table on page 42. This contains in 1000 parts:

	Residuum obtained by evaporating the mineral water.	Ocherous deposit.	Calcareous deposit.
Alkaline, carbonates,	735	......	......
Earthy carbonates,	129	169	980
Ferrous carbonates,	3	......	......
Manganous carbonates,	......	......	4
Iron oxide,	......	474	10
Alkaline sulphates,	42	......	......
Chlorides,	72	......	......
Silica,	8	10	......
Arsenic acid,	0.4	70	......
Other constituents,	10.6	277	6
	1000.0	1000	1000

Alterations Produced by Mineral Springs.—Daubrée, in the chapters devoted to this subject, distinguishes the action of mineral waters upon the rock they traverse, and their action upon artificial substances which have found their way into the mineral water.†

a. Under the first head he cites alunite, kaoline and serpentine as a result of mineral springs in general. I would call attention, however, to the circumstance, not yet sufficiently appreciated, that the rocks in the neighborhood of a mineral spring often have a very different appearance from those at a distance. In the case of springs carrying sulphuretted hydrogen, this is self-explanatory. Sulphur Bank represents the phenomenon in a striking way as regards basalt. Granite is often decomposed in the neighborhood of springs,—as in the Carlsbad region, where some acid springs, like that of Giesshübl, emerging on the contact between granite and the overlying Tertiary rocks, have transformed the granite into kaoline. I have observed similar decomposition at the springs of Johannisbad, in Bohemia, and at many other places. It is to be re-

---

* Dr. H. Ludwig's *Die natürlichen Wässer*, Erlangen, 1862, p. 199.

† *Les eaux souterraines a l' époque actuelle*, ii., p. 67, and *Les eaux souterraines aux époques anciennes*, p. 178.

gretted that these phenomena have been seldom studied, as yet, from a chemical standpoint.

Daubrée has pointed out the effect of mineral water upon various rocks and artificial building-materials in the masonry shafts of the springs at Plombières and Bourbonne-les-Bains;* for instance, the zeolites (chabazite, harmotome, christianite, mesotype, apophyllite) formed in the Roman béton; the hydrous silicates (plombierite, chalcedony, hyalite) in the Roman bricks at Plombières; recent formations of calcite and aragonite, and also the funnel-shaped cavities eaten out of the dressed limestone of the masonry. The latter are specially interesting as having been excavated from below upwards,—that is, in the direction of the ascending spring. Fig. 9 illustrates this action upon such a building stone.

An analagous, and, for our purpose, still more important observation, was made in 1845, at Burtscheid, near Aachen, by J. Nöggerath. A terrace was constructed at that time in the neighborhood of the hot spring, as the site for a house. Blasting in the Devonian limestone exposed several vertical channels of nearly circular section and 20 to 90 centimeters (8 to 35 inches) diameter, some of which contained thermal water and emitted steam. They had been partly choked by rock-débris, but one of them showed a depth of about 4 meters (13 feet). Immediately around these tubes the elsewhere solid limestone had been altered for a distance of 15 centimeters (6 inches) to a gray, earthy mass, almost plastic when damp, and separable in thin scales. In places, this earthy mass had fallen away, and on the sides of the enlargements of the tube thus formed, crusts of white lime-sinter had been deposited.† Nöggerath does not doubt in the least that the mineral water emerged 5 to 6 meters (16 to 20 feet) above the present exit, and eroded the channel for itself. He believes even that the channels of all the mineral springs of Burtscheid and Aachen, which came from the limestone, have a similar shape.

He calls attention to the fact, observed by him and his friend G. Bischof, that the slabs of black marble covering the curb-

---

* *Experimental Geology*, p. 82.

† J. Nöggerath, "Ueber die sogenannten natürlichen Schächte oder geologischen Orgeln in verschiedenen Kalksteinbildungen." Karsten's *Archiv. für Min., Geogn., u. Bergbau*, 1845, p. 513.

ing of the Kaiserquelle, near Aachen, and the Schwerdbad, at Burtscheid, had been transformed by the constant action of the steam upon their inner surfaces into a doughy mass, which could be easily scratched away with the finger-nail.

Besides this evident action of thermal springs upon limestone, we may conclude from the foregoing that such waters, tending to an upward movement, may actually eat their way through limestone to the surface, or to rocks offering communication with the surface. This circumstance was not known to me when I published my monograph on the Rézbánya deposits,* in which I attributed to ground-water the erosion of the channels in the limestone which are filled with ore, instead of allowing them to have been formed by the ascending mineral waters.

The treatise of Nöggerath above cited contains also observations upon the analogy between the thermal-water channels of Burtscheid, the so-called "geological organ-pipes" (*les orgues géologiques*) in the chalk-deposits of Maestrich, and the "natural shafts" (*puits naturels*) in the Eocene limestone of the vicinity of Paris. The latter, however, have shown neither mineral water nor any traces of its former presence, and are of little interest for us. Recent investigations of both the phenomena referred to are unfortunately not now at hand.

b. Regarding the effects of mineral waters upon artificial products immersed in them, we are indebted to Daubrée for the preservation of the numerous important observations in the masonry pits of the springs of Plombières and Bourbonne-les-Bains.†

The springs of Plombières occur in the neighborhood of ore-bearing quartz-veins, and furnish at 68° C. (154° F.) a water rich in carbonic acid but poor in solid constituents, the residuum after evaporation being 400 grammes per ton (0.04 per cent.). Those of Bourbonne-les-Bains, on the other hand, have a temperature of 58° C. (136° F.), and are rich in mineral matter, the residuum being 7000 to 8000 grammes per ton (0.7 to 0.8 per cent.),

---

* *Geol. mont. Studie der Erzlagerstätten von Rézbánya in S. O. Ungarn.*, Budapest, 1874, p. 179.

† "Formation contemporaine de diverses espèces minerals cristallisés dans la source thermale de Bourbonne-les Bains." *Annales des Mines*, 6 series, 1875, viii., p. 439. Also, the German edition of Daubrée's *Études synthétiques*, 1880, p. 57.

chiefly sodium chloride (5800 grammes). They flow from the variegated marls of the upper Trias, underlying the Muschelkalk, in the vicinity of large fault-fissures. Carbonic acid appears to be present in traces only, and the same is true of hydrogen sulphide, which is detected by its odor, and has given rise also to small deposits of sulphur.

In 1874, with the aid of powerful pumps, the abundant current of the spring was successfully overcome, and the foundation of the old Roman curbing was made accessible. The mineral water rises from horizontal clay beds through a funnel filled with sand, which scarcely represents the original channel. At the bottom of the masonry lining a clayey slime was encountered, in which, besides thousands of hazel-nuts, acorns and fruit-seeds, many Gothic and Roman coins were found, with numerous other objects, such as bronze statuettes, needles, rings of electrum, pieces of leaden framing, etc. The gold coins weighed in all 25 grammes, the silver coins 625 grammes, but of the bronze coins there were 20,800 grammes, and many had disappeared entirely, leaving only their impress, and forming shapeless masses of the products of their decomposition, mixed with grains of sand. Of the minerals formed from the bronze, the greater part came from the copper (red copper-ore, copper-glance, chalcopyrite, peacock-ore, tetrahedrite, atacamite), and only one from the tin—on a coin which still showed bronze in its interior, but was covered with a white layer of tin oxide. The action upon lead had produced coatings of galena and phosgenite, scales of lead oxide, and cerussite. Iron had not been altered to ordinary rust; the product of its oxidation contained silica. Moreover, pyrite, instead of the earthy black sulphide often occurring on the surface, had been formed from the iron, and was found covering pebbles and grains of quartz, angular fragments of sandstone, and also some evidently artificial products, such as flint knives—thus indicating indubitably its recent origin.

Strange to say, in spite of the quantity of chlorides in the water, and the great affinity of silver for sulphur, the silver coins had not been very seriously attacked, and their designs were still quite distinct, when they had not been coated with sulphides from the neighboring bronze coins. They must have been protected from chemical action by something not now determinable.

Moreover, iron and silica (or a hydrated silicate) had penetrated the wood found in the springs.

> "At Bourbonne, as at Plombières, the intrusive formations are less than 8 meters (28 feet) below the surface; and yet they are very different from what we are accustomed to see in our laboratories. A temperature was sufficient for them which is low in comparison with that which obtains at greater depths. What forces would we not see at work, if we were permitted to follow downward the channels which have been the pathway of hot springs!"—Daubrée, *op. cit.*, p. 91.

Structural Features of the Deposits of Mineral Springs.—The original conditions at the point of outflow of mineral springs have seldom been preserved intact. Even when their channels have been successfully prolonged through the ground-water to the surface, erosion, on the one hand, has partially removed them (since they often emerge in valley-bottoms), or human agency, on the other hand, has variously disturbed them by diverting, choking, or walling them, or by the erection of buildings with foundations. For our purpose it is important to be able to show that, in all channels extending to the surface and still uninjured, a regular filling with symmetrically arranged mineral crusts may be observed.

Such a regular filling of the fissure-channel of a spring I have seen at the tufa mounds of the Bad of Arczó near Parajd in Transylvania.* The filling of a fissure 25 centimeters (10 inches) consists of variegated crusts of aragonite, as thin as paper, the fibers of which are perpendicular to the walls of the channel. The latest crusts are darker, and give a bituminous odor when dissolved in hydrochloric acid; the oldest are usually milky white, and leave after similar treatment a residuum of gelatinous silica. The water tastes very unpleasantly salt and bitter. The gas which hisses from the depths of the fissure is doubtless mainly carbonic acid, perhaps with an admixture of hydro-carbon.

Since the drawing of the mouths of Steamboat Springs given by Le Conte (*op. cit.*, p. 423) may not be entirely comprehensible, I introduce in Fig. 8 an ideal section of one of the spring-mounds of Arczó.

It is only the channel which is filled with solid, almost transparent crusts; the deposits on the side of the mound are a

---

* F. Posepny. "Studien aus dem Salinargebiete Siebenbürgens," *Jahrb. d. k. k. geol. Reichsanstalt*, Vienna, 1867, xvii., p. 477.

fine-grained, white lime mass, and in the less immediate vicinity of the springs there are in many places horizontal layers of a lime tufa, containing plant-remains.

Pigeon and Voisin describe an analogous but much larger phenomenon in Vichy, at the *rocher des Celestins*, where an almost vertical aragonite filling, 2 meters (6.5 feet) wide and 200 meters (650 feet) long, with fibers perpendicular to the planes of the crusts, may be observed (Daubrée, *op. cit.*, p. 159).

The waters flowing away from mineral springs likewise make solid deposits, which often form horizontal layers, covering considerable areas. These are the so-called travertines—formations analogous to the Carlsbad *Sprudel-* or *Erbsenstein*, etc. But we are concerned at this point with the deposits in the spring-channel itself and in its immediate vicinity, including not merely the crusts upon the walls proper, but also those surrounding large or small fragments of rock within the channel. Many such deposits are characterized by the pisolite formation, which we may observe also in ore-deposits (concretionary iron-ores, etc.). These pisolites are evidently incrusted kernels, the crusts being proportionately much thicker than the kernels. The Carlsbad *Sprudelstein* shows, indeed, the same structure on a small scale as many ore-deposits exhibit on a large scale. The pisolites, like those of Tivoli and Hamman Meskoutine, consist of lime carbonate, pure or slightly intermixed with iron oxide and silica. At the last-named locality pyrite occurs between the layers of carbonate, so that the formation must be pronounced to be crusts of lime carbonate and pyrite upon a foreign nucleus, which was elevated and encrusted so long as the ascending column of the spring had energy enough to move it.

A few words may be well added here concerning the Carlsbad *Sprudelschale* and *Erbsenstein*. As is well known, the *Sprudel* represents an action like that of geysers, ejecting thermal water and steam to a considerable height. The precipitate at the present time is a porous, somewhat ferruginous aragonite or travertine mass. The ground from which the *Sprudel* breaks forth is composed of horizontal layers of a much denser aragonite mass, which can be polished, and furnishes material for artistic lapidary-work. A part of the town of

Carlsbad stands on this so-called *Sprudelschale*, from which new thermal springs sometimes break out, and the structural history of which may have been like that of the rising succession of basins at the Mammoth Hot Springs of Gardiner river, in the Yellowstone National Park.

Certain layers of this *Sprudel*-deposit are exclusively aggregates of pisolites of pea-size, whence the name *Erbsenstein* (pea-stone). Evidently these have been formed, like those of the Hamman Meskoutine spring, immediately at the outflow of the mineral water. The precipitate from the solution (at the moment supersaturated) was deposited around individual rock-grains, which had found their way into the spring, to be for awhile kept in motion by its current. Successive crusts were thus deposited, until the pisolite became too large to follow the movement of the spring and sank to the bottom, where its accessible surfaces received still further precipitate-crusts. It might easily occur, that single cavities might remain, into which the precipitate could not penetrate. These would represent, according to our terminology, the central druse. Fig. 12 illustrates this process, while Fig. 13 shows a single pisolite, including pyrite-crusts, from Hamman Meskoutine.

I have had opportunity to see a completely analogous result produced by falling drops at Offenbánya, where, at certain points in an adit abandoned for some thirty years, water rich in lime carbonate trickled from the roof, forming upon the floor a deposit several centimeters thick. At the spot where the drops fell directly upon the floor, a small basin-like depression was formed, in which lay, like eggs in a bird's nest, various bodies like pisolites, consisting of a sand-grain at the center, surrounded by concentric crusts of carbonate. Some of these formations lying in the middle of the nest were quite loose, so that they were turned over by the force of the falling drops, which explained the tolerably uniform incrustation upon them. Others situated near the edge were already fixed, could not move any longer, and showed at points a deposit of sinter* (Figs. 14 and 15). Similar formations, known as "birds' nests," are described by Schmidt in the old mine-workings of Riegelsdorf and Bieber.† Such formations appear to be by no means

---

* F. Posepny, "Ueber concentrisch-schalige Mineralbildungen," *k. Akad. d. Wissensch*, Vienna, 1868.

† *Beiträge zu der Lehre von den Gängen*, p. 42.

rare in metal-mines. I found, for instance, in Offenbánya, at the face of a level which had been abandoned for some years, that small chips of rock had been covered by the falling drops with two separate thin crusts: first, a white lustrous smithsonite, and thereupon a black, easily-detached crust of a manganiferous substance.* (Fig. 16.) The pisolitic bodies formed by falling drops are not easily confounded with those formed by a flowing spring, and when such are found in the interior of an ore-filling, they cannot well be ascribed to drippings.

Pisolitic forms appear in many ore-deposits. Thus the calamine-deposit of Santander in Spain betrays an oölitic structure, and I have observed in the gold-mines of Verespatak pisolitic forms, the kernel being an aggregation of gold, and the surrounding thin crusts, carbonates of lime, manganese and iron. To this subject I shall recur.

From what has been said concerning the structural relations of mineral-spring deposits, it appears that at the mouths of such springs phenomena are shown, such as crustifications of wall-deposits, pisolitic forms, etc., which we meet frequently in ore-deposits also—an additional reason for declaring the latter to have been formed by mineral springs.

5. ORIGIN OF ORE-DEPOSITS IN THE DEEP REGION.

We have seen that the mineral springs which ascend to the surface are dilute metallic solutions, and that at their outflow (the only point where we can directly observe their activity) they form deposits, containing metals, among other things, and exhibiting a structure which occurs in ore-deposits likewise. We have followed to a not inconsiderable depth one ore-deposit which occurs upon an ascending spring, and have found that, apart from changes conditioned by the vicinity of the surface, it continues its character. Finally, we have encountered mineral springs in many places where mining has followed ore-deposits in depth. Joining these several links of observation, we cannot avoid the conclusion that the ore-deposits found in the deep region are the products of mineral springs, the more so since many of them have a structure and form which can only be explained as the result of precipitation from liquids

---

* See my paper on crustified mineral formations, cited above.

circulating in channels. The deposits from these liquids contain substances which are foreign to the surface and to the shallow region, and hence could not have been brought into circulation by the descending ground-water, but must have come from a deep region, where higher temperature and pressure (the two factors increasing the solubility of all substances) exist.

Comparing the average density of the earth (which is, according to the very recent and careful investigations of R. von Sterneck,* 5.6) with the average density, 2.5, of the rocks forming the earth's crust, we must admit that in the central mass substances much denser than 5.6 have been accumulated, that is to say, the deep region is the peculiar home of the heavy metals.

If we imagine ourselves standing in the deep region in front of the profile of an ore-lode, like the Adalbert at Przibram, for instance, 1110 m. (3600 feet) below the surface and 564 m. (1850 feet) below sea-level, we perceive a fissure-space of discission, filled with symmetric mineral crusts, chiefly argentiferous lead sulphide. Remembering that this filling has been stoped continuously to the surface, we can find no other satisfactory explanation than the hypothesis that it was brought up from still greater depths, and, in view of the comparative insolubility and the large quantity of the metallic sulphide here accumulated, it must have been deposited from perpetually renewed, and, therefore, from *ascending*, mineral solutions. Whoever has had opportunity to study an ore-lode in the deep regions can conceive no other explanation. The miners themselves have always held this opinion; in other words, they have all been *ascensionists.* In the case of ore-deposits occupying tubular channels in soluble rocks, the origin of these spaces is not at once clear; and it has thus happened that one or another observer, misunderstanding the analogy of the substance and the conditions of filling, has suggested a different hypothesis, as, for instance, S. F. Emmons, whose conclusions as to the Leadville deposits I shall take the liberty of controverting in a later part of the present paper. I do not deny that there

---

* I would call attention to the labors of v. Sterneck, pursued upon this point for a decade, and described in the *Mittheilungen des k. k. Militär. Geograph. Institutes*, in Vienna.

are ore-deposits permitting such a different explanation, but they occur in the shallow region only, and not in the deep region.

In the two groups of ore-deposits already discussed, and formed in pre-existing spaces, a distinct crustification leaves no doubt as to the manner of filling. Where crustification is obscure or absent, it is indeed not possible at once to offer this convincing proof of the manner of deposition. Recourse must then be had to the analogy of the substances and their paragenesis. If these correspond with the contents of spaces filled with crusted deposits, a similar origin must be inferred; that is to say, even in cases in which mineral solutions, ascending from the deep region, found no open, continuous channels, but were forced to create the necessary space by the removal of a previously-existing material, the conditions of the deep circulation still controlled. From these considerations it follows that all the deposits of the deep region are referable to one general ruling process, clearly shown to be the action of ascending mineral solutions; that is, they were all formed by ascension.

This conception is diametrically opposed to the view recently suggested by Dr. F. Sandberger, that ore-deposits are formed by so-called lateral secretion. This view was at first asserted to be universally applicable. Afterwards, the author characterized it as holding good for the majority of ore-veins only, and restricted it by the following definition:

> "The theory of lateral secretion was conceived in this sense only, that the material for the filling of veins is derived from the country-rock through gradual leaching by seepage-water (Sickerwasser), which brings the dissolved substance from both sides to the vein-fissure, where it is then converted by chemical decompositions into insoluble gangue-minerals and ores, and so deposited."[*]

It will be seen that he started from the wholly erroneous assumption that the ore-veins of the deep region stood open (like the fissures in a rock upon the surface), so that seepage-water from both sides could deposit material in them. That is, he conceived of a fissure containing air only, and forgot entirely that such open fissures are found exclusively above the

---

[*] F. Sandberger, *Untersuchungen über Erzgänge*, 2tes Heft, Wiesbaden, 1885, p. 159.

ground-water level, below which every newly-formed fissure must be immediately filled with water. The term *sickern* corresponds with the English "seep," "trickle," or "drop," and can only be understood as describing the downward movement of a small quantity of liquid. It is thus impossible to suppose that Sandberger's meaning has been misunderstood; and we are forced to conclude that he boldly extended his conclusions to cover a region with the physical conditions of which he was unacquainted.

A lateral secretion in this sense is, as I have elsewhere shown,* possible above the ground-water level only. It is indeed conceivable that even in the deep region isolated spaces may exist, from which accumulated gases find no way to the surface, and in which formations may occur similar to those in cavities above water-level; but such instances (as at Wiesloch, in Baden, and Raibl, in Carinthia) are demonstrably exceptions to the general rule above stated.

What interests us most is, that in order to establish his theory, Sandberger was forced to discredit the fact of actual deposition in the channels of mineral springs. The proof of this fact at Sulphur Bank and Steamboat Springs was highly inconvenient. Since, as he had said, "waters which flow with such rapidity as that of ascending mineral springs containing carbonic acid are shown by experience to produce no deposits in their channels, but to do this only in the immediate vicinity of their outflow" (*op. cit.*, p. 5), he was not convinced by the conditions shown at Steamboat Springs, where the deposits are near the outflow. With regard to Sulphur Bank, he was not acquainted with the works of Le Conte and G. F. Becker, showing that the ore-deposit is found in the channel itself. Although he did not doubt "that ore-deposits are here observed in process of formation" (*l. c.*, p. 13), he recalled the well-known solubility of mercury sulphide in alkaline sulphides; argued that "the leaching of pre-existing quicksilver-deposits by alkaline sulphides presents no difficulty" (*l. c.*, p. 15); and was inclined to believe that the cinnabar-deposits near the outflow were referable to older ones. Endeavoring thus to render harmless the two instances unfavorable to the lateral-secretion

---

* "Ueber die Bewegungsrichtung der unterirdisch circulirenden Flüssigkeiten."—*Comptes rend. de la session du Congrès géol. internat.*, Berlin, 1885.

theory, he summed up his consideration of them at that time with the remark that "in California no proof is presented of the formation of ore-veins by ascending springs" (*op. cit.*, p. 16). After reading Le Conte's account he returned to the subject in the second part of his work,* asserting (p. 162) that in the numerous excavations connected with the walling-in of mineral springs, it has never been observed that hot springs have deposited "metals" in the immediate vicinity of their channels. He confesses again (p. 161) that here is "unquestionably an ore-deposit, formed by the precipitation of silica and cinnabar from a hot alkaline sulphur-spring, which has found and dissolved mercury sulphide somewhere below;" and admits that hot alkaline sulphur-waters may precipitate, besides quicksilver, also gold, tin, bismuth, arsenic, and antimony,—but not copper, silver, and lead-ores, which are often associated with the foregoing. These, he says, cannot have been deposited from hot alkaline sulphur-springs. "There is, therefore (p. 162), no reason in the conditions of Sulphur Bank for restoring the ascension theory to its former authority in the science of ore-veins."

It will be seen that his chief argument is, that according to his opinion, no metallic deposit has ever been found in the channel of a spring, for he seems not to consider as conclusive the deeper workings at Sulphur Bank. Such a sweeping assertion is easy; for it is not likely that in walling a mineral spring excavations will be carried deep enough to reveal the condition of its channel proper.

Sandberger's contention comprises two propositions: (1) Metals have been found hitherto only in the ocherous deposits from mineral springs; and (2) in walling mineral springs, deposits formed in their channels have not yet been found. These two assertions are not controverted; but the conclusion, that because hitherto, in digging out mineral springs, we have found no metals in their channels, therefore they cannot be deposited in the channels, but only at the outflow, is illogical.

Excavations for the walling of mineral springs do not extend to the channels of the deep region. Heavy pumping is required to penetrate even a few meters below the ground-water

---

* *Untersuchungen über Erzgänge*, Wiesbaden. First part, 1882; second part, 1885.

level; whereas, to decide this question, a depth must be reached at which the ascending spring is not altered by the descending ground-water, the oxidation and chlorination due to surface agencies no longer appear, etc.

We know that temperature and pressure, the two great factors of solubility, are continually diminished as the surface is approached; and we can directly observe one result of this change in the liberation of the carbonic acid absorbed at greater depths. Why should not the substances rendered insoluble by the decrease of these factors be deposited in the channels? If no such deposition has occurred, then the precipitates must have been carried upward by the current, and should be separable by filtration from the water. G. F. Becker, in filtering the Steamboat Springs water before analysis, found (*l. c.*, p. 346) in the filtrate a precipitate of antimony and arsenic sulphides, with silica, which he ascribes to the fall of temperature and the action of low forms of plant-life.

But we find in various closed conduits of mineral water—*i.e.*, in artificial channels—that deposits are formed, not only at the mouth, but also in the channel itself. Why should natural channels form an exception?

I think it has been shown that Dr. Sandberger's chief objection to the formation of ore-deposits by ascending mineral springs is without foundation, and that the entire chain of phenomena corroborates our explanation. But the lateral-secretion theory of Sandberger suffers from several other fundamental defects, which I cannot avoid indicating in this place, because that theory was for a while accepted as a simple and welcome explanation of the genesis of ore-deposits, and began to hinder the progress of knowledge on that subject.

It found many disciples, especially among mineralogists, because it permitted the most extensive genetic generalizations, without requiring the observer to leave his mineral collection and laboratory, to descend into the mine, and to study the ore in the place of its origin. On the other hand, it must be confessed that the promulgation of this theory led to many investigations of rocks, which will be useful to science in other directions.

Sandberger, being convinced that he had detected foreign admixtures of the metals in silicates, felt himself warranted in explaining by his theory all ore-deposits in the silicate rocks; but he could not so well deal with those in limestone, which were cited by Stelzner as a chief argument against the universality of his conclusion.* With regard to Raibl, in Carinthia, it occurred to him to examine the marly slates (*Mergelschiefer*) overlying the limestone; and finding in these, besides traces of Li, Cr, and Cu, more considerable quantities of Pb and Zn, he concluded that the metals in the ore-channels of the limestone under these slates had been leached out of the latter (*op. cit.*, p. 34). This was already a descending, and not a lateral secretion.

In a paper upon the applicability to this case of the lateral-secretion theory,† however, I pointed out that also below the ore-bearing limestone of Raibl, at Kaltwasser, there are silicate rocks, which probably contain likewise minute quantities of metal, and that if Sandberger had successfully analyzed these, he would have been obliged to assume an ascent. In the same paper I argued that the lateral-secretion theory does not account for the sulphur and the metallic sulphides; and I brought forward for discussion the veins of Przibram, assuming that in that district, where sedimentary rocks are traversed by heavy eruptive masses, Sandberger could consider the latter only as the original source of the metals in the veins. From average analyses for the latest year of production, I calculated that each square meter (10.75 square feet) of vein-surface stoped represented 190 kilogrammes (426 lbs.) of metallic sulphides, or in detail:

	Pb.	Zn.	Fe.	Cu.	Ag.	S.	Sb.	As.
Kilogrammes,	132	13	5	0.3	0.8	34.6	2.5	1.7

If these substances had been derived by lateral secretion from the country-rock (the eruptive mass being 30 meters thick by the main vein, or 100 meters for the whole group of veins) there must needs have been in each cubic meter (35 cubic feet) of the country-rock 1.9 to 6.3 kilogrammes (4 to 14 pounds) of metallic ingredients—a quantity not to be called minute. Or, reversing the calculation, and starting with the largest proportion of metal ever found in these eruptive rocks,

---

* A. Stelzner, *Jahrb. f. Min.*, 1881, p. 209.

† *Oester. Zeitsch. f. B. u. H.*, 1882, xxx., p. 607.

it would have required more than one hundred times the thickness of such rocks actually present in the district to supply the contents of the veins. By these calculations and other arguments, I showed, as I thought, the special inapplicability of the theory to Przibram, but I expressed a willingness to examine some of the eruptive dikes for minute metallic admixtures, preferring only that such an examination should be checked by another person.

The management of the government mining department entrusted to the chemist, A. Patera, the investigation of individual samples of Przibram rock, but also called Dr. F. Sandberger to Przibram, where the first tests were executed with the aid of a Commission, of which I was a member.*

Unfortunately an ailment of the eyes forced me to inactivity, and I could do little on the Commission.

Dr. Sandberger submitted a statement (*op. cit.*, pp. 305–327) or compilation, from which it appeared that he attached less importance to the analysis of the eruptive rocks than to that of the stratified rocks, composed of the detritus of the central Bohemian gneiss mass. According to this view, the metals of the Przibram veins came from the mica of the gneiss detritus. According to Dr. Sandberger, however (*op. cit.*, pp. 362–3), the investigation disclosed that "an essential part of the lead and silver contents of the ore-veins is due to the eruptive rocks"—which involves a modification of the above theory.

Twenty-five rock-samples, selected by the Commission, were tested for metallic admixtures according to a method agreed upon (but not very strictly followed) by Dr. Sandberger, H. Freiherr von Foullon, A. Patera and C. Mann, with tolerably concordant results, although Patera in particular expressed some doubts as to the correctness of the method. This led Prof. A. Stelzner in Freiberg† to make a thorough test of the means employed, which showed that Sandberger's method cannot decisively determine whether the metals detected in the

---

* "Untersuchungen von Nebengesteinen der Przibramer Gänge mit Rücksicht auf die Lateralsecretionstheorie von Dr. F. V. Sandberger, ausgeführt 1884–7 und veröffentlicht im Auftrage Seiner excellenz des k. k. Ackerbauministers J. Grafen von Falkenhayn."—*B. u. H. Jahrb. d. k. k. Bergakad.*, etc., xxv., 1887, p. 299.

† A. Stelzner, "Die Lateralsecretionstheorie und ihre Bedeutung für das Przibramer Ganggebiet."—*Jahrbuch der k. k. Bergakad.*, 1889, p. 1.

silicate were original constituents, or whether they are not secondary impregnations, left undissolved by the reagents employed.

It is thus rendered probable that minute metallic admixtures detected in the country-rock by Sandberger's method are really derived from the ore-deposit, *i.e.*, are not idiogenous but xenogenous. His assumptions in this field also are thus shown to be indefensible.

While I acknowledge fully the great importance of chemical data for the explanation of vein-phenomena, I cannot give here, without becoming too prolix, all the chemical views, often quite discordant, and must content myself with the description of a theory of ore-deposits based upon purely chemical grounds, which has just been made public by De Launay. The author starts chiefly from the views of Elie de Beaumont* concerning volcanic and metallic emanations, adding to these the results of the studies of Fouqué, Senarmont, Ebelmen, St. Claire Deville, Daubrée, etc. He begins with the primitive occurrence of magnetite in the eruptive rocks, which he extends to many other metals and minerals whose primitive presence in eruptives has not been demonstrated. Certain metallic substances were segregated in cooling from the molten mass; others have been dissolved from the eruptive rock in depth by "mineralizers," such as emanations of chlorine, fluorine, sulphur, etc., and have been deposited in the channels leading to the surface. De Launay is a very positive ascensionist; he also doubts the primitive deposition of ores in marine basins, and thus comes by the path of chemical speculation to results analogous to mine. Volcanic and ancient eruptive rocks; fumaroles and mofettes; geysers and thermal springs—these indicate the ways by which the metals have reached the earth's surface. But of such assumptions we must obtain assurance through observations in other directions. Views based upon purely chemical conclusions are not sufficiently convincing for us, because they are gained in the chemical laboratory under conditions different, especially as to pressure and temperature, from those which obtain in the deep region.

---

* Elie de Beaumont, *Bulletin de la Soc. géol. de France,* 2 ser., iv., p. 1249.

Manner of Filling of Open Spaces in General.

We know already that cavities, however originated, are always filled in analogous ways. We find in vein-spaces, in the spaces of dissolution, and even in individual geodes of opal and chalcedony, always the same elements of structure, though in the most widely different materials.

Considering the matter closely, we find that many things are peculiar to the shallow region, as the nearest to atmospheric influences; but some things experienced in that region may be used to explain the phenomena of deposits in the deep region also.

Since we have seen that the precipitate in an approximately horizontal pipe, entirely filled with liquid, attaches itself to the whole interior surface, the same must be true for an underground channel, and all the more if it approaches a vertical position. Under such circumstances the deposit or mineral crust will cover uniformly the whole wall-surface.

Evidently the same laws govern here as in sedimentation. When the section of the passage through which the liquid flows under a given pressure is relatively small, the deposit will take place only when the passage is enlarged. This explains the sometimes unequal distribution of ore in one and the same mineral-water channel.

As in a saturated solution a precipitate may be obtained upon any solid body introduced, so in our mineral-water channels deposits will be made upon all solid bodies—splinters or masses of rock fallen into the fissure, loose pieces of older mineral crusts, and individual crystals floating in the liquid.

The size of the rock-fragments here considered is very variable. We might include, for instance, those which are inclosed between two regular vein-branches.' But we will narrow our view to what can be seen from a single standpoint in the mine, and then we observe that horses of several square meters' surface are uniformly crusted, like small pieces of country-rock found in the vein-filling, the only difference being, perhaps, that the crusts are thicker and more numerous upon the larger masses. The fragments of rock, either angular or already more or less rounded, form, when incrusted, the so-called sphere-, cocarde-, or ring-ores. Crusted rock-kernels may often be observed coexisting with distinct wall-crusts. Sometimes the latter are less prominent than the former, and the ore-deposit then has the appearance of a breccia or a conglomerate, the several fragments of which are held together by the mineral crusts. If, on the plane of a given section, there appear no points of contact between the fragments, it must not be concluded that they originally hung free in the vein-space, or that they have been pressed apart at a later period by the force of crystallization of the mineral crusts, for the actual points of contact can be found in a parallel section; at least, I have always found them when I have sliced into plates a specimen on the surface of which they were not shown. I mention this circumstance because many extensive discussions have been based upon imperfect views of single sections, giving deceptive indications of structure.*

I would recommend the frequent preparation of sections and slides of such apparently complicated structures, and I am convinced that seeming contradictions and difficulties would be simply explained thereby. It is only a question of correct observation and representation, for which, it must be confessed, the use of coloring may be necessary. In this connection I must remark that illustrations, erroneous in this respect, have found their way even into text-books, as, for instance, the picture of cocarde-oil given by Cotta,† which is taken from a careful but uncolored drawing by Weissenbach,‡ of which I reproduce a part in Fig. 17. Fragments of mica-slate are crusted with layers of quartz and pyrite, and in the vugs there is sometimes also manganese or brown-spar. The radial appearance of the crusts in the drawing is evidently due to the position of the crystals perpendicular to the wall-surfaces, and is, as a rule, observable in all such cases. The same figure from Weissenbach has been used by A. Daubrée also,§ as an instance of a *filon brècheform;* but the several crusted rock-fragments are separated by heavy lines, which make the representation not only incorrect but incomprehensible.

The phenomenon may be most generally illustrated by Fig.

---

* *E.g., Trans. A. I. M. E.*, 1883, xi., 119.

† *Lehre von den Erzlagerstätten*, Part I., Freiberg, 1859, p. 33.

‡ G. G. A. von Weissenbach. *Abbildung merkwürdiger Gangverhältnisse.* Leipzig, 1836, Fig. 2.

§ A Daubrée. *Les eaux souterraines aux époques anciennes.* Paris, 1887, Fig. 24, p. 64.

18, which represents a section through a gold-specimen from the Katrontza ore-body at Verespatak, and of which I intend to publish in my monograph on the occurrence of gold in Transylvania a series of parallel sections in color. Four pebbles, three of quartz-porphyry and one of mica-slate, are regularly crusted with (1) a thin zone of hornstone, (2) a thin crust of pyrite, composed of several layers no thicker than paper, (3) hornstone, in which occurs (4) a zone, 5 mm. (0.2 in.) in average thickness, of fine aggregates of native gold, extending often into the next following crust (5) of quartz, containing scattered clouds of hornstone. The series ends in this specimen (6) with open central druses. But other specimens from the same deposit show also minute crusts of manganese-spar, to which I shall recur.

Fig. 11, representing the occurrence of cinnabar in the deeper workings at Sulphur Bank, is an interpretation of the description and sketch given by Le Conte (*op. cit.*, p. 28). Fragments of sandstone and slate with somewhat rounded edges are regularly surrounded with crusts of cinnabar which fill the space between, up to the central druse. Sometimes crusts of hydrated silica and pyrite appear also. Fig. 10 is a picture of a rich portion of the surface-workings of 1874, which I sketched at that time in my note-book. The basaltic country-rock is thoroughly cut up by irregular seams, which have disintegrated it to a shaly mass. In the seams, especially where they come together, larger spaces have been formed, often filled with decomposed country-rock, often showing separate crusts of cinnabar and opal, with a central druse. The porous material of rock and filling is impregnated with native sulphur.

Fig. 19 shows the filling of a space of dissolution at Raibl. It is a diagram from the accurate picture in my monograph upon the deposit.* A nucleus of limestone is surrounded by innumerable fine crusts of wurtzite and more compact but less regular layers of galena.

Fragments of earlier mineral crusts, which have been in some way separated from their original position, are often found surrounded by mineral crusts of later origin. An ex-

---

* "Die Blei-und Galmei-Lagerstätten von Raibl in Kärnthen."—*Jahrb. d. k. k. geol. R. Anstalt,* xxiii., 1873, Bd. I., Fig. 13.

ample is shown in Fig. 20, representing boiler-scale from one of the Przibram pumping plants. Here fragments of dislocated scale, about 2 mm. (0.08 inch) in diameter, are enveloped in later, thin crusts, and thus united to a breccia. The mass consists chiefly of fibrous gypsum, the fibers of which stand perpendicular to the surfaces to which they are attached.

Figs. 21 and 22 present a very distinct example, in which earlier mineral crusts, together with adhering pieces of country-rock, are surrounded by recent crusts. These figures are taken from the valuable treatise of I. Ch. Schmidt,* and refer to Zellerfeld in the Hartz, whence A. von Groddeck also has obtained very interesting illustrations of vein-filling.†

I have seen a more complicated example from the Katrontza ore-body at Verespatak, where very rough ancient crusts of black hornstone and parti-colored quartz have been cemented together by deposits of later quartz and manganese spar to a compact mass, with some central druses. Similar conditions will be seen to obtain in the so-called pipe-ores of Raibl, Figs. 25 to 28.

The variable relation between the diameter of the nucleus and the thickness of the surrounding crust naturally contributes greatly to the variety of the resulting appearances. In the pisolitic formation, for instance, the crust is many times thicker than the nucleus.

In some cases the kernels are individual crystals. I. Ch. L. Schmidt describes pisolitic forms from Warstein, in Westphalia, the kernel of which is a crystal of yellow eisenkiesel, about 5 mm. (0.2 inch) in diameter, showing prismatic and dihexahedric faces, and covered first with a thin, white coating, upon which are crusts of coarsely fibrous eisenkiesel. The edges of these are gradually rounded, until egg-shaped spheroids, about 12 mm. (0.5 in.) in diameter, are formed, touching each other at single points, and leaving interspaces, which are either filled entirely with granular eisenkiesel, or contain residual vugs lined with transparent, finely crystalline quartz.

Fig. 24 represents the geologically important occurrence of

---

* I. Christian Lebrect Schmidt.—*Beiträge zu der Lehre von den Gängen*, Siegen, 1827.

† A. von Groddeck.—*Ueber die Erzgänge des Oberharzes.* (Inaugural dissertation.) Berlin, 1867.

crusted kernels of native gold from the Mátyas Kiraly mine at Verespatak. Minute aggregates of native gold are systematically surrounded by distinct, beautifully pink to carmine, thin crusts of rhodonite or rhodochrosite. So long as the kernels were completely separated, or were kept suspended by the disturbance traversing the cavity, these crusts were deposited entirely around each. After they had become fixed, later deposits of the same sort covered them; then followed carbonates of lime and iron; and finally came the quartz, the beautiful water-clear crystal-tips of which project into the central druses.

The occurrence of gold in manganese spar is not rare at Verespatak; ornaments cut from this material are pretty widely sold. But I have found but once such a distinct envelopment of the gold by the rhodochrosite crusts. The figure represents a piece cut for a brooch, which is in my wife's possession. It is specially interesting, also, as showing that the gold was not derived from the secondary decomposition of auriferous sulphides or tellurides *in loco*, but was directly precipitated from the mineral solutions which subsequently deposited the surrounding crusts.

We have seen that within the domain of vadose or shallow circulation peculiar deposits, classed as stalactites, are very common, not only in the spaces eroded by the natural circulation of the ground-water, but also in spaces created through the artificial depression of the water-level by mining. In the latter case, since mining often follows ore-deposits into the deep region, a much larger variety of substances is exposed to alteration, so that stalactitic formations of all kinds of materials may be encountered. Chiefly, however, we find in this form the results of oxidation, and it is somewhat exceptional to meet with the products of reduction, effected by organic matter in the mine. The most frequent of these are stalactites of pyrite.

This circumstance led to the opinion that stalactites in an ore-deposit should be taken as characteristic of a vadose or shallow origin, through the descending movement of the solutions which formed the stalactites. This view has been most clearly advanced by Dr. A. Schmidt.* The earliest formations

---

* *Die Zinkerzlagerstätten von Wiesloch in Baden*, Heidelberg, 1881, p. 94.

in the instructive Wiesloch deposits are the sulphides, marcasite, galena and wurtzite, to the decomposition of the latter of which, through the metasomatic replacement of the carbonate of lime by the carbonate of zinc, the zinc-ore deposits are due. These he held to be clearly vadose in origin; and since the sulphides also occur in stalactites, he concluded that they likewise must have been formed by infiltration from above. The fact that these latter formations now lie below water-level, whereas the formation of stalactites requires a space filled with air or gas, only forced him to endeavor to explain this contradiction by the hypothesis of suitable elevations and depressions either of the water-level or of the land itself.

But all this would have been unnecessary if he had borne in mind that ascending liquids under a certain pressure will penetrate into a cavity from all sides, and may enter through the roof if the bottom and walls are less permeable. He distinguishes in general two forms of development in the original ore-deposition, namely, the filling of the lower part of a cavity with nearly horizontal, undulating crusts of wurtzite, with a little galena, and the stalactites which hang from the roof, there being no discoverable trace of corresponding stalagmites below. This indicates that the cavity was not wholly filled with gas, but only in its upper part, to which, consequently, the stalactitic forms are confined. As to the manner of the later decomposition of the wurtzite, which extends down to the present water-level, there can be no doubt (*op. cit.*, p. 101).

Similar conditions are found in Raibl, where I have carefully studied the stalactites locally called "pipe-ores."* I find these, it is true, not in their original position at the roof of the cavities, but in the midst of the filling, already broken off and surrounded by the latest mineral crust, in a dolomite spar. They seem to have occurred at many points in this deposit, but my observations were confined to two, one of which was on the 5th Johanni level, about 400 meters (1312 feet) above the deepest adit (the bottom of the valley), while the other was on the 7th deep level, about 60 meters (196 feet) below the said adit. The former of these two points was within the influence of the ground-water.

---

* F. Pošepný, "Die Blei-und Galmei-Erzlagerstätten von Raibl." *Jahrb. d. k. k. geol., R. A.*, xviii., 1873, p. 372; also "Ueber die Röhrenerze von Raibl," *Verhandl. d. k. k. g. R. A.*, 1873, p. 54.

Under the conditions, decomposition of pyrite and zinc-blende had been specially great; that of galena less so. It was often possible to extract from the dolomite mass the stems of galena which were loose in it. The axis of such a stalactite-stem (frequently over 10 centimeters—4 inches—long) was often an open space through which one could blow air, whence the name "pipe-ore" given to this surprising occurrence. Specimens not decomposed or in early stages of alteration showed, besides galena, crusts of pyrite and zinc-blende, concentrically disposed around the axis.

Figs. 25, 26, 27 and 28 (taken from my former treatise) and representing sections of individual stalactites, are intended to cover the variety of forms in these occurrences. Fig. 25 shows a circular stalactite in which small quantities of galena may be seen in the pyrite surrounding the axial cavity. The outer crust consists of thin layers of wurtzite (*Schalenblende*). In Fig. 27 a galena mass of rhombic section, with regular striations of secretion, sits immediately on the side of the cavity. In Fig. 26 the annular mass of galena is surrounded by blende. In Fig. 28 a decomposed body of blende lies within the galena mass, which latter is deposited immediately in the granular dolomite. It will be seen that the crusts upon the stalactites present a varying order of succession, and that the stalactites have fallen from the roof at different stages of their growth.

That portion of the ore-deposits which surrounds the localities of these stalactites has an entirely normal structure, corresponding with that of other portions, and can only have been formed in the same way, namely, from ascending mineral solutions in the deep region. When, under such circumstances, a cavity contains stalactitic deposits instead of the ordinary wall-deposits, that particular part of the channel must have been filled with gas. The decomposition of the blende is due here, as in Wiesloch, to the subsequent action of the vadose circulation.

In the Mátyas Kiraly mine in Verespatak, from which I have already described the envelopment of gold-aggregates by various metallic carbonates and quartz, there has been found also a stalactitic form of analogous composition. This specimen is in my possession, but there are two others in the National Museum at Budapest which practically came from the same mine. One of the latter is shown in Figs. 29 and 30, and my own in Fig. 31, in twice the natural size. The latter showed, after being broken from the rock in which it occurred, a projecting thread of gold; and in polishing the surface several annular (and hence crystalline) gold-aggregates were found in the axis of the stalactite. The shaded portion indicates the pink manganese crusts, and the unshaded portion the colorless carbonates. The outermost crusts, separated here and there from the others by a small druse, is quartz.

Wonderful occurrences of this kind must exist in the Vallé mines in Missouri; but we have only mere diagrams of them, which do not exhibit the true details and cannot be corrected with the aid of the accompanying text. The careful objective representation of a series of these tubular deposits would be a service to science. I shall recur to these relations, represented in Figs. 32 to 35, when I come to consider the Missouri deposits again.

The variety of the occurrences described above might be still further illustrated; but enough has been said to furnish from observation the elements for explaining the filling of all crustified deposits. When the elements actually found in such deposits are taken together with what we know of the conditions of underground circulation, no competent person can well believe in any other origin for these deposits than that of the circulation we have described. Whoever has followed the foregoing simple statement of the whole chain of phenomena will be led to distinguish sharply between the effects of the descending vadose and those of the ascending profound circulation, and to avoid the confusion of the two which sometimes characterizes the discussion of the subject.

But there remains a serious difficulty in determining the genesis of non-crustified deposits. Here the indications, by which the structure and gradual growth of the deposit may be traced, are at first lacking. But they will certainly be found by patient search; and this knowledge must be furnished by engineers who have opportunity to study the phenomena on the spot where they occur, namely, in the mine.

The non-crustified deposits consist, however, of the same minerals as the crustified, and cannot well have a different origin; only we are not yet in a position to offer for them similar proofs of the manner of their formation. Certainly they also are the products of ascending mineral solutions; but they were not deposited in pre-existing spaces, and consequently they show no crustification. In describing various instances of this class, I shall have occasion to adduce some data bearing upon their genetic relations.

But even the crustified deposits need to be further illustrated by examples, especially because they seldom occur in nature in pure, unmixed types. We ought not to consider ore-deposits without reference to the medium which contains them; hence we must take into consideration the country-rock, and seek to represent the analogies of nature by grouping them graphically, as it were, with relation to two axes, representing respectively the genetic class and the country-rock. We may thus distinguish the following general groups:

Fillings of spaces of discission (fissures, etc.).

Fillings of spaces of dissolution in soluble rocks.

Metamorphic deposits in soluble rocks; in simple sediments; in crystallines and eruptives.

Hysteromorphous deposits (secondary deposits, due to surface agencies).

PART II.

EXAMPLES OF CLASSES OF DEPOSITS.

I have attempted to show above that in the two regions of subterraneous circulation the formation of ore-deposits must have taken place according to different, almost diametrically opposed principles: in the vadose region through descension and lateral secretion, and in the profound region by ascension, as the product of upward currents. I have pointed out that the deepest rocks reached by mining can scarcely be the original sources of the metallic solutions, and that these sources must lie at still greater depths.

That is to say, I advocate the views of the old school, and stand opposed to the assumptions of the new one, lately become popular, which does not need to go to inaccessible depths for the source of the metals, but professes to find it conveniently by simple chemical tests, without the necessity of leaving the laboratory and searching out the natural deposits. The new doctrine has thus far failed to take into consideration the two different underground regions; and we may expect that in proportion as it comes to do so, its conclusions will acquire quite another meaning.

I think it has been shown that the deposits of the deep region are precipitates from ascending springs. It remains to inquire, what has become of the substances which were not precipitated in such channels, but reached the surface in solution? Evidently these have been taken up, partly by the surface circulation, partly by the vadose underground currents; and, in the latter case, the deposition of such substances in the vadose region is possible. But I do not believe that we are as yet in a position to form a correct conception of the process of such a deposition; and therefore I leave this question open. Possibly, many impregnations, for which we can trace no direct connection with ascending springs, yet which are certainly not idiogenous (*i.e.*, of contemporaneous origin with the rock-matrix), may have originated in this way. Possibly, the sulphides which occur confined to the neighborhood of organic remains have been reduced from sulphates. But this must be confirmed in each case by a direct study of the facts, and not propounded as a safe generalization for all cases.

All these conclusions are based upon the undoubtedly correct hypothesis that the individual minerals of the deposits are precipitates from aqueous solutions. The important part played by the direct products of the barysphere—the eruptive rocks—is not ignored. But there has been a tendency of late to consider the proof of any solvents as superfluous, and apparently to assume that certain minerals were segregated directly from the eruptive magma. With respect to ferriferous oxides, this view has some foundation; but the notion, apparently held in some quarters, that sulphides also were thus segregated from the magma, surpasses my comprehension. It is true that pyrite is sometimes seen upon the lavas of active volcanoes; but this occurs, so far as I know, only when fumaroles and solfataras emit gases and vapors which decompose the rock, and therefore the agency of a solvent is not lacking.. I am therefore obliged to conclude that aqueous solvents are the chief factor in the genesis of ore-deposits; and I shall be guided by this principle in the following illustrations of the leading genetic groups.

1. Ore-Deposits in Spaces of Discission.

The spaces produced in rocks by mechanical forces are predominantly fissures; but simple forms are sometimes rendered irregular by pre-existing conditions, such as those of stratification. Splitting upon a bedding-plane, coupled with a simultaneous longitudinal movement (such as gave rise to the ore-stock-works which the Norwegian miners call "lineal") may produce very complicated spaces, which must, however, be classed as spaces of discission.

Every fissure is the consequence of a tendency to dislocation transmitted into the rock. Hence the principal effect of the process is the production of the dislocation, not that of the fissure.* Where yielding stratified rocks are exposed to such a force, they first bend in its direction, and the fracture takes place when the limit of elasticity is passed. In such cases it is evident that the movement precedes the fracture. Fig. 70, from Rodna, and Fig. 69, from Raibl, are examples. In the latter, the gently southward-dipping contact between limestone and slate is bent and faulted by a N. and S. fissure. At Kisbánya, in Transylvania (Fig. 99), the strata of gneiss and chloritic slate, striking N. and S., are so bent by the E. and W. Nagynyerges vein as to give the appearance of an ore-bed.

Although the fissures produced by dislocating forces appear to be straight, they exhibit (as may be observed where veins have been traced for long distances) various changes of direction and more or less gradual curves. This hinders or checks the movement of one convex portion upon another, and promotes the creation of open spaces. The dislocating force, however, continually crowds the projecting surfaces together, and thus a space already partly filled with mineral deposit may be closed, or an open space may be filled with the detritus of friction. But the space finally left open facilitates communication with the deep region, from which it is filled.

According to this conception, the vein-sheet must not be regarded (as is too often done) as a uniform plate of ore. On the contrary, it consists of several portions of very unequal value. The most valuable, doubtless, is the cavity-filling which forms

---

* F. Pošepný, "Geol. Betracht. über die Gangspalten," *Jahrb. d. k. k. Bergakademien*, Vienna, 1874.

the *bonanza* proper. In another portion the mineral solutions have been forced to penetrate the country-rock and impregnate it with ore. A third portion remained altogether impenetrable to the solutions, and represents barren ground. These three kinds of ground may evidently show, at least in the same district, a certain regularity of relation; and of course it is most important to determine for a given district some law of distribution of the rich ore-bodies. In certain instances some knowledge of this distribution has been, in fact, successfully acquired for a given vein before it had been exhausted by mining. In many other cases we cannot establish the law, even afterwards, because the most necessary records were not made during the exploitation. On the whole, we must confess that our knowledge of the laws of bonanzas is nothing to be proud of. In this respect the work of Professor Moissenet may be consulted.*

Obviously, in all such investigations, the question of the origin of the fissure must be separated from that of its filling. The former can be answered only upon the broad basis of a knowledge of the stratigraphic relations of the whole vicinity, and with reference chiefly to the physical properties of the rocks, while in the latter their chemical properties come to the front.

As a rule, however, the country-rock of an ore-vein is more or less altered, not only by decomposition, but also by subsequent solidification, thus rendering much more difficult the comparison with conditions existing far from the vein. This alteration of the country-rock is universally ascribed to the mineral solutions which deposited the ore; and it is not improbable that a close study of it might enable us to draw conclusions as to the nature of these solutions. Unfortunately, petrography is still confined mainly to fresh, typical rocks, and the study of the decomposed country-rock of ore-veins has not been cultivated so much as could be wished.

All veins which exhibit friction-phenomena, such as crushed country-rock, slickensides, and striations, are structurally fault-fissures. Such a vein may be conceived, therefore, as the

---

* M. L. Moissenet, *Études sur les filons de Cornwall; Parties riches des filons; Structure de ces parties*, etc., Paris, 1874. Engl. tr. by J. H. Collins, London, 1877.

boundary-surface of a mass which has undergone movement. The vein-phenomena of the Hartz especially support this conception.

Some vein-fissures are confined to a given rock, and do not extend into the adjacent rock. These cannot be ascribed to structural dislocation, but must rather be considered as caused by changes of volume in the immediate formation. They are often called fissures of contraction. The most striking example which I have encountered is shown in Fig. 36, which is from the gold-district of Beresov, in the Ural mountains. Palæozoic slates are there traversed by a number of granite veins, 20 to 40 meters (66 to 131 feet) thick, and striking chiefly N. and S.; and each of these granite veins is again traversed by E. and W. gold-quartz veins, which at the borders of the granite either become barren or cease altogether. Near the Beresov is the Pysminsk district, in which the granite veins are replaced by diorite and serpentine; but strange to say, the gold-quartz veins occupy in these rocks the same position as in the peculiar Beresov granite, locally called beresite. Judging from Beresov alone, one might suspect the veins to have been filled from the granite; but the occurrence in Pysminsk suggests caution.

Finally, the veins of the well-known very deep mines of Przibram might be ascribed to the contraction of the eruptive dikes in which they occur (although they depart here and there into the stratified rocks); but we cannot dream of deriving their metallic filling from the dikes. The Commission, already mentioned, established to test the applicability of the lateral-secretion theory to Przibram conditions, found the material of the dikes to be the same in depth as in the upper zones. The largest amount of metallic contents attributed to the diorite dikes would account for a portion only of the thickness of ore in the veins. The greater part must certainly be regarded as of deep origin; and it is more convenient to treat the entire metallic contents of the veins as derived from greater depths.

Granting, then, that the vein-spaces at Beresov were formed by the contraction of the granite dikes, the vein-filling must be ascribed, like that of other deposits, to metallic solutions ascending from the deep region.

With regard to structure, the fillings of ore-veins very often exhibit distinct crustification, and sometimes even a symmetric succession of crusts from both walls to the central druse. But this phenomenon often retires into the background; crustification becomes indistinct or disappears, as is frequently the case in gold-quartz and other metamorphosed veins, in which its last traces appear in the crystal-tips of the central druse and the occasional indication of fibers perpendicular to the walls.

Sometimes one part of a vein shows distinctly a crustification which in other parts is discerned with difficulty, or is even wholly absent. Fig. 53 represents a specimen from the Drei Prinzen Spat vein in the eighth level of the Churprinz Friedrich August mine at Freiberg. It is interesting also by reason of the two dislocations which it exhibits. The oldest vein (*a*) of quartz, with irregularly disseminated galena and zinc-blende, is traversed and faulted by a second, very clearly crustified, vein, the filling of which consists of hundreds of very thin alternate crusts of (*b*) fluorite and quartz and (*c*) barite, symmetrically arranged on both sides, with a central druse (*d*) containing a gray earthy mass. A quartz seam (*ef*) then faults both veins. The manager of the vein assured me that the specimen occurred in the vertical position in which I sketched it. (In order to be certain at all times on this important point, it is advisable, before removing a specimen from its natural position, to mark it in color with a vertical arrow, head downward.)

Very often the crustification of a vein-formed ore-deposit is only to be traced in the appearance of the whole, since each of many irregular veinlets may represent separate mineral crusts. Accurate pictures of such occurrences are highly instructive, since the complications are often so great that the most detailed description can convey no correct notion. Figs. 45 to 52, by reason of their small scale, do not give all the details contained in the originals from which they are taken. Figs. 45, 46, and 47 are from Weisenbach's famous book,* and represent Freiberg occurrences. The rest are from Austrian publications.† Figs. 48, 49, and 50 refer to Przibram,

---

* *Abbildung merkw. Gangverhältn. aus d. sächs. Erzgebirge,* Leipzig, 1836.

† *Auf Befehl s. Exc. Julius Grafen Falkenhayn herausgegebene Bilder v. d. Lagerst. d. Silber-u. Bleibergb. zu Przibram,* etc., Vienna, 1887. *Geol.-bergmänn Karte mit Profilen u. Ortsbildern zu Joachimsthal,* etc., Vienna, 1891.

Figs. 51 and 52 to Joachimsthal. We have in Fig. 47 a specimen, so to speak, of the transition from a vein to a bedded deposit. But this is not the type called by the Germans bed-vein (Lagergang), which is strictly a fissure-vein, the fissure of which coincides with the plane of stratification instead of crossing it. Sometimes it is a joint or cleavage-plane (often confounded with the bedding) which the bed-vein occupies—a case which, I believe, I have found at Mitterberg, in Salzburg, and at the Rammelsberg, near Goslar.

In this category belong also the instances of a squeezing of strata near the vein, so that hanging- or foot-wall, or both, show for a certain distance a stratification parallel with the ore-deposit, and only beyond this zone does the normal stratification in a different plane appear. This case is best represented by Fig. 99, a sketch showing an E. and W. vein in a country of slate striking N. and S. The occurrences at Rodna (Fig. 70) and Raibl (Fig. 69) furnish also some illustrations, though here it is chiefly barren fissures which traverse and bend the stratification.

The text-books usually present only simple outline-sketches of such conditions; and accurate pictures are calculated to surprise those who have not been much in mines, by exhibiting the complications of the actual occurrences. (Of course, complete objective accuracy would require photographs of polished surfaces.) I will here refer only to one of the most complex pictures, shown in Fig. 47 and taken from Weissenbach's collection (*op. cit.*, Plate 22). The Gabe Gottes vein of the Bescheert Glück mine at Freiberg consists of separate masses of decomposed gneiss, bounded by barren fissures, and the stratification of which has been disarranged by their mutual pressure. The fissures have no filling, but the gneiss shows filling, nearly representing its stratification, *i.e.*, in planes almost perpendicular to the walls of the vein. According to my view, the vein being in this place split up into small fissures, a movement must have occurred, probably on the lowest of these fissures shown in the picture; but the result, instead of being an ordinary fault, was a pulling-apart of the hanging-wall strata, which created spaces perpendicular to the vein-plane, and approximately between the strata. These spaces were subsequently filled in the same way as was the simple main fissure itself in other parts of this vein. The case may furnish also an explanation for certain kinds of bed-veins.

The greater number of ore-veins, as of ore-deposits in general, occur in eruptive rocks—a circumstance which doubtless indicates that their metallic contents have been derived, directly or indirectly, through these or other media, from the barysphere. The most productive ore-veins are wholly in such rocks, but others occur in stratified rocks, traversed by eruptives. Comparatively few occur wholly in stratified rocks. In such cases large faults have unquestionably opened communication with the barysphere. To emphasize these relations, I will bring forward some illustrations from well-known ore-vein districts comprising such occurrences:

a. In stratified rocks, entirely unconnected with eruptives;

b. In the neighborhood of eruptive masses, and partially enclosed therein;

c. Wholly within large eruptive formations.

a. Ore-Veins in Stratified Rocks.

Genuine ore-veins entirely unconnected with eruptive rocks are not easily to be found—especially not in cases of important and well-studied districts. Clausthal, in the Hartz, still comes nearest to fulfilling these conditions. The Hartz range is a mass of folded palæozoic strata, which lifts itself, in lenticular form, above the North German plateau of mainly Mesozoic rocks. The strata comprising the Hartz generally strike at right-angles to the W. N. W. direction of the axis of the range, but most of the faults are approximately parallel to this axis, so that the terms "axial" and "cross" mean here the opposite of what they would mean in ranges, the main axes of which coincide with the strike of the strata.

Clausthal.—The ore-veins of Clausthal are somewhat peculiar. There are zones of altered rocks, 20 to 80 meters (66 to 262 feet) wide and extending as far as about 15 km. (9 miles), in which the ore-bodies are somewhat irregularly distributed. These rock-zones are called vein-clay-slates (Gangthonschiefer), to distinguish them from the ordinary slates (Culmschiefer) of the district; and recent careful investigations have shown that their composition practically corresponds with that of the latter. They are therefore in fact country-rock, altered for the most part mechanically, and only to a slight extent chemically. They are foliated; but the foliation rather parallels the planes of movement, being somewhat steep, while the strata of the surrounding region have generally but a slight dip. These zones may therefore be best conceived as the result of the friction of the great masses which have here been rubbed together.

In recent times, chiefly by A. von Groddeck, it has been actually proved that these zones represent great faults, along which either the foot-wall mass was moved S. W. downward, or the hanging-wall was lifted N. E. The vertical movement, measured at certain points, would be about 400 meters (1312 feet); but it is probable that the movement of one mass upon the other did not follow the true dip, and that the horizontal component was much greater than the vertical. The faulted portions of a kersantite vein discovered by Groddeck show that each southern mass was moved further west, or each northern mass further east.

The network in these zones of dislocation is also peculiar. As indicated in Fig. 37, lenticular masses have been isolated, after undergoing severally a movement in the direction of the axis of the Hartz range; so that the whole zone of lenticular masses expresses the displacement which the solid crust has experienced. The structural significance of the zones is thus clearly disclosed, as a means of communication with a deep region from which the mineral solutions ascended, to deposit ores in the fissures of dislocation. As I have already remarked, an ore-vein is thus represented as the boundary of a displaced rock-mass, and so is brought into direct structural relation with the country-rock.

A glance at the geological map of the Hartz Mountains will show, however, that even this region is not free from eruptive rocks; for the stratified formations crossing the mountain axis are traversed by masses of granite, which have evidently played a part in the building-up of the range above the plateau. Moreover, according to the investigations of Dr. K. A. Lossen,* and others, contact-metamorphosis of the stratified rocks has

---

* "Geol. u. petrogr. Beiträge zur Kenntniss des Harzes," *Jahrb. der k. preuss. geol. Landesanstalt ü. Bergak. für* 1881, p. 47.

proceeded from them. E. Kayser* fixes the elevation of the granite between the end of the Carboniferous and the beginning of the Permian, and since several of the faults extend into this rock, he thinks it cannot have been a factor in the fissure-formation. Lossen, on the other hand, is inclined to ascribe to the granite an active part in the formation of the ore-deposits, and (if I understand him correctly) to believe that these deposits were influenced by their position against the granite nucleus of the Hartz Mountains, which is said to lie steep on one side and more flat on the other, beneath the sedimentary strata.

Accurate geological surveys of the Hartz have noted a large number of fault-fissures, some of which connect the two great ore-deposits of Clausthal and Andreasberg. Those which are called *Ruscheln* resemble the dislocation zones of Clausthal. They are fissures, up to 30 meters (98 feet) wide, approximately parallel with the mountain-axis, and filled with a clayey or fragmentary material, full of striations and slickensides, and generally of dark color.

Andreasberg.—Roughly parallel with these *Ruscheln* run the silver-ore veins of Andreasberg, which carry ore only on one side of the *Ruscheln*, and lose their ore when they approach the latter. It was formerly imagined that the two main *Ruscheln* enclosed a lenticular mass of the country, to which the silver-ores were confined; and H. Credner† still expresses this view. But Kayser (*op. cit.*, p 443) observes that the mines have disclosed a convergence of the *Ruscheln* to the west only, and that a similar convergence to the east has been purely assumed from analogy, whereas the surface-indications are rather those of a wider separation in that direction. (See Fig. 38.)

We have here a case in which the ores occupy, not, as in Clausthal, a previously prepared zone of dislocation, but a network of veins. H. Credner has pointed out that the mineral solutions were unable to penetrate the walls of the dislocation-zones, and conceived in this connection that these walls enclosed a lenticular body of rock. But the main question concerns the origin of the more recent network of fissures. We

---

* "Ueber d. Spaltensystem am S. W. Abhang des Brockenmassivs," etc., *Ibid.*, p. 452.

† "Geogn. Beschreib. d. Bergw. distrikts von. Andreasberg," *Zeitsch. d. deutsch geol. Gesell.*, xvii., p. 221.

must assume that when the dislocation-zones were formed, the mineral solutions had no opportunity to enter them, because (as was the case in many great faults, *e.g.*, those of Przibram) no spaces of discission were formed. Afterwards, however, a second system of fissures originated, adjusting itself to the conditions created by the first, and producing rock-fragments, the relatively slight movement of which did not fill the interstitial spaces with the detritus of friction.

But outside of the angle between the *Ruscheln*, there are also veins, which, considering their direction, may be continuations of the silver-veins inside, although, being differently filled, they are not so regarded.

It was formerly attempted to connect two eruptive rocks with the formation of these ore-veins: the granite which appears to the north, beyond the fault-fissures; and the diabase which touches them at many points to the south. The latter, however, is now considered to be a stratified layer in the series of the country. Both rocks have been passive in the formation and the filling of the fissures, and we must look again to the deep region as the source of the ores.

b. Ore-Veins in the Neighborhood of Eruptive Masses.

The Erzgebirge.—It would be impossible here to pass in review the innumerable veins of the *Erzgebirge* in Saxony and Bohemia. Such a review will soon be furnished by the publication of a work on this subject by the eminent Saxon mining geologist, H. Müller (who has received the honorary title of "Gangmüller," to distinguish him from the many other Müllers of Germany). In this region, veins in the greatest variety occur in gneiss, with here and there an eruptive dike; but the latter can scarcely be considered as more than indications of a former communication with the barysphere.

Besides different porphyries and diorites, there is an occasional dike of basalt. At Joachimsthal, in Bohemia, we can recognize pre- and post-basaltic ore-deposition. We find here, as in many other districts, two vein-systems at right angles; one striking N.–S., and accompanied with porphyry dikes; the other striking E.–W., and accompanied with dikes of basalt and (according to recent views) phonolite. The E.–W. fissures are occupied partly by basaltic dikes, partly by ore-veins which were deposited, some before and some after the basalt, a satisfactory proof that the fissures were formed at the period of basaltic eruption. How far the basalt took part in the ore-deposition, however, has not yet been shown.

In the basaltic and "basalt-wacke" dikes of this district, at the considerable depth of some 300 meters (984 feet) below the surface, petrified tree-trunks were found, a fact which furnishes an analogy to the reported discoveries in the Bassick mine in Colorado.

Przibram.—An entirely different picture is presented by Przibram in central Bohemia, where we encounter not only a great structural fault, but also eruptive dikes, which are followed by most of the ore-veins.

In central Bohemia the general strike is NE.–SW. for all rocks except the diorite dikes, which strike N.–S., thus varying 45° from the prevailing direction. Above the granite lies first a formation of pre-Cambrian slates; upon this follows unconformably the Cambrian system, consisting below of conglomerates and sandstones, and above of fossiliferous slates. Sections across the strike show repetitions of the pre-Cambrian and Cambrian strata due to great faults, which likewise strike NE.–SW. (Fig. 40).

The one main fault which has been exposed by mining to the depth of 1110 meters (3600 feet) is properly a so-called *Wechsel*, by which the older stratum (in the hanging-wall of the fault) has been slid over the later stratum (in the foot-wall). Several other faults, similar in character, though not explored on an equal scale, occur in the district; and it may be imagined that before this shoving together of the Palæozoic strata of central Bohemia they must have occupied a much larger area than at present.

This main fault, called the "*Lettenkluft*," is constituted by a zone of clay and crushed rock, from 2 to 10 meters (6.5 to 33 feet) wide. At Przibram itself, the sandstones which contain the ore are succeeded in the hanging-wall side by pre-Cambrian slates. A little further SW., at Bohutin, granite appears on the hanging-wall of the *Lettenkluft*—evidently, as the cross-section indicates, the granite foundation, here outcropping a second time, of the whole Palæozoic series.

Numerous N.–S. dikes occur, and in the ore-bearing zone they are so close together that some cross-sections show them to constitute almost one-third of the total rock-mass. The ore-veins are mostly in these diorite dikes. Only occasionally do they enter the stratified rocks, returning soon to the dikes they have left, or to others of the group. In dip also they mainly follow the dikes, so that we may here assert with confidence that the already existing dikes determined the formation of the ore-bearing vein-fissures.

As already narrated in Part I., this district was made a test of Sandberger's lateral-secretion theory. Careful and repeated analysis showed the presence of metals in the rocks, but could not decide the question whether these metals were primitive ingredients or secondary impregnations. Since such metallic traces occur in both the eruptive and the sedimentary rocks, but cannot possibly be in both cases primitive, it is probable that they are in both cases secondary. There is then in this case, notwithstanding the connection of the ore-veins with the dikes, no proof that they were formed by the leaching of the country-rock. If the vein-material (as is very likely) was derived from eruptive rocks, these were situated much deeper than the eruptive rock disclosed down to 1110 meters (3640 feet) below the surface, or 500 meters (1640 feet) below sea-level.

The Cambrian sandstone basin of Przibram is unsymmetrical; one side dips gently northwest, the other (next to the fault) slightly southeast. In the latter part, which is also more highly metamorphosed, lies the bonanza or rich ore-ground, which therefore starts *from the intersection of the great structural fault with the zone of eruptive rocks*, in other words, from the point relatively nearest to the barysphere.

In the steeply-dipping sandstone series, certain strata are petrographically characteristic; and when these are traced to the intersecting dikes, it becomes clear that the latter (and hence the ore-veins also), are fissure-faults. Thus Fig. 39, a section through the Franz Joseph shaft, shows dislocations of the strata (adinole-beds) as great as about 200 meters (656 feet).

It should be added that the dikes present different kinds of eruptive rock, and that they are generally decomposed in the neighborhood of the ore-veins—a result naturally to be attributed to the action of the mineral springs; also, that stratified rocks show, near the granites, a contact-metamorphosis which has converted them into hornstone. This phenomenon recalls the Hartz, especially the St. Andreasberg district.

c. Ore-Veins Wholly Within Large Eruptive Formations.

Hungary.—If we turn to Hungary, we find many veins wholly included in eruptive rocks. One of the best known districts is that of Schemnitz, which presents in geological conditions the nearest analogue of the Washoe district and the Comstock lode in Nevada.

In both cases, various eruptives, principally Tertiary, such as diorite, andesite, trachyte and rhyolite, ranging to basalt, are spread over a Mesozoic (mainly Triassic) foundation. The N. and S. extension of these masses and of the ore-veins they contain is alike in both districts. The number of veins at Schemnitz is very large, and they exhibit a very great variety of filling. In some of them, so-called "ore-columns," *i.e.*, specially rich ore-channels (chimneys or shoots), have been recognized. Those in the Grüner vein, according to M. V. Lipold,* are short horizontally, but much prolonged in the direction of their pitch, obliquely on the dip of the vein. In other ore-veins, *e.g.*, in the Spitaler master-lode, which is about 40 meters (131 feet) wide, and has been traced for 8 km. (5 m.); also in the Bieber and other veins, the ore-bodies are said to have covered large areas of the vein-sheet. The ore richest in gold is reported to be the so-called *Zinnopel*, a crust consisting of jasper, with pyrite, chalcopyrite and galena, which surrounds fragments of an earlier quartz crust.

In the trachyte range of Vihorlat Gutin, which runs NW. and SE., approximately parallel with the Hungarian boundary, there is a series of gold and silver mining districts, containing occasional large veins with numerous small ones. Among the former are those of Nagybánya and Felsöbánya, where several domes of trachyte or of andesite, breaking through the late Tertiary "*Congerien*" strata, are in turn traversed by large veins, which split up near their outcrops, so as to exhibit in vertical cross-section a fan-shaped arrangement.

---

* "Der Bergbau von Schemnitz in Ungarn," *Jahrb. d. k. k. geol. R. Anstalt.*, 1867, p. 403.

Further east is the Kapnik mining district, containing a series of separate veins; then comes Rota, similar in character; and finally (over the line in Transylvania), the district of Oláhláposbánya, the veins of which are partly in the eruptive rock, partly in the old Tertiary strata which it traverses.

Throughout the range, silver-ores predominate, occasionally with a considerable gold-value. In the eastern portion, copper-ores appear.

The Dacian Gold-Field.—In southwestern Transylvania, in the Dacian gold-district, all the gold-mines are grouped in connection with four separate eruptive zones of recent origin. The main rock of the region is Cretaceous sandstone, with occasional exposures of Jurassic and Triassic strata, the latter of which include heavy outflows of melaphyre, and also masses of crystalline rocks. The recent eruptives, comprising porphyry, diorite, andesite, basalt, etc., occur in a triangle, the base of which is formed by the widest range, the Cietrasian, which strikes NW. and SE., and in which are the mines of Nagyag, Magura, Füzesd, Boiza and Ruda. In a second, approximately parallel range, are the mines of Faczebaja and Almás; in a third, those of Vulkoj and Verespatak; and in a fourth, forming the apex of the triangle, those of Offenbánya.*

These mines, which are for the most part very ancient (pre-Roman), I shall treat fully in a monograph now in course of preparation. In the whole Dacian gold-district the predominant deposits are fissure-veins, sometimes represented by mere "knife-blade" seams, continuous for short distances only. In some places, as in the celebrated Verespatak district, other types of deposit are represented, the ores of which, however, also occur in spaces of discission, namely, in eruptive breccias, between the related fragments, in the form which I have elsewhere called typhonic masses; but these are ore-bearing only where they are in contact with the ore-veins. The same is true of the conglomerates into which these breccias sometimes pass, and in which the ore takes the place of the interstitial cement, as I have explained in a preceding chapter, and illus-

---

* F. Pošepný, "Allgem. Bild d. Erzführung im Siebenb. Golddistrikte," *Jahrb. d. k. k. geol. R. Anstalt.*, xviii., p. 297.

trated in Fig. 18. For further elucidation, I show in Fig. 41 a breccia, and in Fig. 42 a conglomerate. (It should be observed that the mutual relation of the fragments of a breccia can be recognized only when they have not suffered much movement after fracture.) In both these specimens, the rock is quartz-porphyry with quartz-crystals of pea-size. In Fig. 41 the interior of the fragments is considerably decomposed, whereas the exterior shows a thin layer, either of undecomposed rock, or of material subsequently impregnated with silica from the open interstices, and thus made capable of resistance. Sometimes the porphyry is found to be traversed by a complex network of fissures, filled (except as to some wider spaces of intersection) with a clastic mass, like sandstone. The interstices of the conglomerate, Fig. 42 (except the spaces containing crusts of manganese spar and quartz), are filled with a clastic cement, mostly silicified into hornstone.

This sort of ore-filling is comparable in some degree with ore-deposits in soluble rocks, when the filling has passed from the space of discission proper into the rock, after room has been made for it in the latter by dissolution. In the cases before us such room was made by the partial washing away of the (probably clayey) cement of the breccias and conglomerates.

Verespatak.—The gold-district of Verespatak is situated at the north end of the second eruptive range. The two porphyry masses of Kirnik and Boi form a center, around which sandstone and porphyry-tufa lie almost horizontally, and in part unconformably, upon folded Cretaceous sandstones below. The whole district is surrounded by a zone of trachytes, andesites, and their lavas, which once (as may be inferred from the fragments remaining on the porphyry and tufa) overspread the entire district, and have been removed by erosion, laying bare the two older eruptive masses of the porphyry.

A funnel-shaped depression seems to have been formed in the folded Cretaceous strata, from the middle of which ascended the porphyry-outflows, furnishing also the material for the porphyry-tufa, which fills this funnel-shaped basin.

The principal gold-bearing rock is the porphyry, yet the tufas and the Cretaceous rocks near the porphyry-outflow carry gold; whereas, no gold or ore of any kind occurs in the trachytic and andesitic lavas which once covered the region.

Vulkoj.—At Vulkoj, however, at the southern end of the second eruptive range, almost the opposite is the case. Here the older and deeper quartzose rock carries little ore, while gold abounds in the overlying andesites. Several mines of the Dacian gold-district have encountered in depth the stratified rocks through which the eruptives came, and the result has generally been disastrous to the miner, the ore-veins having either ceased entirely or become pinched to barren fissures. In the first case it would appear that the vein-fissures had been formed by the contraction of the eruptive material. But, in general, it should be said that these phenomena are by no means clearly and reliably reported. The prejudices of the miners play too large a part in their reports. This much is certain, that any fissure, in passing from one rock to another, is likely to exhibit a certain irregularity in both direction and filling, and that a change of this kind should not be allowed to discourage at once all further exploration.

In some cases there has been found, below an eruptive rock containing ore-veins, a decomposed breccia of the same, which was quite barren. The great porphyry mass of Kirnik, at Verespatak, has been pierced through and through with ancient and modern workings, like the pores in a sponge. In recent years deep adits have been driven into it to reach fresh ground, but with unsatisfactory results. A short time ago the deepest of these adits encountered in the nucleus of the Kirnik mass, not the ore-bearing porphyry, but decomposed clastic rock and porphyry-breccia, which may be supposed to be the filling of the crater-opening. The Vulkoj mass, which has been almost cut into two halves by very ancient open-workings along its crest, contained a series of N.–S. veins, the richest of which (the Jeruga) was cut in depth by adits from both sides. On the south side appears a slaty Cretaceous rock, underlying the porphyry, and extending (see Fig. 43) upon the Jeruga plane, with two offsets, to the deepest adit on the north side, where it strikes the decomposed breccias, in which the very rich ores mined above can no longer be found to continue.

As to the continuation of the veins in the slaty rock, the following facts are pertinent. West of the Vulkoj mass, in the sandstones and slates, there is another gold-field, that of Botesiu, the veins of which are analogous, both in strike and in ore-filling, to those of Vulkoj. Botesiu shows no eruptive rocks; nevertheless, a study of the whole region shows that the formation of its vein-fissures must have been connected with them, and it is even not impossible that they may once have extended as far as this, and may have been removed by subsequent erosion. It follows that we must assume the Vulkoj veins to extend below the andesite into the slate, though this has been doubted by some. Fig. 44 shows the situation in an E.–W. section.

In the region of Boitza the eruptive zone (predominantly of quartzose dacites or porphyries) crosses an exposure of Mesozoic limestones and melaphyrs, and the veins pass directly from the porphyry into the underlying melaphyr.

At Nagyag, Magura, and Füzesd, in following the gold-veins in depth, masses of Tertiary sandstones and conglomerates are formed, broken through and enveloped by the eruptive rocks.

At four places in the Dacian gold-district, namely, Offenbánya, Faczebaja, Fericiel and Nagyag, telluric ores occur. In the neighborhood of Zalatna there is cinnabar, and at several points near Körösbánya there are copper-ores carrying a little gold. Gold is, however, mainly connected, as has been observed, with the four ranges of Tertiary eruptives, and appears chiefly in these rocks, though also in the stratified rocks which they traverse.

The occurrence of gold in this case is thus somehow related to the eruptions; but since I have never found it as a primitive or idiogenous constituent of these rocks, I do not believe that it was derived originally from them. There is, therefore, nothing left but to consider the eruptions as the agents of a communication with the deep region, from which at these points the mineral springs ascended. The Dacian gold-district will furnish, upon further exploration, important contributions to the inquiry into the original source of the gold. For instance, if the auriferous character of the veins of Vulkoj should be found to continue in the shaly sandstones underlying the andesite, my view would be confirmed.

The Comstock Lode.—The most thoroughly studied American vein-phenomena bearing on this question are doubtless those of the Comstock lode. It is not necessary to enter here upon a detailed description. I content myself with a reference to the three large treatises upon the district,* of which Becker especially discusses the genetic question. To appreciate this question, however, some simple illustrations are required; and these have been compressed into Figs. 58 to 63.

As already observed, the general geological conditions of the Comstock lode show a strong analogy to those of the Schemnitz district. Only occasional bodies of sedimentary rocks are found, while the principal mass of the whole elevated region consists of a great variety of eruptive rocks, principally of the more recent periods. The altitudes of the more important points above sea-level are about as follows:

	Meters.	Feet.
Mount Davidson (the highest point of the region), ...	2420	7941
Outcrop at the Gould and Curry mine (the datum-line for measurements of depth),	1950	6400
The Sutro Tunnel, at different points, 1840 to 1865 feet below datum-line, . . .	1390 1382	4560 4535
The deepest point in the Belcher and Crown Point shaft, 3414 feet below datum, . .	910	2986

These figures alone indicate the immense extent of the eruptive material.

The stratified rocks occur in a considerable continuous body at Gold Hill, in the southern part of the district, while in the northern part only a small body enclosed in eruptive rocks is found in the Sierra Nevada shaft.

The several eruptive rocks have been differently defined at different times, according to the changes in petrography and in the methods of investigation pursued. Becker distinguishes: 1. Basalt (B). 2. Later hornblende-andesite (LHA). 3. Augite-andesite (AA). 4. Earlier hornblende-andesite (EHA). 5. Later diabase or black dike (LDb). 6. Earlier diabase (EDb). 7. Quartz-porphyries (QP). 8. Metamorphosed diorites (MDr). 9. Porphyritic diorites (PDr). 10. Granular diorites (GDr).

---

* Clarence King, *U. S. Geol. Explr. of the 40th Parallel*, iii., *Mining Industry*, Washington, 1870.

J. A. Church, *The Comstock Lode: Its Formation and History*, New York, 1879.

G. F. Becker, "Geology of the Comstock Lode," etc.—*U. S. Geol. Survey Monograph*, Washington, 1882.

11. Metamorphic rocks (M). 12. Granites (G). This classification is based upon careful microscopic examination.*

The two principal veins (the Comstock and the Occidental) strike N.–S., and the Comstock has been traced 5 or 7 km. (3 or 4 m.), according as its branches are omitted or included in the measurement. The position and the branching of the veins are shown in the sketch-map, Fig. 58, in which the two most important eruptive rocks, the diorite and the diabase, are emphasized by shading, the others being indicated by letters, as in the above list. The diorite forms the foot-wall from Gold Hill to Virginia City. South of Gold Hill metamorphic slates form the foot-wall, and even extend across in part to the hanging-wall side, as does the diorite to the north of Virginia City. Moreover, in one place a dike of diabase—the so-called "black dike,"—occurs immediately on the foot-wall.

The hanging-wall is principally diabase, at least in depth. In the upper region it is sometimes covered with other eruptives, most frequently with hornblende-andesite.

On the whole (with variations at some places), the Comstock presents wide, gently-dipping masses, predominantly of crushed and decomposed country-rock, and enclosing large flat "horses" of the same. The filling is, as a rule, saccharoidal granular quartz (sometimes more compact), in which the ores are very finely disseminated. At some points they have occurred concentrated, forming the bonanzas to which the colossal gold- and silver-production of the district is due. The ores are silver-ores (stephanite, polybasite, argentite), with sometimes galena and zinc-blende. The bullion produced from them contains about half its value, or 6 to 7 per cent. of its weight, in gold.

Some of these bonanzas were in the upper region and came to the surface. Others (like the richest one of all, in the Consolidated Virginia and California mine) were found in the deep region; and it is asserted that they were limited on all sides, without connection with other ore-bodies. This would

---

* Messrs. Arnold Hague and J. P. Iddings (*Bull.* 17, *U. S. Geol. S.*, 1885, "On the Development of Crystallization in the Igneous Rocks of Washoe," etc.) have stated as their conclusion that GDr, EDb and AA are identical; PDr. is EHA; MDr is LHA; and LDb is B; apparent differences being due to conditions of cooling. In *Bull.* No. 6, *Cal. Acad. of Sc.*, 1886, Mr. Becker, after a reinvestigation of the locality, denies this conclusion *in toto*, so far as the Comstock rocks are concerned.

make them unlike our ore-channels or chimneys, which usually do have interconnection. But I cannot conceive of their formation in any other way than upon the hypothesis that in such places more open spaces existed, through which larger quantities of dilute metallic solutions passed and made deposits.

The distribution of the bonanza-areas upon the vein-area is quite irregular; and it has not been possible hitherto to trace any connection between the bonanzas and the petrographic or structural conditions in their vicinity. In form they are equally without any law, as far as has yet been observed. The bonanzas of the Con. Va. and Cal. consisted of a main body and three lenticular masses higher up, which, taken together, have a flat pitch to the north. The bonanza between Belcher and Yellow Jacket, on the other hand, followed the true dip of the vein; while the bonanza in Justice—a mine on the NW.–SE. branch, which dips NE. much less steeply than the main lode—shows again a north pitch.

This NW.–SE. branch of the Comstock shows a filling different in some respects from that of the main lode, and may be considered as a cross-vein, running into the Comstock, or into the black dike which accompanies its foot-wall. (Becker's atlas, ix.)

In the Justice mine, namely, the filling is mostly calcite, with little quartz, instead of quartz with very subordinate calcite, as in the main lode. According to Becker (*l. c.*, p. 219) the calcitic filling is characteristic of the whole SE. branch. According to Church (*op. cit.*, 173), compact crusts of calcite alternate in the Justice mine with their quartz crusts. This is the only clear report of crustification anywhere on the Comstock. (I believe, however, that I was able to observe upon a rich specimen from the Con. Va. bonanza, after polishing, a parallel structure in the mineral aggregate. I received this specimen in 1876 from Mr. Fair, one of the "bonanza kings," as a sort of compensation for the refusal to permit me to enter the then rich mine!)

A comparison of the many cross-sections of the Comstock published by King, Church and Becker, and representing, of course, various stages of knowledge of the vein, shows that no normal or average section can be given, because the condition at different points on the strike are so different, and at some places, *e.g.* the junctions of the branches, developments have not given satisfactorily complete exposures. The sections, Figs. 59 to 63, are given (on a scale too small to show much) merely to illustrate the distribution of the country-rocks. They are reduced from Becker's monograph. In the three northerly sections the foot-wall is granular diorite; in the two southern (Yellow Jacket and Belcher), and along the SE. branch, it is metamorphic slate. In the southern portion, the so-called black dike (according to Becker, later diabase) appears on the foot-wall, and follows the vein beyond the point where the SE. branch leaves it. The hanging-wall is diabase, except at the northern end, where diorite becomes the hanging-wall as well as the foot-wall. In the upper region, however, earlier diabase is covered by other eruptives. Diabase is the hanging-wall of the SE. branch also; but in the foot-wall of that branch, besides the metamorphous slates, granular diorite and quartz-porphyry appear.

So far as the sources of the eruptive rocks can be inferred, they were all (except that of the diorite) on the hanging-wall side of the vein, as were also the mineral springs which subsequently decomposed these rocks. But the ascending thermal waters encountered in these mines were within the vein itself; whence it may be concluded that the ore-bearing solutions came by that road from the deep region, and not, according to the lateral-secretion theory, from the side. In other words, the Comstock ores were not washed from those rocks which have been mined between 1950 and 910 meters (7941 and 2986 feet) above sea-level, but from material lying much deeper.

The investigations of G. F. Becker were made at a time when importance was still attached to Sandberger's theory, and the correctness of his method of inquiry was assumed. The matter takes a different aspect when we (quite justifiably) doubt whether the minute metallic admixtures detected by wet or dry analysis were originally in the rock, and acknowledge that they may possibly have entered it afterwards. This is evidently the case with the precious metals in the pyrite of the ore-bearing rock. That this pyrite is a secondary impregnation can be proved with the microscope, and is admitted by Becker also. In my opinion, any eruptive rock may give rise by metamorphosis to the type which we call, in Hungary, greenstone, greenstone-trachyte, etc., and which F. von Richthofen named propylite, because of its frequent occurrence as the country-rock of ore-deposits. Whether the precious metals can be detected in this rock depends wholly upon its impregnation, or that of one of its constituent minerals, with pyrite. But it does not follow that this was the primitive condition. From this standpoint are to be regarded the metallic values reported by Becker, and here reduced, for the sake of better understanding, from cents per ton to grammes per 1000 kilograms. A pyrite washed from decomposed diabase, near the face of the north branch of the Sutro tunnel, contained 3 cents silver and 8 cents gold, *i.e.*, 0.72 grm. silver and 0.12 grm. gold, per metric ton. The pyrite from the slates in the Belcher mine carried even 18 c. (4.32 grm.) silver and 20 c. (0.30 grm.) gold. Fresh diabase is said to have contained 4 to 5 c. (0.6 to 0.7 grm.) gold; the diorite of Bullion ravine, only a trace; while the andesite yielded about as much as the diabase. Augite separated by Thoulet's method from the diabase was found to be eight times as rich as a corresponding quantity of the feldspar.

Comparative investigations are reported to have shown that the decomposed diabase contains only half as much silver as the fresh—a circumstance which was interpreted in favor of the lateral-secretion theory, on the assumption that the decomposed diabase had given up half its silver to the vein-filling.

Since the diorite in the upper portion of Bullion ravine shows only traces of silver, but at the mouth of the ravine, near the vein, contains a considerable amount, Becker considers this indicative rather of an impregnation of the rock proceeding from the vein.

Moreover, the andesites and quartz-porphyries also contain small amounts of silver; while the strongly calcareous metamorphic diorite carries 8 c. (1.92 grms.) per ton, which might be connected with the vein-filling in the Justice mine. Finally, the basalt contains nearly as much silver as the older diabase; but the basalt cannot be cited as a source, because it comprises the freshest rock in the district, and shows no trace of decomposition in its olivine (Becker, *l. c.*, pp. 223–225). These facts would be favorable to the notion of lateral secretion, if only it could be proved at the same time that the metalliferous character was primitive. But our knowledge does not go so far as that; and the Comstock, like the deep mines of Przibram, ceases, therefore, to be a proof of the lateral-secretion theory.

The Comstock differs in many respects from typical ore-veins. It is properly a quartz-vein, in which, at various points, important ore-concentrations have been formed, not showing (except in the Justice mine) any clear crustification, though this may have been present at some time, and may have been obliterated by metamorphosis of the vein-mass, *e.g.*, through the replacement of calcite by quartz. It is also, in the main, a contact-vein, between a diorite foot- and a diabase hanging-wall, with steep spurs running upward into the diabase and traversing also still more recent eruptives.* Some of these peculiarities are represented in other districts.

2. Ore-Deposits in Soluble Rocks.

In this group we shall find two genetic types represented: the fillings of spaces of dissolution, and the metasomatic deposits, the origin of which will be particularly considered, together with some related metamorphic deposits in soluble rocks, which have not yet been sufficiently studied to be classed apart.

The expression "soluble rock" is to be understood in its ordinary sense of solubility in the waters commonly represented on the earth's surface. Acid and caustic waters will attack, more or less, nearly all rocks, though not so as to dissolve them completely, as we see limestone dissolved. I include especially among the soluble rocks, rock-salt, gypsum, limestone, and dolomite. Of the following instances I shall describe most fully those which I have personally studied, giving only the essential outlines of other related occurrences.

Rodna.—The ore-deposit of Rodna, in NE. Transylvania, is interesting to me (apart from analogies which it offers with Leadville, Colo.), as the first in which I had the opportunity to study the origin of an ore-deposit by replacement.

It is situated on the line of two andesite ranges, having a common strike,—the Hungarian Vihorlat Gutine, stretching

---

* This is denied by Hague and Iddings, *op. cit.*, p. 41.—See foot-note on p. 91 of this paper.

NW., and the Transylvanian Hargitta range, running SE.,—and at the point where this line cuts through the mass of the Rodna Alps. The predominant rock is mica-slate, with numerous intercalations of limestone, and is traversed by many dikes and masses of andesite. Ore-deposits have been found at many points in the district. The most important, situated in the Benyes mountain, was carefully studied by me in 1862, after the ore-bodies in the mine had been worked out. J. Grimm had examined the mine in 1834, and had considered the deposits to be primitive beds at the contact between limestone and mica slate, and to have occupied that position before the andesite eruption, by which they had been much shattered.

The ores (pyrites, black zinc-blende, and argentiferous galena, slightly auriferous, with quartz and calcite) often occurred, it is true, on the gently-dipping contact-planes; but in certain E. and W. lines they stood steeply, much like veins. In these places the flat deposit, and with it the stratification, had suddenly turned upward, and it was clear to me that the occurrence represented a peculiar form of fault, namely, a bending of the strata, followed by fracture in the direction of the dislocating force, when the limit of cohesion had been passed. Here and there, in these steep places, the stopes had been carried beyond the contact, and the resulting appearance was as if the steep deposit had been the primary one, and had supplied the ore to the contact. Occasionally eruptive breccias were observed along the steep deposits. At lower levels, in the downward continuation of the fissure of the steep deposit, eruptive rocks and thin breccias occurred; and these became predominant in the lowest part of the mine.

The structure of the ore-beds was mainly massive, and not crustified. In some places, however, druses had been developed, which showed the same paragenetic succession as the mass of the bed, and which contained pseudomorphs of pyrite and galena after calcite. The thickness of the ore-bed was extremely variable, the greater part of the contact-area being scarcely worth working, while at single points colossal masses of ore were found. These circumstances led me to consider the deposits, not as contemporaneous in origin with the rock, but as subsequently formed by the circulation of mineral waters along the contact-planes. In other respects I adopted at that time the explanation of J. Grimm.*

Mining was then active chiefly on the north slope of the Benyes divide; and the sedimentary rocks were cut off towards the south by andesite. I pointed out that on the south slope, beyond the andesite, there were various ancient mines, and recommended that they be explored in depth, by means of an adit. This led to the discovery of several deposits, which gave new life to the industry. After cutting through the andesite, the explorers found steep deposits at the contact of andesite and limestone, and, in the limestone, near its contact with the mica-slate, a flat deposit, which, being above the ground-water level, had been transformed into carbonate of lead.

The somewhat complicated conditions are shown in Fig. 70, as far as this can be done in a single section. The deposit at the contact of andesite and limestone indicates at once a genetic connection with the eruptive rock, and renders it probable that the ore-beds also are due to the after-effects of the eruption. Even on the north slope there were some reasons for this conclusion. For instance, at the ore-bodies locally called *Thonstrassen*, ores occurred in the midst of eruptive breccia, which could not be taken for fragments of the orignal bed. Baron Constantine von Beust† found traces of "ring-ores," indicating a formation in open cavities.

In seeking an explanation of all the facts, I was led to give up the view of J. Grimm,‡ which he, however, still maintained, citing Offenbánya as another instance in which a pre-existing deposit on the contact between limestone and mica-slate had been shattered by an andesite-eruption. But in that instance, also, I had the opportunity to satisfy myself that the then accessible mine-workings showed no fragments of an earlier ore-deposit, but only ore-formations under the influence of the andesite.

Grimm had had in mind the deposits of Rodna and Offen-

---

* Some results of my studies at Rodna will be found in the *Verhandlungen d. k. k. g. R. Anstalt.*, 1865, pp. 71, 163, 183, and 1870, p. 19.

† "Bemerkungen über d. Erzvorkommen von Rodna," *Verh. d. k. k. geol. R. A.*, 1869, p. 367.

‡ J. Grimm, "Zur Kenntniss der Erzvorkommen von Rodna," *Verh. d. k. k. geol. R. A.*, 1869, p. 367; and F. Pošepný, "Die Natur der Erzlagerstätten von Rodna," *ibid.*, 1870, p. 19.

bánya when he established, under the first division in his systematic classification,* the second sub-division, "Occurrences of Ores as Fragments of Earlier Deposits, in Breccias," etc.

Offenbánya.—Offenbánya, in the Transylvania gold district, has various deposits analogous to those of Rodna, and also veins, with telluride ores. We are here interested in its mass-deposits, at the contact of limestone and andesite, one of which is illustrated in Fig. 71.

Beneath the limestone widely extending through the district, mining has disclosed a mica-slate (the so-called underground slate); and at the contact of the two a flat, pyritous deposit. The whole stratified series is traversed by andesite; but near its contact with the limestone a steep, rich mass-deposit extends from the surface down to the mica-slate. This deposit is highly crustified, and was evidently formed in a pre-existing space.

The flat deposit shows no crustification, and may have been formed by metasomatic replacement of the lime at the contact between the impermeable and the soluble rock. The analogy with the conditions on the south slope of the Benyes mine, at Rodna, is evident, though I do not know whether at Rodna the flat deposit has been followed as yet to its junction with the steep one.†

Rézbánya.—Rézbánya in SE. Hungary represents different conditions. Here, in an indistinctly stratified Mesozoic limestone, occur long spaces filled with ore, descending steeply and irregularly in shape like that of the cavity produced by pouring a stream of warm water upon a snow-bank. This extreme case is of great theoretical interest, although such ore-bodies having but one considerable dimension, and that in the most unfavorable direction for mining, mainly downward, are not attractive from a commercial standpoint. I visited Rézbánya first in 1868, and published some observations concerning it, which may have contributed to induce the Hungarian government to take up the subject later, and intrust to me a more thorough investigation. I will here mention only some things,

---

* *Die Lagerstätten der nutzbaren Mineralien*, Prague, 1869, p. 32.

† At the time of the visit of G. vom Rath, in 1878 (described by him in the *Zeitschr. d. d. geol. Gesellsch.*, xxx., 1878, p. 556), this ore-body, 28 meters (92 feet) thick, had been developed for a height of 85 meters (280 feet) and a length of 120 meters (394 feet) without reaching its termination.

interesting from the genetic standpoint, and refer for details to my published monograph upon the subject.*

In the Rézbánya region, lying above clay slates and Permian and Liassic sandstones, appear numerous isolated bodies of limestone, indicated by their fossils to be of various ages, from the Lias to the Neocomian, seldom distinctly stratified, and, when they are traversed by eruptive rocks, often showing a crystalline structure. The ore-filling is mostly confined to the neighborhood of the eruptives, and sometimes to the contact, where garnet-rock occurs as a well-known product of local metamorphosis. Since my examination, there may have been, in this region, many interesting and scientifically important developments, which are unfortunately unknown to me. On the basis of my old notes only, I shall confine myself to the description of a single district, cut off from commercial communication, that of Valle Sacca. The name is that of the valley, which heads in a high mountain range of Permian and Liassic sandstones, and after a short course ends in a wild limestone cañon, leading into the Galbina valley. The sides of Valle Sacca consist chiefly of limestone, which is traversed by a number of eruptive dikes and one larger mass of a syenitic character. Fig. 64 gives a somewhat generalized section of the NW. slope of the valley and district on the line of the so-called fourth adit. At the adit-mouth is cut the syenite mass, which extends also to the opposite slope; and the adjoining portion of the limestone has been metamorphosed to a crystalline mass, while the limestone further SW. is for the most part still compact. On the west side, the limestone adjoins sandstone along a N.–S. line, which doubtless represents a large fault. Approximately parallel to it run the greenstone dikes, which, though they seem to be mutually parallel, in reality intersect one another at very acute angles, thus constituting a highly elongated net-work. The dikes are not alike. Most of them may be considered aphanitic or dioritic; one, however, is quartz-porphyry, with dihexahedra of quartz, of pea-size.

The principal deposit is the so-called Reichenstein stock, which had been worked, during the period prior to my visit, to a depth of about 400 meters (1300 feet), from its outcrop,

---

* *Geologisch-montanistische Studie der Erzlagerstätten von Rezbánya*, Budapest, 1874.

340 meters above the deepest adit, to a level 60 meters below the adit. Fig. 65 shows the form of the ore-channel on the strike. The horizontal section of the body was most frequently circular or elliptical. In some places one dimension strongly predominated, so as to give the appearance of a fissure-filling. At the outcrop, according to the old maps, there was but one channel. Below, this divided into neighboring and mutually connected branches. Several of these might continue parallel and independent for considerable distances. The total sectional area of the channels averaged perhaps 20 to 30 square meters (215 to 322 square feet); but at some levels the deposit was only present in traces, whereas at others it had many times its average section. Fig. 66 shows, by the difference between the plumb-line and the arrow, the angle between the true dip and the pitch of the ore-body, oblique to it.

The ores were doubtless sulphides originally, but were afterwards oxidized in places. Rich silver-ores predominated, especially argentite, pieces of which weighing several pounds appear to have been no rarity. Besides this mineral there were hessite (telluride of silver), tetrahedrite, redruthite, galena, bismuthinite, and various pyrites. Taking these together with the oxidized ores, the deposit represented a whole mineral cabinet. The maximum silver-value was reported as 12 to 20 kilos per 1000 (1.2 to 2 per cent.), the gold being 3 grammes to each kilo of silver. The percentage of lead was about twenty times, and that of copper about ten times, as great as of silver. The metric ton (2206 pounds) would yield, at this rate, 24 to 40 per cent. of lead, 12 to 20 per cent. of copper, 12 to 20 kilos (386 to 643 ounces Troy) of silver, and 36 to 60 grammes (1.15 to 1.83 ounces Troy) of gold. The deposit was therefore a bonanza in the American sense. In fact, it yielded from $100 to $150 per ton.

Although I could not see this deposit in process of extraction, I was able to conclude positively, from specimens of the ore and from the analogy of similar deposits in the district, that it had been formed by the precipitation of successive crusts.

As regarded the origin of the cavity, I was at first influenced in my views by the numerous caves of the region. The mines repeatedly reached caves, into which the mine-water could be discharged without filling them, there being some subterranean outlet. But these caves, as I have explained in Part I., were formed by descending liquids of the vadose circulation; and to assume a similar origin for the cavities filled by the ore-bodies would be to assume that the latter cavities were formed in a manner directly opposite to that in which they were filled—which is highly improbable.

It was not until later, when I had become acquainted with the observations of J. Nöggerath (cited in Part I.) on the thermal springs of Burtscheid, that I recognized that ascending mineral springs are able to cut their own way to the surface, forming the channels which they ultimately fill with ore. The most difficult feature of all, namely, the nearly cylindrical form of the ore-bodies of Valle Sacca, was thus satisfactorily explained.

The channel of the Reichenstein body runs vertically for 400 meters (1312 feet) in limestone between greenstone dikes; or, in other words, in a zone of lime between two zones of impermeable rock. The dikes therefore control its direction. It follows downward nearly at the angle of their steepest dip, but with a pitch southward, giving it a "false dip."

The sections of the various workings show that the ore-body apparently ended at one side of the dike and recommenced at the other side, as if it had passed through. In that case, porous places in the dike-mass, at the intersection, will have determined the track of the channel. It is significant that the Reichenstein ore-channel passes in depth through the dikes to the SW., towards what is probably a great fault-fissure, and not in the direction of the present drainage. Nor could the former deep drainage from this channel have been to the NE. along the contact between the limestone and the underlying Liassic sandstone (which, in fact, appears at a lower level, where the Valle Sacca joins the Galbina valley), for the reason that all the barriers of the greenstone dikes, unquestionably extending from the limestone into the sandstone, would have opposed that flow. The stratigraphical conditions thus exclude the possibility that this channel was formed by vadose circulation, and render more probable the view that it owes its origin to the ascending waters of the deep circulation, which certainly affected the filling of it.

Raibl.—Raibl, in Carinthia, is the best representative of a group of deposits which were at a recent period taken to be genuine beds even by V. M. Lipold,* then the best authority on the mines of the Alps in general. Here and there, as, for instance, by A. Morlot,† observations were made which threw some doubt on this conception; but since they did not fit into the prevailing system, they remained disregarded. It was my fortune to establish the truth of the situation. Prof. von Groddeck kindly characterized my investigation of it as "opening a new path," and adopted the filling of spaces of dissolution as a class in his system (*op. cit.*, pp. 10, 236, etc.).

Such deposits occur in Carinthia, in an E.–W. limestone alpine range, of which Raibl is the western end; and also somewhat further north, in the zone of Bleiberg, near Villach, chiefly in a limestone, early denominated for this reason the ore-bearing limestone, and more recently determined as Triassic.

The ores occurred mostly in the vicinity of certain intercalated slates, which seemed always to occupy the same "Raibl horizon," and thus led to the conclusion that the ore-deposits (naturally believed to be of contemporaneous origin) likewise occupied a fixed horizon. But it soon appeared that the slate at Bleiberg belonged to a somewhat different horizon in the Trias; and I ventured to assert that the impermeability of the slates, as compared with the solubility of the limestone, had had something to do with the ore-deposition, which was a secondary formation in the rocks.

There are found at Raibl, some distance below the slates, in the limestone which conformably underlies them, what seem indeed at first glance to be beds of ore. They consist chiefly of a coarsely crystalline galena, with pyrites, and a zinc-blende (wurtzite) in very thin crusts, hence called *Schalenblende.* A closer study, however, of the extremely distinct crustification reveals that it does not represent the stratification, which, on the contrary, it crosses at all angles, being in fact the filling of irregular spaces, traversing the limestone in every direction.

Further light is furnished by the seams which here occur. As is generally the case in limestone, these are rarely wide

---

* *Jahrb. d. k. k. g. R. Anst.*, 1862, *Verh.*, p. 292.

† *Ibid.*, 1850, i., p. 266.

fissures, but usually mere partings between two polished walls in close contact. Slickensides, etc., identify them at once as results of friction, caused by the forcible rubbing together of walls perhaps originally irregular. The plane of contact with the slates offers a means of determining the extent of the movement along some of these insignificant-looking seams; and it appears that dislocations as great as 40 to 60 meters (131 to 196 feet) have thus taken place. Since the slates possess some flexibility, they were sharply bent in the immediate neighborhood of the fault, a feature which, on account of its theoretical importance, I have illustrated in Fig. 69.

In the seams themselves (locally called *Blätter* or "leaves") there can be, of course, no deposit of ore; but such deposition occurs outside of the fissure, when soluble rocks like this limestone are traversed. Geode-spaces were thus leached out, and are found filled with distinct mineral crusts, as is shown in Fig. 72, representing the face of a level on the so-called *Johanniblatt.*

It cannot be doubted that the ore-supply came from the seams; and when we find such seams also in large and rich deposits of similar character, like those on the north slope of the Königsberg at Raibl, we must concede to them a similar significance as regards the ore-deposition.

To the more important of these seams, J. Waldauf von Waldenstein* and Dr. W. Fuchs† had already called attention. These are the Morgen, Abend, Johann and Josef. The first three meet at an angle of about 30°, and form the boundaries of ore-bodies, extending downwards along the seams with a horizontal length of 40 to 80 meters (131 to 262 feet) and a total thickness (including portions too poor to work) of 10 to 50 meters (33 to 164 feet). Many of the mine-managers believed that there was here a continuous ore-bed which had been faulted into separate bodies by the seams, and numerous exploring levels were undertaken to develop this assumed bed, but all in vain. Nothing was found, except a few more or less independent ore-shoots on one or both sides of the seams, similar to those which have been encountered in recent years at Leadville.

---

* *Die besonderen Lagerstätten d. nutzb. Mineralien,* Vienna, 1824, Plate III., Fig. 4.

† *Beiträge zur Lehre von den Erzlagerstätten,* Vienna, 1846, Plate I., p. 23.

The foregoing observations will facilitate a comprehension of Figs 67 and 68, the former showing a section (not strictly in one plane) of the ore-shoots in the government mine, and the latter a similar picture of the Struggl private mine. In the former, separate ore-bodies are observed to the distance of 500 meters (1640 feet) above the bottom of the valley, and in 1870 the continuous ore-shoots extended from 425 meters (1394 feet) above to 150 meters (492 feet) below that level, a total vertical height of 575 meters (1886 feet).

It will be seen that the several portions of the slopes descend more or less parallel with the stratification and the lime-slate contact, but with steps or offsets. The highest portion of the Abendblatt ore-shoot is about 300 meters (984 feet) in the foot-wall of the slate-contact; at greater depths there are portions 130, 150, 85 and finally 10 meters only (426, 492, 279 and 33 feet) from that plane.

It thus appears that the ore-shoots are approaching the contact in depth, and will probably follow it below. It is, therefore, not here the case that a particular layer in the limestone has favored the formation of spaces of dissolution. If that were true, the ore-body, notwithstanding the convergence of the seams southward, should maintain a more or less uniform distance from the contact, which it does not do, either in the section of Fig. 67 or in that of the Struggl mine, Fig. 68, where the opposite occurs, namely, the ore-shoots depart from the contact in depth. I must confess myself unable to explain these variations in the Raibl ore-shoots with the light afforded by the mine-workings down to 1870. But I am convinced that the explanation will be found by further thorough study. Meanwhile, I can only claim the credit of having placed the inquiry upon what I deem to be the true road, and express my regret that in the twenty years since the publication of my monograph on the Raibl deposits no further progress seems to have been made in the interpretation of the very numerous analogous ore-deposits.

The North of England.—I cannot omit to mention here the region, classic in this respect, of the North of England. Lead mining is actively carried on in the carboniferous limestone of Northumberland, Durham, Cumberland and Westmoreland, where the limestone alternates with sandstone and slate, and occasional intercalated eruptives or their tufas. This formation is traversed and faulted by a variety of seams and veins; and the veins are generally richer where they are in the limestone. The thinner and more extensively faulted of the limestone strata are entirely severed, so that they appear in different horizons on opposite sides of the faulting-fissure. Where they are thicker or less widely thrown by the fault, however, limestone appears on both sides of the latter. It is obvious that an accurate picture of these conditions would furnish valuable data concerning the ore-genesis.

The several descriptions of the mines do not specify whether the ore of such veins as become rich in the limestone occurs in the fissures proper or outside of them in spaces of dissolution in the limestone. The latter is clearly the case in the so-called "flats." In certain horizons, where the seams encounter the soluble lime-stratum, the ore-filling departs from the fissure into the geodes of the rock, forming frequently very rich ore-bodies of highly irregular form, but flat, by reason of their following the soluble stratum. The ore-filling continues to a very uncertain distance from the fracture-plane, and is generally accompanied with frequent cavities, the walls of which are covered with crusts of calcite, blende and galena. Empty caverns also occur.* We cannot but recognize immediately in this description the type as to character and position of the Raibl deposits, the druses of which are here represented by the incrusted cavities. The empty caverns have doubtless been formed by subsequent processes of dissolution.

These phenomena occur in the North of England on a very large scale. Veins are mentioned which have been traced for several miles, and the connected subterranean channels of dissolution must be also of considerable length. The existence of laterally extensive ore-channels, and hence of an underground circulation of mineral waters not formerly suspected is thus revealed, and an entirely new light is thrown upon the so-called "ore-beds."

These observations are confirmed in another quarter by developments in Western North America, where very numerous

---

* See J. A. Phillips, *Ore-Deposits*, p. 180; also, D. C. Davies, *Metalliferous Minerals and Mining*, London, 1880, p. 216; and the works of W. Wallace, T. Sopwith, Westgarth Foster, C. E. De Rance, R. Hunt, etc.

ore-deposits are connected with limestone. It is impossible to bring forward here the whole of this material. I must limit myself to certain localities, which have been thoroughly studied and described in publications.

Leadville.—I will begin with Leadville, the recent blossom of the mountain-world of Colorado. I am, indeed, not personally acquainted with this locality, the importance of which was not recognized until after my visit to the United States; but my lively interest in it is testified by the article concerning it, which I laboriously compiled in 1879 from the incomplete data then available.* Later, when S. F. Emmons had finished his surveys, but before the publication of his epoch-making work,† I had opportunity to exchange views with him concerning the genetic condition, and to confess that I was unable to share his opinion as to the downward course of the mineralizing solutions—an opinion which was opposed to the then prevalent belief. The mine-workings have been greatly extended since that time, and Emmons's suggestion has been shown by several mining engineers,‡ on the basis of thorough studies underground, to be untenable; so that the Leadville deposits appear, as regards the origin of their metallic contents, to form no exception to the history of other similar deposits. I think Emmons himself must have acknowledged the force of these criticisms, which do not detract in the least from the merit of his accurate investigation of the district.

On the west slope of the Mosquito range appears a series of undulating Palæozoic strata, with heavy layers and intrusive masses of eruptive rocks, and traversed by numerous faults. This formation covers a large area, only a comparatively small portion of which, namely, the vicinity of Leadville, is ore-bearing,—a circumstance which of itself points to a local origin for the ore. As is well-known, the series of rocks has the following order downwards: white porphyry, blue limestone, gray porphyry, white limestone, lower quartzite,—which I will de-

---

* "Leadville, die neue Bleistadt in Colorado."—*Oesterr. Zeitsch.*, 1879.

† "Geology and Mining Industry of Leadville."—*U. S. Geol. Survey,* Monogr. xii., Washington, 1886.

‡ F. T. Freeland, "The Sulphide-Deposits of South Iron Hill."—*Trans. A. I. M. E.*, 1885, xiv., 181; C. M. Rolker, "The Leadville Ore-Deposits."—*Ibid.*, p. 273; A. A. Blow, "The Geology and Ore-Deposits of Iron Hill."—*Ibid.*, 1889, xviii., 145.

note, for brevity, by their initial letters. The ore-deposits occur chiefly at the contact between the first two members of the series, below the WP. and above the BL. In the upper levels they are oxidized and chloridized (doubtless in this, as in other places, through the action of descending ground-water); in lower levels they appear in their original form as sulphides. That this was the condition in which they were originally precipitated, Emmons admits; only their position seems to him to exclude the hypothesis of ascending solutions. He says (*op. cit.*, p. 573):

> "The principal water-channel at the time of deposition was evidently the upper contact of the blue limestone with an overlying porphyry; and from this surface they penetrated downwards into the mass of the limestone. It may be assumed, therefore, that the currents were descending under the influence of gravity, rather than ascending under the influence of heat."

But he omits to explain how he conceives it possible that mineral solutions descending by gravity, and hence certainly having been in contact with the surface-region, could deposit sulphides. Assuming such an explanation to be furnished by reduction through organic substances, the question arises whither such descending currents could go. Here the theory is in conflict with our conception of the underground circulations.

As A. A. Blow has shown, however, a leaching of the WP. cannot by any means have supplied the ore; for this rock is not at all decomposed, as in that case it must have been. On the other hand, there are found in the intrusive beds and dikes of the lower GP. various indications that this rock had more to do with the ore-deposition. Along these dikes lie the ore-shoots,—in other words, the channels in which ore was deposited.

It was at first tacitly assumed that the ore occupied the whole plane of the contact, although it was known that the richest bodies occupied particular zones in this plane. The importance of these ore-shoots was recognized later; and we may now consider the Leadville occurrence as presenting, not a single contact-deposit or ore-bed, but a complex group of ore-shoots, such as we have observed in other ore-deposits in limestone. These ore-shoots lie, in Leadville, at the contact between the soluble and the eruptive rock; while in Raibl they appear near the contact of two stratified rocks, one soluble and the other impermeable. The physical process forming these ore-shoots was doubtless the same in both cases. The mineral solutions, ascending under pressure, and seeking a path to the surface, followed, as some would say, the line of the least resistance; or, as I would prefer to express it, there was established in the soluble rock a line of maximum circulation, resulting in the dissolving-out of a channel.

Such dissolution, however, occurred not only on the contact between WP. and BL., but also at other contacts. Thus L. D. Ricketts (Rolker, *l. c.*, p. 284) gives a section of a mine on Carbonate Hill, showing a second, deeper ore-horizon between the GP. (dike porphyry) and the underlying limestone. According to Rolker, the BL. of Fryer Hill was relatively thin, and has been replaced with ore and accompanying minerals, all but small remnants of dolomitic sand. These are generally above the ore, *i.e.*, along the upper contact, whereas, according to Emmons's theory, they should be replaced with ore.

The sections given by F. T. Freeland (*l. c.*, Figs. 1 and 6) show two ore-horizons, the thicker of which is below the WP., and the other below an intrusion of GP.; and Mr. Blow's sections from Iron Hill reveal similar phenomena (see Fig. 73, a section through the McKean shaft). The ore-shoots are, of course, irregular in form; but a main general direction can be recognized, which is eastward in Fryer Hill, but northeastward in Carbonate and Iron Hill, representing the course of the channel through which the mineral solutions circulated.

In the data at hand concerning the structure of the deposits, nothing is said of a distinct crustification. It is to be remembered, of course, that mining operations hitherto have been largely confined to the upper and decomposed zone, whereas this phenomenon, if ever so fully developed, would show itself clearly only in the undecomposed zone. When we read, however, of great "horses" of country-rock, encountered in the midst of the ore, we must believe that the deposit is due not so much to a metasomatic replacement of the limestone as to the filling of spaces of dissolution; and hence it should exhibit the characteristic sign of such a filling, namely, crustification. It seems to me that this point has not received the attention it deserves; and I hope that observations in the undecomposed ore-zones will give more definite data as to structure. It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville.

Impressed by Emmons's views, and long before the connection of the ore-deposition with the GP. of the dikes had been shown, I wondered, at one time, whether the ore might not have come somehow from the fault-fissures into the contact-channels. But Mr. Emmons pointed out to me that the faults contain only ore which has been dragged in from the pre-existing bodies, the formation of which was complete before the faulting took place.

Conditions analogous to those of Leadville are exhibited in most of the ore-deposits in limestone occurring in the American West. But, with few exceptions, we have only hasty descriptions of them, and sometimes nothing more than business "puffs."

Red Mountain.—A remarkable occurrence has been described in the Red Mountain district, Ouray county, Colorado.* In the midst of the deposits of the San Juan region, which are connected with eruptive rocks, appears a body of Mesozoic strata, carrying, at the contact of a quartzite with the underlying limestone, a deposit of the sulphides of iron, lead, copper, silver, and the products of their decomposition, rich in silver and somewhat auriferous (2110 to 3980 grammes of silver and 3 to 6 grammes of gold per metric ton, or 59 to 111 ounces of silver and 0.08 to 0.17 ounce of gold per ton of 2000 pounds). At certain points the ores extend far down into the limestone, and in the section shown in Fig. 74 the ore follows a fault-fissure through the whole thickness of the limestone into a second quartzite stratum below. The stratified formation is mostly covered with andesite, in which occur ore-bearing veins in fissure-form.

In the neighborhood, at Mineral Farm, another contact-deposit between limestone and quartzite is known, consisting of barite with argentiferous galena and tetrahedrite. Both the above deposits are but briefly described, and perhaps have not been extensively worked. Their conditions of position and the

---

* G. E. Kedzie, "The Bedded Ore-Deposits of Red Mountain District," *Trans. A. I. M. E.*, 1886, xvi., 570.

predominance of lead- and silver-ores strangely remind one of Leadville.

In the adjacent Territories of New Mexico and Arizona various copper-deposits occur in limestone, and at its contact with eruptive rocks; as, for instance (according to the outline-description of A. F. Wendt*), in the Clifton and Bisbee districts. The sections accompanying Mr. Wendt's paper remind me of some of the deposits described in my monograph, at Rézbánya, at Mĕdnorudjansk, and at Bogoslavsk in the Ural. Fig. 75 is an interesting section from the Clifton district, in Arizona, showing two steep ore-shoots, parallel with the felsite dike, and a flat one, parallel with the bedding.

Utah.—With respect to Utah, the paper of O. J. Hollister† gives a general survey of the deposits of the Territory, and mentions a number which occur in limestone. Some of those in central Utah I have had the opportunity to see personally, during the period when mining was still confined chiefly to the decomposed upper levels. I refer to the Prince of Wales and the Reed and Benson, in Big Cottonwood; the Emma and the Flagstaff, in Little Cottonwood; the Old Telegraph, in West Mountain, and the Hidden Treasure, in Dry Cañon district.

Palæozoic strata are here traversed by frequent eruptive dikes, and by two intersecting systems of faults. The ore-deposits, of varying thickness, in the limestone have, as a rule, the form of "chimneys," either lying flat, with the bedding, or standing steeply along the dikes and faults. This gave rise in the beginning (when the nature of the deposits was not understood, and the conception of a typical "lode" generally prevailed) to a series of disappointments and mistakes in mining, of which the history of the Emma mine furnishes an interesting example. Apparently the irregularity and the complications of these deposits came to be better known afterwards.

The (sometimes very rich) ores consist chiefly of sulphides of lead and silver, and the products of their decomposition. In some cases (*e.g.*, Hidden Treasure) cuprite occurs, with native copper; and in the Camp Floyd district cinnabar also is found.

Nevada.—In Nevada, adjoining Utah on the west, deposits of this class are likewise abundantly represented. I will men-

---

* "The Copper-Ores of the Southwest," *Trans. A. I. M. E.*, 1886, xv., 25.

† "Gold- and Silver-Mining in Utah," *Trans., A. I. M. E.*, 1887, xvi., 3.

tion only the two districts which have been most thoroughly studied, namely, White Pine and Eureka.

With regard to the former, the work of Arnold Hague (1870)*, demonstrating the peculiar character of the White Pine deposits, led me to seek for European analogues.† I found that, apart from the condition of the ores, which at White Pine are found in the oxidized and chloridized zone, there was an analogy with all the European ore-deposits in limestone, but especially with the conditions at Raibl.

Devonian limestones and calcareous slates are overlain at White Pine by Carboniferous clay-slates, sandstones and limestones; and the ores occur only in Devonian limestone and at its contact with the calcareous slates on a N. and S. anticlinal. The ores and the associated minerals (quartz, calcite, gypsum, fluorspar, barite, rhodonite, rhodochrosite, with the chlorides, bromides, oxides, and carbonates of various metals, especially silver, lead and copper) fill the cavities in the limestone and surround its fragments.

The various mines represent different stages in one and the same process. In the Eberhardt, two fissures crossing the anticlinal bound the ore-body (like the *Morgenblatt* and the *Abendblatt* at Raibl). This consists of a lime-breccia (Kalktyphon), the fragments of which fit together, and are cemented by ore-bearing quartz seams. The Hidden Treasure mine contained the ore in geodes, at the contact of the limestone and slate. In the Aurora, the ore was in bodies stretching N. and S. In Bromide, Chloride and Pogonip Flats, the ores occurred in geodes and masses included in lime-breccia, in a zone parallel with the bedding. It is Arnold Hague's opinion that the Eberhardt mine probably represents the source of the ore-solutions which impregnated the limestone, wherever cavities existed, up to the level of the overlying calcareous slates, which were impermeable to the solution. The slate-cover having been removed by erosion, the ores thus accumulated below it were exposed immediately at the surface; and the surprisingly large product of the district was derived from open cuts and shallow workings.

---

* "Geology of the White Pine District," *U. S. Geol. Surv. of the 40th Parallel*, vol. iii., *Mining Industry*, p. 409.

† F. Pošepný, "Das Erzvorkommen vom White Pine District, u. dessen europäische Analogien," *Verh. d. k. k. g. R. A.*, 1872, p. 186.

The other leading analogue in Nevada is found in the Eureka district, and was made widely known and practically significant by the law-suit between the Eureka and Richmond companies,* which involved the definition of a deposit not contemplated in the United States mining law. Similar difficulties have arisen under the old European mining codes. Such deposits were known in some districts of Europe, but they were not so widely distributed as the fissure-veins, for the conditions of which the ancient codes were framed. Conflicts were therefore inevitable. I will mention only Bleiberg in Carinthia (which presents some degree of analogy with Eureka), where, besides the general mining code, special statutes became necessary, departing from the usual rules with regard to prospecting and the location and the acquisition of claims.

The geological conditions of the district have been described in an elaborate monograph by J. S. Curtis,† based on the developments existing in 1882. Further knowledge may have been gained since, but, so far as I know, nothing later has been published. I made a brief visit to Eureka in 1876; but as no comprehensive maps of the mine-workings were then available, I could only observe in a general way the analogy with European deposits examined by me.

According to Arnold Hague,‡ the series here occurring of Prospect Mt. quartzite, Prospect Mt. limestone, Secret Cañon shale, and Hamburg limestone is Cambrian. The ore is confined to the limestone first named, and in particular to a portion thereof on the N. E. slope of Ruby Hill, enclosed between two fault-fissures. The features of the NW.–SE. ore-bearing zone are too variable to be indicated by a normal cross-section. Fig. 76 shows a generalized and Fig. 77 an actual section, as represented by Curtis.

The main fault-fissure separates, in the upper level, the massive limestone in its hanging- from the crushed, ore-bearing limestone in its foot-wall. In the lower levels it shows, in the

---

* R. W. Raymond, "The Eureka-Richmond Case," *Trans. A. I. M. E.*, 1877, vi., 371.

† "Silver-Lead Deposits of Eureka," *U. S. Geol. Surv.*, Monogr. vii., Washington, 1884.

‡ "Abstract of Report on the Geology of the Eureka District," *Third Ann. Rep. of U. S. Geol. Surv.*, 1881–1882, Washington, 1883, p. 241.

foot-wall, quartzite with intercalated "Lower shale," and in the hanging-wall, further down, shale and quartzite. An ideal restoration, above the present saddle of Ruby Hill, of the foot-wall rocks which have been removed by erosion, would bring to light a relative displacement of 150 to 600 meters (492 to 1968 feet), the indications being that the foot-wall has been lifted. This would explain at once the crushing of the limestone in the foot-wall, and the creation of a second fault near the contact between the limestone and the underlying quartzite.

The ores occur chiefly in the well-known form of chimneys and in individual masses, mostly interconnected by traces of ore, at least at the depth where the two faults come together. In the mines to the SE., about 180 meters (590 feet) from the Eureka-Richmond boundary, the fissures come together at the depth of about 400 meters (1312 feet), the line of their intersection thus dipping gently NW.

The ores encountered in the upper zones, above water-level, were, with the exception of a few insignificant remains of sulphides (mostly argentiferous galena), oxidized ores, such as cerussite and anglesite, chlorides, etc., carrying a considerable amount of silver and a little gold. The present water-level follows approximately the line of intersection of the two faults, but the fact that oxidized ores have been found still deeper indicates that the water-level was once lower down.

It might consequently be expected that caves formed by the vadose circulation would also occur at considerable depths, especially as the whole wedge of limestone is traversed by ore-shoots, the oxidation of which would, of course, give occasion for cave-formations. The newly-formed caverns would often lie along the ore-channels, and especially in their upper portions. (See J. S. Curtis, *l. c.*, p. 100.)

Some of the irregularly distributed ore-bodies follow rather the quartzite-limestone contact; others rather the main fissures, with a NW. dip, like that of the limestone wedge. Of the two largest bodies, which have furnished the chief product of the district, the east ore-body exhibits a steep SE. pitch for nearly 400 meters (1312 feet), and the west ore-body, for nearly an equal distance, a flat N.W. pitch.

In considering their structure, we must distinguish sharply between their original and their decomposed condition. The latter often hinders a clear recognition of the former. The strata-like deposits of cerussite and other products of decomposition mentioned by Curtis (*l. c.*, p. 98) are perhaps, like those in my sketch, Fig. 78, from the Old Telegraph mine, remains of the original crustification, and his statement (p. 104) that "when the ore is not oxidized there are no signs of a banded or concentric structure, and the phenomena observed point entirely to substitution of the sulphurets for country-rock," may thus be explained. In like manner his assertion, in the same place, that "the internal structure of the ore-masses in no way resembles those of Raibl," is so far correct that the original filling is at Raibl extraordinarily distinct, and at Eureka, on the contrary, perhaps, only obscurely traceable.

I personally saw in the Eureka mine some small ore-masses which exhibited crustification, if not in a striking degree, yet sufficiently to be recognized by an impartial observer. Mr. Curtis himself (*l. c.*, p. 98) says that "rounded boulders of limestone as a nucleus" occasionally occur in the ore-mass, and that in a limestone-breccia "small masses of ore sometimes completely fill the spaces between the limestone walls,"—two phenomena which indicate crustification, and are explained by the hypothesis of a filling of pre-existent spaces.

A metasomatic removal of the limestone, such as has taken place in the secondary calamine-deposits of Raibl, cannot well be supposed for the original ore-deposition at Eureka, but may have attended the formation of the secondary, decomposed products.

I believe that later mining in deeper zones has developed more clearly the structure of the original Eureka deposits, and that specimens of the ore have shown, after polishing, traces, at least, of crustification.

In short, I consider the original Eureka ores to have been deposited in pre-existing spaces by ascending mineral solutions, while their decomposition and the formation of the caverns are the effects of descending surface-waters.

I agree with Mr. Curtis that the ore-solutions ascended from the deep region through the "main-fissure" (which has, in the NW., the character of a *Blatt* at Raibl, and in the SE. part of the district is filled with rhyolite), and that they formed and filled the ore-channels in the soluble, fissured limestone.

Missouri and Wisconsin.—We have dealt thus far with ore-deposits in mountain districts, where tilting and folding, as well as the occurrence of eruptives, betray a disturbance of the original relations of stratification. But there are also deposits in limestone in plateau-regions, where the strata show no considerable disturbance. Under this head two great districts deserve attention; namely, the lead-regions of Missouri and Wisconsin.

Concerning the former, we may refer to a number of more or less detailed descriptions.*

We have in this case not a perfect plateau, since here and there domes of the underlying Archæan come to the surface, as especially in the continuation of the Ozark mountains; but the predominant character is nevertheless that of a structural plateau. The ore-deposits, chiefly confined to the Silurian limestone, are in part primary xenogenous and in part hysteromorphous (débris) deposits; the latter, as is well known, consist of the detritus from the weathering and erosion of the outcrops of the former. In the former we find all the phenomena encountered in the deposits of mountain regions. One of these is peculiarly developed, namely, the gently inclined cavities or ore-channels, shown in the Vallé and Bish mines of Jefferson and St. Francis counties, concerning which J. R. Gage has given some (unfortunately not very clear) notes and sketches.

In the Vallé mines, a shaft 49.9 meters (164 feet) deep, situated 33.5 meters (110 feet) above the valley-bottom, encountered at three different depths, respectively of 44.5, 46.3 and 49.9 meters (146, 151 and 164 feet), flat-lying ore-channels, 1 to 2 meters (3 to 6 feet) wide, which, winding in different directions, produce networks, connected at the intersecting points by chimneys from one level to the other. The cross-section of these channels in the horizontal limestone or dolomite contracts sometimes to a few square centimeters, or enlarges to

---

* J. R. Gage, "Lead-Mines of S. E. Missouri," *Geol. Surv. of Mo.*, 1873–4, p. 603, and *Trans. A I. M. E.*, iii., 116.

G. C. Broadhead, "The S. E. Mo. Lead-Districts," *Ibid.*, p. 100.

A. Schmidt and A. Leonhard, "The Lead- and Zinc-Region of S. W. Mo.," *Geol. Surv. of Mo.*, 1873-4, p. 384.

A. Schmidt, "The Lead-Region of Central Missouri," *Ibid.*, p. 503.

several square meters, with a height of 3 to 4 meters (10 to 12 feet).

The original metallic filling was galena, pyrite and zinc-blende, but is already oxidized to cerussite, anglesite, smithsonite and calamine, which are accompanied with barite and a red clay. We are specially interested in the original structure of this filling; but this is not easily detected in the mere diagrams at hand.

Figs. 32 to 35 reproduce four of Mr. Gage's sections, the first three being Figs. 17, 18 and 19 of his paper in these *Transactions*, and the fourth, Fig. 72 of his article in the report of the Missouri survey. They indicate for both the metamorphosed and the original mineral crusts a prevailing horizontal position, so that we might conclude that the deposits took place in cavities, the upper portions of which were filled with gas only. A very peculiar formation is the red clay which in some instances covers the walls of the caverns and surrounds on all sides the central filling. The data at hand afford no clue to its origin.

Mr. Gage's description of Fig. 35 (*l. c.*, p. 618) is as follows:

> "Fig. [72] represents the occurrence of these minerals. The solid limestone contains a fissure, entirely filled with minerals and gangue. The minerals are completely enveloped by the red clay. Above are two thin folds of silicate of zinc, separated from each other and from the limestone by the red clay. The folds of the zinc-ore are sometimes perfectly solid, being from one to six inches thick, and consisting of alternate layers of the same material in very compact folds; again, the mass of zinc-ore is from one to six inches in thickness, but, instead of being dense, consists of a thin crust, with a cavity, whose interior walls are lined with beautiful, brilliant crystals of the silicate and occasionally the carbonate of zinc. More rarely, crystals of galena are in the cavities, but in this case are invariably covered with a thin coating of the silicate; and not infrequently portions of the cavities are partially filled with red clay, highly impregnated with oxide of iron, and having the appearance of a highly decomposed brown hematite. Occasionally heavy spar (barytes) lies in a dense mass in close contact with the zinc-ore; but more frequently it is associated with the galena. Often, but not invariably, immediately below the folds of zinc-ore, occur irregular masses of the zinc-ore in the crystallized form, as pseudomorphs of galena," etc.

All the doubts which arise concerning the mode of this formation would probably be solved by a series of *objective* pictures of it; and it is to be hoped that an occurrence so interesting theoretically will be accurately recorded before it is too late.

The deposits occurring near the "islands" of granite and porphyry have special interest. While the Silurian limestones of the surrounding country, farther from these islands, present chiefly only lead- and zinc-ores, other metals, such as copper, cobalt, and nickel, occur as the Archæan foundation-rocks are approached; and this circumstance is, to my mind, an indication that the source of the lead-deposits also is to be sought in depth.

Mine la Motte.—As an example, I may cite the district of Mine la Motte, to which I once made a brief visit. The rock here is usually the same, namely, a Cambrian dolomite, containing, however, sandy portions and a clayey stratum characterized by numerous fossils (*Lingula*). The ore occurs predominantly as an impregnation in the rock, more concentrated in a given zone. The so-called sandstone does not here, as in other instances, cut off the impregnation; it is, in fact, only a sandy limestone and dolomite, and its carbonates can be replaced by ore as well as those of adjoining strata.

I thought that I noticed in the open workings called the Jack and the Seed-tick diggings a very remarkable phenomenon; namely, the ore-impregnation in the almost horizontal stratified rock was conformable not to the bedding but to planes crossing it at a very acute angle (about 10°). A pretty long terrace was exposed; and the impregnation-planes cut pretty regularly through the sandy dolomite also. This appearance indicates plainly a later formation of the ore, independent of the deposition of the rock-strata; and one is almost involuntarily forced to believe that it was the former ground-water surface which formed the cavities to be impregnated. But it was, and is, inconceivable to me how these cavities could be filled with sulphides; and I can only urge that occurrences of this kind should be subjected to a more thorough study than it has been in my power to give to them.

Wisconsin.—In Wisconsin, and in parts of Iowa and Illinois, there is an extensive true plateau, the calcareous members of which contain many and various deposits of lead- and zinc-ores. An excellent monograph concerning them, by my esteemed friend, Prof. J. D. Whitney,* is at hand. The author

---

* *Report of a Geological Survey of the Upper Mississippi Lead-Region*, Albany, 1862.

seeks to show that the mineral solutions depositing these ores came from above, not from below. He appeals to the circumstance that of the two stratified formations, the upper and the lower Magnesian limestone (underlain by an upper and a lower sandstone, respectively), the ores occur chiefly in the upper, and only seldom, and in small quantity, in the lower; while the two sandstones (the lower of which is assigned to the Potsdam) do not reveal any traces of ore, as they should do if the solutions had come from below. I confess that this conclusion is not obvious to me. There may have been a passage through these sandstones at a distant point, not yet exposed; and the mineral solutions may have found or created spaces in the soluble rock.

The argument that the ores must have come from above because it has not been possible to discover, in the Wisconsin region, fault-fissures and eruptive dikes, such as have brought up similar ores in the north of England and other places, seems to me likewise inconclusive. And as little can I accept the explanation of an occurrence near Dubuque, discovered by T. Lavins and described by Whitney (*op. cit.*, p. 291 and Fig. on p. 392), which I reproduce in Fig. 79. The fragments of galena, crusted with cerussite, which hang from the roof of a natural cavern, are taken as a proof that the solutions which deposited them must have come from above. But a continuation of this cavern is indicated in the bottom, filled with clay, mixed with scattered pieces of galena. In my opinion, this was doubtless originally the filling of a vertical fissure, which was enlarged by the ground-water, as indicated by the dotted line. The symmetrical crusts, as I suppose, of that filling were in part broken up, and fell into the clay accumulating in the space below; while the upper part of the filling remained attached to the rock of the roof.

3. METAMORPHOUS DEPOSITS.

Metamorphism has been most truly defined by A. de Lapparent as the sum of the chemical changes undergone by the sedimentary rocks after their deposition. General or regional metamorphism, affecting the rocks over wide areas, is distinguished from local or contact-metamorphism, caused in certain groups of strata by eruptive intrusions. In studying the occurrence of useful minerals, we occupy rather the local standpoint, and start with an assumed original condition of the rock, though its really original character may not always be demonstrable—understanding thereby, for our purpose, a so-called typical condition, usually shown at most places where the rock occurs.

We distinguish the replacement of some constituents of a compound rock, for which the term "impregnation" is more appropriate, from the replacement of the whole homogeneous mass by metasomasis. But since every rock undoubtedly contains small primitive cavities, it is difficult, and sometimes impossible, to decide whether a new, xenogenous substance has not been deposited in such pores; and a case of this kind would fall under our notion of impregnation. The new substance may indeed have found entrance through the pores, if the mineral solutions were under sufficient pressure to overcome the friction of their walls, at least in the line of least resistance; and these solutions, thus introduced, may attack and replace one or another element of the rock. The entrance of such solutions will be greatly facilitated by the fissuring of the rock, whether by internal or external forces. We find in connection with ore veins, and also with the thinnest mere seams, an impregnation of the country-rock, which Cotta has called subordinate or dependent (*unselbständige*) impregnation.

The particles of certain substances possess a peculiar mutual attraction. In the sandstone of Fontainebleau occur aggregates of calcite crystals, which have come together in spite of the separating medium of sandstone; and in a similar way, as we have seen, another substance of strong crystallizing power, namely, galenite, forms, in the pipe-ores and script-ores of Raibl, crystalline masses, in spite of the intervening diaphragm of a foreign medium.

In like manner are formed the so-called concretions, the calcareous and marly masses (*Lösskindlein*) in the Loess, and the *Marleker* of the ancient Scandinavian beaches. For the formation of the former, occasion was given by decaying plant-roots; for that of the latter, by various animal remains, mussels, fishes, etc. In Norway, they have preserved a complete fauna of the Glacial and post-Glacial epochs.

Similarly, we find in some spherosiderite concretions of the Saarbrücken coal-basin the remains of fishes. A discernible nucleus is not always found in such concretions; sometimes no cause for this peculiar formation can be discovered. The concretions occurring in stratified rocks are usually lenticular, comprising portions of several similar strata. Even spherical forms, resembling pisolites, occur.

If we imagine, for instance, spherosiderite concretions formed closely side by side in one stratum, we shall have a regular bed of clay-ironstone. Leaving out of view the agency of fissures, or contacts with intruded rocks, impregnations following certain strata may be formed, constituting a second kind of ore-beds. A third kind may result from the more or less complete replacement of the original rock, especially when the latter is a soluble precipitate, like gypsum or limestone. In thick limestone formations the ore-beds occur at the contact with insoluble rocks, as at Rodna.

In all these cases the deposits have the form of a bed, but the ores rarely cover the whole contact-surface, occupying, on the contrary, only certain zones of it. In other words, in these as in other deposits, ore-shoots occur.

Much more complicated relations result when the mineral solutions ascend along structural fissures and rock-contacts; and in order to a comprehensive description of this suite of phenomena, it will be well to consider first the simpler conditions obtaining in soluble rocks, and afterwards the more complex occurrence of such deposits in crystalline and eruptive rocks. We will, therefore, review the metamorphous deposits as they occur in (*a*) distinctly stratified rocks; (*b*) soluble precipitates; and (*c*) crystalline schists and eruptive rocks.

a. Metamorphous Ore-Deposits in Distinctly Stratified Rocks.

We find in unquestionable sediments not only metallic oxides and salts, but also sulphides, in the form of ore-beds which, by reason of this stratigraphical relation, have been held to be of contemporaneous origin, that is, idiogenous. As a consequence, it has been necessary to assume that they were precipitated in a sea-basin, in which, before and after their precipitation, only barren sediments were deposited. These metals must, therefore, have been dissolved in the water of the basin, and that in very large quantity, as indicated by the frequently great thickness of the ore-beds. But for such an assumption we have no present analogy.

The Deposition of Ores from Sea-Water.—In this particular, however, we have to do rather with suggestions than with demonstrations of fact. So far as sea-water is concerned, traces of metals have been found in the water itself, in the ashes of marine plants, and in the solid constituents of marine animals, for instance, corals by Malagutti, Bibra, and Forchhammer.* Traces of silver, iron and manganese were detected in the water, and lead, zinc, cobalt and nickel in the marine organisms; and since there are in sea-water small amounts of hydrogen sulphide, Bischof considers the deposition of metallic sulphides from the sea to have been possible. He observes (*op. cit.*, p. 432) that the occurrence of metallic sulphides in sedimentary rocks, such as that of copper and silver sulphides in *Kupferschiefer*, or that of lead sulphide in *Buntsandstein*, may be thus explained; and even indulges (p. 836) in the following teleological conclusion:

> "Since it cannot be doubted that the rivers flowing into the ocean bring with them metallic salts, though in very dilute solution, it seems a wise arrangement that in the hydrogen sulphide of sea-water a precipitant is presented to throw down the smallest minima, and thus to prevent the gradual accumulation of substances *so injurious to animal life.*"

Of the various metals dissolved in sea-water, iron is least injurious to animal life. Indeed, animal life assists, in the so-called lake-ores, the segregation of this metal. Moreover, the precipitation of ferrous and ferric oxides from concentrated solutions is probable, so that a precipitation of iron-ores directly from sea-water seems to be established as a possible origin for some iron-ore beds.

But the conveyance of metallic salts by rivers to the ocean and the formation of hydrogen sulphide in sea-water are unquestionably continuous; and the precipitation of metallic sulphides must, therefore, have taken place uniformly in all sediments and precipitates of the ocean; whereas, we find the ore-beds in fact only in certain strata. If these are to be thus explained, we must assume that the ocean was at certain periods much more strongly impregnated with metallic salts—a scarcely

---

* G. Bischof, *Chem. u. Phys. Geologie*, vol. i., Bonn, 1843, pp. 445–447.

tenable hypothesis as applied to the mighty deep,—or we must suppose with Carnall, as H. Hoefer has recently done,* a subsequent re-deposition of the primitive metallic salts, contained in minute quantities in the sea-deposits—in other words, their solution and re-precipitation at certain horizons. Hoefer cites the lead- and zinc-deposits of Upper Silesia and other districts, which occur in marine Triassic limestones. He assumes the maintenance of uniform horizons by these deposits to be demonstrated, but points out that some of these horizons were already ore-bearing when first formed.

In short, a number of investigators have adopted the hypothesis of an original ore-deposition from the ocean, without giving any other reason than the observed relations of stratification. Yet, in a considerable experience with ore-deposits in marine limestones, I have never been able to find genuine ore-beds among them, but always only ores of subsequent introduction; so that I feel warranted in believing that such ore-beds proper do not exist.

As to the primitive ore contained in marine sediments and precipitates, innumerable chemical analyses, especially of limestone, have failed to show the metallic traces which, according to the above hypothesis, should be present. For this reason, as I have already observed, even Sandberger did not venture to derive the metals from the limestone, preferring, for instance, at Raibl, to look to the overlying slates.

The maintenance of certain ore-bearing horizons was set up by A. von Groddeck, to render more plausible the notion of a direct deposition from the ocean; but I do not believe it possible to prove such an identity of horizon for different ore-deposits. Similar ores and stratigraphical conditions are not confined to the Trias. On the Rhine, in England and in America they occur at much lower horizons in the Palæozoic rocks. Even in Carinthia the ore-bearing limestones of the richest deposits do not occupy the same horizon. That of the Raibl slate is very different from that of the Bleiberg slate (carrying *Ammonites aon*), and the deposits in these localities are by no means beds, but, as I have shown, channels in the limestone, filled with ore.

---

* "Die Entstehung der Blei-, Zinc- u. Eisenlagerst. in Oberschlesien."—*Oesterr. Zeitsch. f. Berg. u. H-wesen*, 1893, xli., p. 82.

Ore-Deposition in Fresh Water.—The demonstration of direct ore-deposition in fresh-water strata encounters the same difficulties, though it may be supported by the same chemical speculations. Here the hypothesis is favored by the analogy of the lakes of regions without drainage to the sea, in which the salts brought in by rivers are necessarily concentrated by evaporation. But since organic life is restricted in these salt lakes to a few animal species, the analogy can have but a limited application. Moreover, it would be necessary to suppose cataclysmic changes, like the interposition of a period of no drainage in the midst of an epoch of fresh-water sedimentation.

Without the assumption of such cataclysms, I do not believe that the Mannsfeld *Kupferschiefer*, in which the organic (fish) remains can be traced continuously from foot- to hanging-wall, could be explained in this way. It deserves mention, that some of the earlier geologists, like Freiesleben, accepted the sometimes contorted attitudes of the *Palæoniscus* in the *Kupferschiefer* as a proof of contemporaneous ore-depositions, and alleged that these fishes had been thrown into violent contortions by the copper-solution, in which condition they died and were buried in the sediment. The *naivete* of this diagnosis (which, nevertheless, some modern writers have not hesitated to repeat) is evident. Contorted fish-remains occur in other formations outside of the *Kupferschiefer*, and clearly show the advanced state of decomposition in which the bodies reached the sediments.

The Kupferschiefer of Mannsfeld.—The Mannsfeld *Kupferschiefer*, as is well known, is a thin bed of bituminous slate, lying between the Permian sandstone below, and the marine member of the same formation, the *Zechstein*, above, and containing sulphides of copper, silver, lead, zinc, antimony, mercury, nickel and cobalt. The copper amounts to 20 to 30 kilograms (44 to 66 pounds), and the silver to 125 to 150 grammes (4 to 5 ounces, Troy) per metric ton of 2204 pounds. In polished sections, the ore can be seen in thin leaves lying between laminæ of slate, and often accompanied by gypsum. But the same ores occur in scattered bunches in the sandstone below, and small bodies of redruthite are found in the limestone above.* This circumstance alone, that ore occurs also

---

* See Groddeck's *Erzlagerstätten*, § 58, and Cotta's Manual, § 50.

in the marine limestone, above the fresh-water *Kupferschiefer*, is unfavorable to the contemporaneous origin of ore and rock.

Kupferschiefer in Thuringia and Bohemia.—The same bituminous slate occurs in the Thuringian forest on the south slope of the Hartz, and in other points a considerable distance away. It must therefore have been deposited in a large basin. But it is a question, whether it anywhere carries ore and deserves the name of *Kupferschiefer*.

In NE. Bohemia, the same Permian slate, with almost the same fossils, is widely distributed, but without the marine member which covers it in Germany. The Permian of Bohemia carries copper-ores in many places; and in one locality, namely, at Hermannseifen, these ores occur in the bituminous slate, which might properly here be called *Kupferschiefer*. I had opportunity in 1858 to examine the mines. The richness in metal was not unsatisfactory; but there was much complaint of the numerous faults which seriously enhanced the difficulty of mining.

Precisely the same difficulty exists at Mannsfeld and in the Thuringian forest, as Cotta (*op. cit.*, § 50) reports in part as follows:

> "The fault-fissures themselves are, however, rarely ore-bearing, yet often seem nevertheless to have influenced the ore-bearing character of the strata traversed by them. This influence is shown in the increase or diminution of the proportions of ore, not only in the immediate neighborhood, but sometimes also for a considerable distance, even as far as the next master-fault. It is shown also in the transfer of the metallic contents from one stratum to another."

This and other observations concerning the influence of the faults upon the ore-distribution bear decidedly against the contemporaneity of the ore-deposits, and in favor of a later introduction of ore through the fault-fissures.

But this conclusion becomes much clearer upon a consideration of the remaining occurrences. Thus, according to Cotta (*op. cit.*, § 39), the *Kupferschiefer* at the edge of the Thuringian forest is not so rich in ore as on the southern border of the Hartz. More important than the copper-slate itself are the fault-fissures which traverse the whole group of strata, but only carry ore in certain zones in which they intersect certain strata—the *Kupferschiefer* among them. "Strange to say," observes Cotta, "near Camsdorf it is almost exclusively where the *Kupferschiefer* has suffered such disturbances that it is rich enough to repay mining." In speaking of Riegelsdorf he says, "The cobalt-ores have in some cases made their way from the veins into the country-rock."

Westphalia.—At Stadtberg (*op. cit.*, p. 76), in Westphalia, there are even several copper-bearing strata, and these are cut by copper-bearing veins. At Bieber, veins traverse the whole group of strata into the underlying mica-slate, and "the irregularly distributed ore occurs, strange to say, chiefly interleaved in the mica-slate, and not, as in the Hartz and the Thuringian forest, in the horizon of the *Kupferschiefer*; while, on the other hand, the impregnations from the veins have penetrated chiefly the bituminous marly slate."

In consideration of the expressions partly quoted *verbatim* above, it is difficult to see how there can be any doubt of the secondary nature of the ore-deposits in the *Kupferschiefer* throughout. Yet Groddeck* has reproved me for coming to this conclusion. He says himself† expressly (evidently having in mind the typical Mannsfeld occurrence):

> "The ores were laid down contemporaneously with the slime-deposit, the bituminous marly slate as the ore-matrix." . . . . "It is entirely impossible that the ores could have entered the bed somehow from the fissures, at a later period, after the covering of the marly slate with more recent rocks. If we assume that the ore-solutions were introduced through the fissure faulting the bed, it remains inconceivable why the filling of metallic sulphides, through a field of many square miles, should be uniformly and exclusively confined to the stratum of marly slate, about ½ meter (19.5 inches) thick, and should not also occur more or less near the fissures in the strata above and below, there being in these no lack of carbonates and bituminous constituents, available as precipitants of the solutions—the *Stinkschiefer*, for instance, lying not far above the *Kupferschiefer*, being rich in such substances."

Groddeck here overlooked the principle, elsewhere urged by him, that a single link in a whole chain of phenomena should not be exclusively considered. He contemplated only the special development at Mannsfeld; assumed, moreover, similar developments for many square miles, which show in fact many variations, and did not take into account the circumstance that when the *Kupferschiefer* is not cut by fault-fissures, it is also not valuable for mining. Finally, he was unac-

---

* "Bemerk. zur Classification d. Lagerstätten," *B. u. H. Ztg.*, 1885.

† *Erzlagerstättenlehre*, § 142.

quainted with the theoretically important occurrence of the *Kupferschiefer* in Bohemia. The contemporaneous origin of the ore and rock at Mannsfeld was with him, so to speak, a dogma, as may be perceived in some of his expressions (*op. cit.*, p. 302):

> "The local ore-bearing character of the foot- and hanging-walls of the *Kupferschiefer*-bed is no proof to the contrary, for it is always confined to the immediate neighborhood of the bed." (?)
>
> "Into the sea, rich in fishes and plants, from which the marly slate was deposited, flowed abundant metallic solutions, which killed the organisms and were themselves reduced by the products of decay." (?)

The first of these propositions becomes logical if it is simply reversed in sense; and the bold hypothesis of the second indicates a doubt which the author is seeking in this way to set at rest. His statement (p. 302):

> "It is not to be doubted that metallic sulphides may be formed at the earth's surface, under ordinary pressure and temperature, beneath a water-covering which excludes the air,"

is quite correct; but when he adds:

> "And there is therefore nothing to prevent the belief that sulphuretted ores could be precipitated at the same time with the deposition of sedimentary rocks,"

it is necessary to add, "*provided* the metallic salts were present in the sea-basin."

This is, indeed, the center of gravity of the whole question; and, as I have shown, the proposition presents an improbability.

Various other peculiarities of individual ore-occurrences are cited in favor of the theory of contemporaneous origin; but all of them, when impartially weighed, are equally consistent with a different genetic explanation, and fail to be as significant as the Mannsfeld type for the theory in question.

The Copper-Sandstones of Bohemia.—In Bohemia and on the west slope of the Urals, the copper-ores of the Permian strata occupy by no means a continuous horizon, but occur as impregnations in different beds, beside, above, or below one another. There are here, as in the German *Kupferschiefer* mines, fault-fissures which may have served as ore-conduits; and in these regions the notion of a primary sedimentary origin of the ores has not been so often suggested. At some places in Bohemia, as, for instance, at Starkenbach, melaphyres appear above the ore-beds.

In almost all these, as in many of the German deposits, the copper sulphides, especially redruthite, occur in the neighborhood of plant-remains; and oxidized copper-ores predominate, as a rule, in the ore-beds in sandstone.

Not only Permian, but also Triassic and still more recent sandstones, exhibit analogous deposits, containing lead, silver, and antimony, as well as copper. At Boleo, in Lower California, such an ore-deposit is known in Tertiary strata. The range of illustrations, therefore, is an extensive one. I can mention but a few.

St. Avold.—Concerning the copper-ores in the Triassic sandstone of St. Avold and Wallerfangen, Groddeck gives (p. 90) a brief description, based on an article by C. Simon.* The sporadic ores are most abundant in the vicinity of fault-fissures; but only single strata are rich, while other porous layers near by are barren of ore. The ores extend in zones, independent of the course of the fissures, which they often even cross at right-angles. These two features are said to prove the contemporaneous origin of the ore and rock, "since the enrichment of a zone where it is cut by the fissures can be simply explained by the leaching-out of ores in higher strata, and their re-deposition in or near the fissure." I must confess that this explanation is not satisfactory to me. Figs. 80 and 81 illustrate the situation.

At Bleiberg, in St. Avold, concretions of galena, of pea-size, occur in the sandstone; and below the same layer considerable masses of solid galena are encountered.

The Lead-Deposit of Mechernich, near Commern.†—This deposit has a special interest in this connection, since it consists of sandstone of considerable thickness, somewhat porous, and impregnated with small concretions of galena (*Knoten*), which have often been considered as contemporaneous in deposition

---

* *Berg. u. H. Ztg.*, 1866, p. 412.

† Baur, "Das Vorkommen von Bleierzen am Bleiberge bei Commern," *Eschweiler Pumpe*, 1859.

F. W. Huperts, *Der Bergbau u. Hüttenbetrieb des Mechernicher Bergw. akt. Vereins*, Köln, 1883.

Ellsworth Daggett, "The Lead and Silver Works of the Mechernich Mining Company," *E. and M. J.*, xxiii.

with the rock. The district, situated on the north edge of the Eifel Mountains, embraces a zone about 7 kilometers (4¼ m.) long, through Call, Keldenick, Mechernich and Strempt. Already in the Roman period, at the Tanz Mountain, near Keldenick, mining was done upon galena veins in the Devonian limestone, which is overlain by the sandstone and conglomerate of the variegated sandstone formation. The conglomerate covering the sandstone has the name of *Wackendeckel*, and sometimes carries ore, the cement between its pebbles being traversed by galena and oxidized products, especially cerussite, which were formerly mined.

It is at present the sandstone, impregnated with galena concretions (*Knoten*) to the extent of 5 to 30 kg. (0.5 to 3 per cent.) of lead, and 1 to 6 grammes (0.03 to 0.18 oz. Troy) silver per metric ton of 2204 pounds, which is the principal basis of an extensive mining industry.

The thickness of this *Knotensandstein*, the number of its intercalated conglomerate layers, and the richness in ore of each stratum vary greatly, as do also the number, direction and manner of throw of the fault-fissures by which it is traversed. Fig. 82, representing the stratigraphy SW. of the boundary of the mining grant at Meinerzhagen, shows the irregularity of the displacements. Within the grant, the several *Knoten*-layers are united into a single bed, about 22 meters (72 feet) thick, separated by a conglomerate layer from the Devonian rocks below, and overlain by another conglomerate, the so-called *Wackendeckel*, above which is the barren red sandstone. In general terms, there lies here upon an impermeable floor a pervious group composed of sandstones and conglomerates, overlain by argillaceous red sandstone and loam.

The *Knoten*, never larger than peas, exhibit, when prepared in thin sections and mounted in Canada balsam, crystalline aggregates of galena, in which the crystal-faces are turned outwards, away from the center; that is, they are by no means composed of spherical masses, as they seem to the naked eye to be, when examined as they come from the crumbly rock. Their distribution in the sandstone generally follows the bedding; but in the neighborhood of the cross-faults I observed an accumulation of *Knoten* in zones parallel to these steep fissures. Moreover, I found occasionally in the fissures themselves threads of galena and pyrite; and hence I do not doubt that the ore-deposition here was secondary, and proceeded from the fissures. To gain a clear view of this question, it is necessary to include the ore-occurrence in the conglomerates, where, as already observed, it impregnates the material cementing the pebbles, and also the nearest ore-occurrence in the Devonian limestone, where it appears in fissure-veins.

In my opinion, the loose, pervious sandstone, enclosed between less permeable strata, and cut by many fault-fissures, was impregnated by ascending springs, which employed it as a path in their circulation; but it cannot be determined what constituted the centers around which the galena concretions are formed. May it have been minute particles of feldspar, such as are still occasionally visible; or was it organic substances, which have now entirely disappeared?

Freihung.—Perhaps additional hints may be furnished by the mines of Freihung in the Bavarian Upper Palatinate, which Cotta considers analogous to those of Mechernich. Here galena and cerussite impregnate the *Keuper* sandstone, the steep dip of which they share. At the Nuremberg Exposition of 1882, maps, ore- and rock-specimens from the mines of the Bavarian Lead-Mining Co. were exhibited. Fig. 83 is a section through the Vesuvius mine. I was struck with numerous specimens of tree-stems changed to galena; and, coming subsequently into possession of such a specimen, I had a polished section prepared from it. The pieces of these stems exhibited are about 20 centimeters (8 inches) long, and elliptical in sections, say 5 to 7 by 10 to 15 centimeters (2 to 3 by 4 to 6 inches). The fiber and the annual rings could be recognized on the surfaces of fracture, but were extremely plain in the polished section. Indeed, they were indicated by the cleavage of the specimens. I have thin slivers, 2 to 4 mm. (0.08 to 0.16 inch) in diameter and several centimeters long, representing the fibers of the original wood. The former bark is replaced by a zone of first pyrite, and then quartz grains cemented with pyrite. I do not know that the determination of the species of the wood has been attempted, but I think it should be approximately practicable. Fig. 84 is a diagram of the section of such a stem altered to galena.

Certainly we have here another instance showing that the organic substance attracted metallic solutions and reduced them to sulphides, and this under conditions similar to those of Mechernich. The latter occurrence may, therefore, be most simply explained by the hypothesis of an organic substance, distributed through the rock, which reduced the circulating mineral solutions and occasioned the formation of the concretions (*Knoten*).

Silver Reef.—Accustomed as we are to find silver associated with lead-ores, we are surprised by the occurrence, in the Silver Reef district of Utah, in probably Triassic sandstones, of silver accompanied by copper. So far as can be gathered from the various descriptions at hand,* there occur here two beds (the outcrops of which are called "reefs") which carry silver, either exclusively or with a little copper—the former usually as a chloride, but sometimes native; and the latter in the ordinary oxidized ores. It may be reasonably inferred that the deposit has been thus far exposed in its upper, chloridized and oxidized zones; and that in depth it would be found to contain sulphide-ores. Whether such depth has been reached by the miners I do not know.

The beds consist of red and gray argillaceous sandstones and arenaceous clay-slates, between the laminæ and in the cross-joints of which the ores occur, being the more concentrated, the more highly fissured the condition of the rock. Although traces of silver are found throughout the bed, the pay-ore is confined to separate chimneys or channels, which descend on the true dip, or pitch obliquely to it. The richest bodies are said (Rolker, *l. c.*, p. 25) to be most frequently found above a certain thin, very clayey, sandstone stratum. Very often, but not always, the silver-ore is accompanied by carbonized vegetation, such as trunks and stems of trees, and reed-like plant-remains, which are covered and impregnated with horn-silver. The copper- and silver-ores, while occurring to a certain degree in association, seem to exclude one another, and are seldom found in actual mixture.

---

* "The Silver Reef District, Southern Utah" (by R. P. Rothwell or Thomas Couch?), *Eng. and M. Jour.*, xxix., pp. 25, 45, 59, 79, 351.

C. M. Rolker, "The Silver-Sandstone District of Utah," *Trans. A. I. M. E.*, ix., 21.

J. S. Newberry, "Report of the Stormont Silver Mining Co.," *E. and M. J.*, xxx., p. 269.

The same sandstone which here carries ore is said to be represented in the plateau cut by the Colorado river; but there the strata are horizontal and undisturbed, whereas in the ore-district they dip rather steeply, are much disturbed, and are in many places covered with eruptive rocks, including basalt. This neighborhood to eruptives renders it probable that here, as in so many other places in Western America, the ores have been introduced by the mineral springs which usually follow eruptive activity. Rothwell, Couch, and Rolker are of this opinion; whereas, Newberry is inclined to suppose a contemporaneous origin of ores and rock. The principal arguments for his view are, the alleged great area of silver-bearing Triassic strata in that region; and the circumstance that the richest bedded and lenticular ore-bodies are enclosed in almost impermeable slate-clays, which would not have permitted a subsequent entrance of the mineral solutions. Neither of these statements disproves the secondary origin of the ores. They could have been deposited in any given way on a large scale, as well as a small one; and that the almost impermeable slate-clays did not prevent the entrance of solutions is proved by the subsequent alteration of the original filling to chlorides and oxides.*

Moreover, the deposits are not regular strata, but chimneys and channels in parts of strata, and this character, which they possess in common with so many other deposits, should be decisive in favor of their secondary origin—a conclusion which, in my opinion, is always reached when observations are not confined to single localities, but extended over whole series of analogous phenomena.

Copper-Deposits of New Mexico and Arizona.—Traces of similar ore-distribution in sandstones seem to be not infrequent in the American West. Thus F. M. F. Cazin† says of the copper-ores of the probably Triassic sandstones of the Nacimiento mountains in N. W. New Mexico, which J. S. Newberry had described in 1860:

> "The ore occurs nearly exclusively as the petrefaction of the leaves, stones, limbs and trunks of palms. Frequently the ore is coated with a film of jet or coal. It

---

* Compare F. M. F. Cazin, "The Origin of Copper- and Silver-Ores in Triassic Sandrock," *E. and M. J.*, xxx., p. 381.

† "New Mexico *vs.* Lake Superior as a Copper-Producer."—*E. and M. J.*, xxx., pp. 87, 108.

is always easily separated from the rock. The ore is predominantly erubesite, copper-glance and melaconite, and it appears to be distributed all over the massive stratum, but is more densely collected on seams and cleavages, in some instances forming a single layer of petrified parts of palm-wood."

This occurrence, which is analogous to those in Bohemia and in the province of Perm, was declared to possess great economic importance. Its later developments are not known to me.

W. P. Blake* has described an analogous occurrence in the sandstones and conglomerates overlying the granites in Copper Basin, Yavapai county, Arizona, where the copper-ores are found unconnected with any organic substances. In the underlying granite, however, there are fissures filled with copper-ores. He thinks it probable that copper sulphides circulating in the highly permeable sandstone were precipitated as carbonate by carbonate of soda, while the resulting sulphate of soda escaped in solution, to be concentrated by evaporation, forming deposits of thenardite, which is common in Arizona.

Lower California.—At Boleo, opposite Guaymas, on the peninsula of Lower California, E. Fuchs† has described a remarkable deposit of copper-ores in Tertiary sandstones, conglomerates and tufas, which must be mentioned under this head. The east slope of the (mostly eruptive) mountain range extending through the peninsula is a plateau, gently descending towards the Gulf of California, and cut by precipitous cañons. It is formed of strata containing characteristic Miocene fossils. Tufas decidedly predominate, and the series contains three or four copper-bearing beds, covering a large area, and out-cropping in many places in the cañons. These lie immediately upon conglomerates of pebbles of eruptive rock (different and characteristic for each horizon) and are overlain by clayey tufas. The whole is traversed by several fissures, of which the largest and most important is a fault-fissure, occurring at the western border of the district and striking about parallel with the seashore.

In the ore-beds above the ground-water level, disseminated oxidized ores prevail, such as black oxide of copper, and the

---

* "The Copper-Deposits of Copper Basin, Arizona, and their Origin."—*Trans. A. I. M. E.*, xvii., 479.

† "Note sur les Gisements de Cuivre du Boleo."—*Assoc. Française pour l'Avancement des Sciences*, 1885.

protoxide, with atacamite ($CuCl + 3\ CuO + 3H_2O$), azurite, malachite and chrysocolla, with crednerite ($2\ Mn_2O_3$, $3\ CuO$). In the second ore-bed (counting downwards) there are peculiar globular concretions, like oölites, of copper oxide and carbonate, sometimes several centimeters in diameter, which are locally called *boleos*, whence the name of the district. Though greatly interested in this type of ore, I have never succeeded in getting specimens, and am unable to form from the hasty description of Fuchs a clear conception as to its genesis.

The third bed lies in part below the ground-water level, and contains, in addition to the foregoing minerals, the copper sulphides chalcosine (Cu_2S) and covelline (CuS).

The ore-beds are composed of tufa (the slime, according to Fuchs, of volcanic eruptions), in which ores in disseminated spots and veinlets ("*sous forme de mouche ou de veinules*") as well as globular concretions, are irregularly distributed, with a visible tendency to concentrate towards the bottom of the bed, where they form a compact ore-layer, 15 to 25 centimeters (6 to 10 inches) thick.

With regard to genetic questions, we must bear in mind that the fossils found in these strata indicate an open though not very deep sea; it is, therefore, impossible to assume that iron-, manganese- and copper-ores were dissolved in it, and were precipitated from it at the same time with the rock. A periodical metallic precipitation, three or four times repeated, in an open marine basin, is out of the question; and we are forced in this case, even more strongly than elsewhere, to assume a secondary origin for the ores. The data necessary for its explanation are still wanting, but can undoubtedly be secured by the further advance of mining work. E. Fuchs contented himself with pointing out the after-effects of eruptive processes, and did not enter upon the genetic question. Certainly the conglomerates underlying the ore-bed must have played an important part, representing, very likely, the channels through which the mineral solutions ascended, to be reduced, probably by the presence of organic matter, in the tufas above.

b. Metasomatic Deposits in Soluble Rocks.

A metasomatic replacement of the original rock material was clearly proved long ago for some instances—*e.g.*, calamine-deposits—while in other cases, where proof has not been obtained, analogies in the observed circumstances speak for such an origin. Parts of such deposits, it is true, may be fillings of spaces of dissolution, rendered unrecognizable, as such, by the absence of clearly defined crustification in the ore-precipitates. We must accustom ourselves to the fact that for many deposits, not yet closely enough studied, it is impossible to determine positively the mode of genesis, and we must often choose provisionally, of the two modes just named, the one which appears to represent better the given data.

Calamine-Deposits.—The calamine-deposits of Raibl in Carinthia, Wiesloch in Baden, Vieille Montagne, with its vicinity, in Belgium and Germany, and other places, furnish, in the fossils of the limestone which have been transformed into calamine, the clearest proofs of a metasomatic replacement of the carbonate of lime by carbonates and silicates of zinc. Moreover, the structure and form of the ore-deposits is characteristic of this origin, these being mostly bodies of irregular outline, with portions projecting far into the country-rock. Often the progress of the replacement can be traced. Thus, at Raibl (Fig. 85), in places where the process has started from seams, the gradual advance from the seam into the rock may be observed; the outermost portions being relatively the most recent, and lying against a peculiarly uneven, rough surface of limestone.

Sometimes features of the original rock-structure are repeated in calamine, as, for instance, the cellular structure of the so-called *Rauchwacke* (the *cargneule* of the Swiss geologists), which consists of a skeleton of thin, smooth lime-partitions, from among which the limestone has been in part dissolved away, or left only in separate decomposed splinters. This is evidently the result of a very complex metamorphosis, which Groddeck has observed also in the quicksilver-deposit of Avala in Servia. The cell-walls, which represent the fillings of cracks in a shattered limestone, have been subsequently changed to calamine, and covered with botryoidal clusters of that mineral (Fig. 86).

Calamine is frequently formed by atmospheric agencies above the ground-water level, and is a frequent accompaniment of lead- and zinc-deposits in limestone.

Space does not permit the description here of the manifold deposits in Belgium, Rhenish Prussia, Westphalia, Upper Silesia, Sardinia, Algiers, etc., which are, moreover, not known to me by personal observation. The text-books of Cotta, Groddeck and Phillips give some account of them, and refer to sources of more detailed information.

Laurium.—It is only in recent periods that the features of the extensive mining region of Laurium in Greece,* worked two thousand years ago, have been described. Although various kinds of deposits are represented, most of them belong under the present head.

In the Camaresa district, a series of nearly horizontal, non-fossiliferous limestones and crystalline schists is cut by a number of eruptive dikes, and suddenly assumes on the NE. a steep dip, probably indicating a considerable dislocation. The whole group is traversed by a number of ore-veins, which, in the schists, are often rich enough to pay for mining. But the main mass of the ores lies on the contact between limestone and schist, and extends into the former in separate bodies or shoots. At the so-called second and third contacts, the bodies have a prevailing funnel-shape and a vertical position. Fig. 87, an illustration from Huot, shows the apexes of the funnels to point on one contact upward, and on the other downward—but, in either case, into the limestone, according as it overlies or underlies the schist. The first form may be explained by the pressure of the ascending solutions. The second, as shown in this figure, is perhaps somewhat ideally sketched; at least the sections of this third contact given by Cordella show ore-bodies following the contact-plane itself.

According to Fig 88 (also from Huot) the ore-bodies are funnel-shaped in N. to S. section, but from E. to W. have a flat westward pitch, which is hard to explain unless it represents some kinds of cleavage parallel to the dislocation already mentioned. Below the second contact, which carries chiefly lead, there are (at the Jean Baptiste shaft, for instance, according to Cordella) great masses of calamine, the secondary origin of which from zinc-blende is doubtful, since it would involve the assumption that the ground-water zone had extended to

---

* A. Cordella, *La Grèce sous le Rapport Géologique et Minéralogique*, Paris, 1878; and *Le Laurium*, Marseilles, 1869. A. Huot, *Rapport sur les Mines du Sumium*, 1880, and *Mémoires de la Société des Ing. Civ.*, 1876–78.

this depth. As to the present subterranean water-level, I find in the descriptions at hand only the statement that the region generally is very dry, and that the ancients, who mined to the depth of 120 meters (394 feet), had no water to hoist. With regard to the structure of the galena-deposits, I may say that I saw in the exhibit of the *Cie. Française des Mines de Laurium*, at the Paris Exposition of 1867, masses of galena, blende and pyrite showing distinct stratification, but did not learn from which deposit they came.

Which of the various eruptive rocks of the district (eurite, porphyry, diabase, serpentine, trachyte) gave occasion for the ascending springs which brought up the ore, cannot as yet be determined.

The minerals accompanying the products of decomposition in such deposits, particularly of calamine, are naturally often limonite and other ores of iron. In many countries these play an independent part, being often formed by the metasomasis of limestone, as proved by the irregular masses of the deposits and the contained fossils transformed into ore.

Alsace.—An instance is furnished by the so-called *Bohneisenerze* of Alsace and adjacent regions which have been described and correctly explained by Daubrée.*

At Liebfrauenberg, irregular, lean beds of this character, composed principally of limonite, but scarcely workable with profit, lie on both sides of an anticlinal of Vosges sandstone, and are covered with alluvium. In one place, however, near Goersdorf, an undecomposed body of pyrite and mispickel occurs instead of limonite.

Cumberland.—In Cumberland, limonite-deposits occur on the contacts of the Carboniferous Mountain limestone, both with the overlying millstone grit and with the underlying Silurian schists. They are connected with fault-fissures, on both sides of which they appear as is shown in Fig. 89, taken from a paper by Mr. J. D. Kendall.†

Carniola.—The Alps offer some remarkable examples of *Bohneisenerze.* These occur, according to A. von Morlot,‡ in the

---

* *Les Eaux Souterraines aux Époques Anciennes,* p. 79.

† *Trans. N. of E. Inst. of M. E.*, 1878, vol. xxviii., pl. xxviii.

‡ "Geol. Verhältn. von Ober-Krain," *Jahrb. d. k. k. Geol. R. A.*, i., 1850, p. 407.

region of Wochein in Carniola (known for its iron-ores and bauxite) in the dolomite and limestone mountains only, and either in the form of beds under the dolomite detritus, or in clay, in the caverns of the dolomite. Fig. 90 is a section showing the latter form. In this case the flatter-lying cavern was partly filled with lime-detritus and clay up to its connection with a higher vertical cavern, while the latter was filled with *Bohnerze* enclosed in loam, and had been mined, according to Morlot, to the considerable depth of 250 meters (820 feet). Here and there a nucleus of pyrite is found in the iron-ore. The beds and mass-deposits of bauxite associated with limonite sometimes show also the "bean-structure."

c. Deposits in Crystalline Schists and Eruptive Rocks.

Without entering here upon a discussion of the subject of regional metamorphosis, I may remark that, as a general rule, the older a rock is, the more changes it will be found to have undergone; yet that these changes do not advance in all places uniformly. Many Cretaceous and Tertiary formations of the Alps present a highly metamorphosed, and therefore ancient, appearance; while many Silurian formations—as, for instance, that which surrounds St. Petersburg—have been so little altered that the fossil shells which they contain still have the mother-of-pearl luster. Some regions, in a word, have been more strongly attacked than others, through causes which we will not here pause to consider; and when we follow the stratified groups downward, we come upon the various crystalline schists, often traversed by eruptives, and showing no longer any trace of the clastic sediments, which have been wholly transformed to crystalline masses. We cannot hope to find petrified organisms in these masses; but the occurrence of disorganized organic material in the form of anthracite and graphite proves that at the time the rocks were formed, organic life must have been represented in the sediments.

Many indications, available in the distinctly sedimentary rocks as guides in the determination of the relative age of their ore-deposits, are here wanting. The bedding becomes more and more obscure, and is sometimes no longer distinguishable from the cleavage. Many of the ore-deposits in these rocks have also become in whole or in part crystalline, adjusting themselves to the prevailing stratification or cleavage, so that most of them present a bed-like structure and form. Whoever believes in the possibility of a contemporaneous formation of the ores with the rocks will not trouble himself here with genetic speculation, but will see in these deposits simply "ore-beds," according to the old classification.

Taberg, Sweden.—The circumstance that magnetite is a constituent of many eruptive rocks has inclined many geologists to regard masses of magnetite in the neighborhood of such rocks as immediately belonging to them. This theory originated in connection with the Taberg deposit, in Smaland, Sweden, and was propagated by F. L. Haussmann,* W. Hissinger,† and A. Daubrée;‡ and Taberg has been regarded ever since as an example of the primitive existence of magnetite-deposits, those of Kackanar, Visokaya, Gora, and Blagodat being classed with it.

The question arises, where the line is to be drawn between an eruptive rock containing magnetite and a magnetite deposit. An eruptive rock, like that of Samokov, in the Pils mountains in Bulgaria, from the weathered detritus of which magnetite is obtained by ore-dressing, is not properly an ore-deposit; but, on the other hand, that of Taberg, where the ore is not only finely disseminated in large amount, but also occurs in separate, solid veins, may fairly be so called. According to A. Sjögren,§ the rock consists of olivine, magnetite, and a little plagioclase, with mica and apatite as accessories. In other words, it is an already metamorphosed rock. Considering that at several places in Scandinavia magnetite occurs in the crystalline schists also, it seems unlikely that the magnetite of Taberg belongs to the primitive rock. This is confirmed by the observation of Th. Kjerulf, that all the ore-deposits of Norway follow the courses of eruptive rocks. Taberg will scarcely prove to be an exception, and may, therefore, be regarded as a secondary or xenogenous ore-deposit.

Before proceeding further I must mention the action of the

---

* *Reise durch Skandinavien,* Göttingen, 1811–18, i., p. 165.

† *Versuch einer mineralog. Geographie von Schweden* (Woehler's translation), 1826, p. 205.

‡ *Scandinaviens Erzlagerstätten* (edited by G. Leonhard), Stuttgart, 1846, p. 25.

§ *Neues Jahrb. f. Mineralogie,* 1876, p. 434.

mineral solutions upon the country-rock of some veins, which might be also classed as impregnation. In this respect tin-deposits are most interesting, because they carry ore, not only in the space of discission, *i.e.*, the vein-fissure, but to a large extent in the neighboring country-rock also. If the veins occur in granite, this is changed for a certain width into greisen, *i.e.*, it is robbed of its feldspar, which is even, in some cases, replaced by cassiterite and associated minerals. Thus are formed the beautiful pseudomorphs of cassiterite after feldspar, which adorn many mineral collections. (See Fig. 91.)

Figs. 91–93 are taken from C. Le Neve Foster.* Fig. 91 represents the alteration of the granitic country-rock to greisen on both sides of a fissure, which is here filled with symmetrical quartz-crusts, to the central druse or comb. Often such fissures occur close together; and since each has its own zone of greisen, the result is a *Stockwerk*, constituting a metamorphosis of the granite, and formed by these fissures.

Cornwall.—In the slate or *killas* of the Cornish miners, there is often a disturbance of the bedding in the neighborhood of the fissure (Fig. 92), such as is observed in connection with fault-fissures elsewhere; but in this case the *capel*, or adjacent portion of the slate, is altered chemically also, being impregnated with quartz and traversed by streaks of ore. The fissure itself is filled with quartz, cassiterite, chlorite, pyrite, and fragments of the *capel*. When several fissures come together, the result is somewhat complicated, but can be reduced to the simple case just described.

Still more interesting is the tin-deposit of East Wheal Lovell, described by the same authority.† At the side of a narrow quartz vein the ores occur in the granite, from which they are not separated by any definite boundary, so that the ore-body is an almost vertical shoot, confined to the neighborhood of the fissure, yet lying in the country-rock. It is clear that a mineral water of high solvent power must have ascended under great pressure, in order to bring about such effects in a rock ordinarily regarded as insoluble. Fig. 93 shows the situation of

---

* "Remarks on some Tin-Lodes in the St. Agnes District," *Trans. Roy. Geol. Soc. of Cornwall*, 1877, ix., pl. iii.

† C. Le Neve Foster, "Remarks upon the Tin-Deposits of East Wheal Lovell," *Trans. Roy. Geol. Soc. of Cornwall*, 1876, ix., pl. ii.

one of these ore-shoots in granite, at the East Wheal Lovell mine.

The ore-deposits in metamorphous and eruptive rocks occur especially in the great crystalline northern areas, in Scandinavia, Canada, and the northeastern United States.

Scandinavia.—In Scandinavia, the science of ore-deposits, like that of petrography, has had a comparatively independent development. Although these countries have been often visited by foreign observers, few analogies with European deposits have been noted—chiefly, no doubt, because of the peculiar character of the occurrences examined, but also partly because of the differing standpoints and views of native observers. In recent times a difference of interpretation has developed itself between the Norwegian and the Swedish geologists; and the former, since Kjerulf, have approached more nearly the Continental view.

As already remarked, Kjerulf traces all the ore-deposits of Norway to the filling of spaces of discission, and particularly of a peculiar space, produced by the sliding of the rock along a bedding-plane, and locally called a *Lineal.*

With respect to the ore-filling, he points out that the occurrence of the ore-deposits must always be studied on the large scale, and that this method shows the ore-deposits to occupy certain lines, characterized by the presence of eruptive rocks.* The ores appear chiefly in the crystalline schists, but also in traces along the contact, and sometimes in the eruptive rocks themselves. In the first case, the different sulphides, mostly accompanied with quartz, lie parallel with the bedding or cleavage of the rock, and thus look like beds; but their secondary origin is indicated by the slickensides, the branching of the deposits and other signs. Sometimes it is made evident by the course of the ore-masses, cutting across the bedding or cleavage. In the museum at Christiania there are many large specimens of the ore, some of which, having been polished, show this structure plainly. Pictures of some of them have also been published by Kjerulf.†

---

* *Die Geologie des südl. u. mittl. Norwegen* (authorized German edition, by Dr. A. Gurlt), Bonn, 1880, pp. 81, 284, 293.

† "Pragstufer med Braeciestruktur fra Muggruben og Stovarts," *Magazin for Naturvidens, Kobern*, xxvii., B., p. 335.

In this connection, the primitive ore-bearing character of the *Fahlbänder* (so often cited by geologists as primary ore-beds, which enrich the veins by which they are crossed) is entirely denied (*l. c.*, p. 323). It has been proved that the ores of the Modum fahlbands are connected with malakolite and the augite rock which intrudes in "lineal" form between the steep strata of quartz-schists. Figs. 94 and 95 are intended to show the appearance of these deposits, formerly deemed to be beds. The former represents a specimen from the Kongens mine at Roras, and the latter a part of the specimen illustrated by Kjerulf, from the Mug mine at Trondhjem. In the former, the subsequent entrance of the ore is at once recognized. The latter appears as if the crystallization of the minerals had taken place after the ore-impregnation.

Of course, the political boundary does not divide the nature of the ore-deposits of the Scandinavian kingdoms. Those of Sweden are often the continuations of the Norwegian. The crystalline rocks are here peculiarly developed, and have also been peculiarly named by the Swedish petrographers. In the Swedish granulite, for instance, one would scarcely recognize its Continental namesake. These rocks are not in general so coarsely crystalline that their constituent minerals can be distinguished with the naked eye. The so-called eurites are still finely crystalline, and the *hälleflinta* is almost amorphous, consisting only of the ground-mass of the massive rocks. The beds and mass-deposits of the crystalline rocks are often, like many of the Norwegian deposits, associated with talcose and chloritic slates. Sometimes limestone is also present, as at Falun, Tunaberg, etc., where the ores lie on the limestone contacts. The ores of some of the deposits suffer in depth a remarkable change. Thus the mass of copper pyrites at Falun has diminished in depth; but on the other hand, gold-bearing quartz-veins appear in the midst of the pyritic body, and have yielded in recent years considerable amounts of gold.

Ammeberg.—I will cite as an example one of the most interesting deposits, namely, the zinc-blende mine of Åmmeberg,* belonging to the Vieille Montagne Company, which I have personally examined.

---

* A. Sjögren, "Undersökning of den omgrifande Bergarten on Åmmebergs Grufvor." *Geol. Föreningens i Stockholm Förhandl*, 1880, v.

In a winding line, chiefly E.–W., and about 3½ kilom. (2 m.) in length, occur steeply-dipping beds of zinc-blende in granulite, or gneiss resembling granulite. At certain points they show very beautiful, close folds. At first glance they seem to be genuine intercalated beds of the same age as the rock. The ores, however, do not continue along the whole line, but form separate lenses, up to 15 meters (49 feet) thick, which show a distinct stratification, consisting in layers of fine-grained to amorphous material resembling *hälleflinta*, alternating with the coarser granulite. Fig. 96 is a polished specimen, which exhibits clearly the secondary ore-invasion. The original bedding is here indicated by a series of light and dark dense *hälleflinta* layers; and these are broken through by masses of coarsely crystalline rock and of ore. The entrance of the ore into the coarsely crystalline layers seems to have been attended by an enlargement of their volume, which resulted in their breaking through the dense layers.

The same explanation is required for some parts of the bed, in which, between the plane surfaces of two fine-grained barren strata, ore occurs in highly folded and contorted layers. This folding is due by no means to an exterior mechanical energy, but to interior chemical forces.

Some of the blende layers carry a considerable admixture of galena, as, for instance, the two ore-layers shown in Fig. 97, separated by a fine-grained, yellow to brown, barren stratum of eurite. The whole mass is traversed by fine fissures perpendicular to the bedding, which are filled with leaf-silver, looking like tin-foil. A replacement with ore of the original rock-constituents is here beyond question.

It is supposed that the blende has taken the place of the mica of the granulite. But the whole country-rock also is metamorphous. At the open cut of the Godegärd II. mine-working I found in the midst of the schists what I took to be limestone, but I subsequently lost on my journey the specimens intended for more careful examination. But petrographers have probably long since determined this point.

This Åmmeberg deposit, then, although so distinctly bedded, is by no means of primitive origin; and still less can such an origin be supposed for the others, which occur as lenses of the greatest variety of filling, enclosed in the crystalline schists.

If mica may be replaced with zinc-blende, magnetite, etc., such a change will, of course, be confined to certain portions of the rock, immediately within range of its cause; and these portions, as distinguished from the rest of the country-rock, are to be considered mineral deposits.

Some of the ore-deposits of the Alps have a certain similarity to those of Scandinavia; for instance, Prettau, in the Ahrn valley, in Tyrol; Brennthal, near Mühlbach, in Salzburg; and Schneeberg, near Sterzing, in Tyrol.

Prettau in Tyrol.—There is here a very ancient copper-mining industry, which was overwhelmed in 1878 by a great disaster, and will not soon recover; namely, the settlement at the smelting-works was buried by an avalanche so deep in débris that it has been necessary to sink shafts nearly 20 meters (65 feet) deep and mine out the stock of manufactured copper and other objects of value.

The crystalline schists, which here strike E. and W., and dip steeply S., contain impregnations of copper and iron pyrites, very short horizontally, but considerably prolonged on the dip. The deposit has been opened to a vertical depth of 500 meters (1640 feet), representing 600 meters (1968 feet), so that the horizontal projection, or distance between the top and bottom, is only 350 meters (1148 feet). Figs. 56 and 57 are a vertical section and plan. Figs. 54 and 55 are sketches from the roof and side of the Ottilie gallery, where the chlorite-slate and pyrites present highly complicated forms, somewhat like the structure I have observed in the Transylvania rock-salt. It may be explained, in my opinion, either by an interior increase of volume or by a distortion of the chlorite-slate in the steep westward-pitching line indicated by the ore-deposit. It is extremely difficult to form a correct conception of this deposit. I was able to study some of the lower levels only.

It is remarkable that the pyrites-mine of Brennthal, near Mühlbach, shows an entirely similar structure and form of ore-bodies, and almost the same westward pitch upon the E.–W. plane of the stratification. It looks as if dynamic movements connected with the mountain had played a leading part in thus determining the same pitch for the ore-bodies of deposits on opposite sides of the Central Alps.

Where the ore-body begins to grow poor, and the pyrites appear disseminated in grains and crystals through the chlorite, the secondary character of the impregnation is clearly recognizable. The space for the massive ore-body was probably prepared by mechanical forces. That a metamorphosis was the cause is not likely, because the original minerals of the stratified group could scarcely have assumed such abnormal form and dimensions.

The older rocks occupy in America large areas; and there also many ore-deposits occur and are worked which, although somewhat unlike those of Scandinavia, belong to a similar type. I do not intend to describe here the numerous and well-known ore-deposits of the Eastern and Northern States; but I cannot avoid brief mention of some peculiar types.

Lake Superior.—The copper-district of Lake Superior offers a number of very interesting occurrences, some of which, though developed by extensive mining, and often described at considerable length, have not yet been satisfactorily explained. It is remarkable that copper and silver occur here almost exclusively native; but it is very generally admitted that this is not the usual primitive form of copper. Sulphides seem to occur but seldom, and they receive, as a rule, no attention. I saw once, at Lac-la-Belle, an old working upon pyrite, chalcosite and galena, which was said to have carried some native copper in its upper levels. But Foster and Whitney do not mention it.*

The native copper of this district occurs notoriously in both veins and beds, in a stratified group lying between the Huronian and the Cambrian, and traversed by numerous flows of eruptive rocks.† We are here concerned with the beds. The ore in the Calumet and Hecla mine is a conglomerate of porphyry pebbles; another, in the Copper Falls mine, is a dark lava-flow, the so-called "ash-bed." The latter is impregnated with copper on both sides of the Owl Creek vein, which trav-

---

* *Report on the Geology and Topography of a Portion of the Lake Superior Sand-District*, i., Washington, 1850, p. 139.

† M. E. Wadsworth, "Notes on the Geology of the Inland Copper-Dist. of L. Superior," *Bull. of Mus. of Comp. Zool.*, Harvard College, Cambridge, vii., 1880.

R. Pumpelly, "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," *Am. Jour. Sci.*, 1872, iii.

R. Duer Irving, "The Copper-Bearing Rock of L. Superior," *U. S. Geol. Sur.*, 3d *Ann. Rep.*, Washington, 1883.

erses it (Fig. 98); while in the Calumet and Hecla conglomerate copper sometimes constitutes the cementing material.

In both masses the spaces now filled with copper were unquestionably once filled with other substances; and the present conditions are the result of whole series of complicated replacements.

R. Pumpelly, who originally believed in a contemporaneous origin of the copper and the enclosing rock, became subsequently convinced that the copper had replaced especially epidote and chlorite, and that certain phases of metasomatic processes were here represented. The eruptive rocks have usually been strongly attacked—for instance, the pebbles of the conglomerate, the rocks on Isle Royale, etc. Some portions, on the other hand, *e.g.*, the Ash-bed, have been little attacked. The former instance (which the latter, it is true, contradicts) was used, long before Sandberger, as proof of a sort of lateral-secretion theory; and now and then, where the copper-bearing rock was overlain by an eruptive flow, the theory of descending solutions was also brought into play.

Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore-depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive flows between the sedimentary strata, so that the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all the deposits, suits also the exceptional case cited by R. D. Irving, namely, the Nonesuch copper-bed in the sandstone of Porcupine Mountain, far from an eruptive outflow.

As to the condition in which the ores were first deposited, and the manner in which they became reduced and associated with zeolites, additional data must be sought for the formation of an opinion.

Sudbury, Canada.—Quite recently, A. B. von Foullon has published his observations in the Sudbury region, Canada,* expressing certain theoretical conclusions of great interest,

---

* "Ueber einige Nickelerzvorkommen," *Jahrb. d. k. k. R. A.*, xliii., 1892, p. 276.

which, however, flatly contradicted my view. They concern the pyritic deposits which occur in Huronian rocks, but at the borders of eruptive outflows of diorite, etc., and were described by T. G. Bonney* and afterward by R. Bell.† The ores are associated with masses of diorite, intercalated conformably in the stratified rocks. The ore-bodies have the form of "stockworks," and consist of an irregular mixture of rock and metallic sulphides (?). In the ore, which contains gold, platinum, tin, lead, silver, zinc and iron, occur also feldspar, quartz and apatite. This account, taken from Bell's description, indicates a strong analogy with the Scandinavian deposits.

Foullon, who made in this field a series of highly valuable observations, supported by careful chemical analyses, expresses himself finally, concerning the genesis of these deposits, as follows:

> "The irregular mixture of pyrites and silicates, presenting copper pyrites and magnetic pyrites enclosed in the rock in the most varied quantities and in all conceivable forms; and, furthermore, the circumstance that sometimes the ore occurs disseminated in the diorite, and sometimes the diorite is enclosed in the ore, now the rock, and again the pyrites, being the ground-mass, prove unmistakably their contemporaneous origin. At certain periods of the diorite eruption, the magma was rich in accessory constituents which rendered possible the formation of the metallic sulphides; and these were segregated during solidification."

R. Bell has expressed himself still more plainly.

> "The ores are not of humid, but of molten origin, as is proved by their occurrence in the diorite, with which they ascended. The masses of molten diorite must have remained long liquid, so that the metallic sulphides could separate, become concentrated at certain points, and continue with the fragments of diorite. Large quantities of the molten diorite, and the heavy metals, must have retired again."

These surprising statements assume a chemical impossibility, namely, the presence of metallic sulphides in the magma of the molten eruptive rock, after the fashion conceived by H. C. von Leonhard,‡ on the strength of metallurgical analogies.

Shaft-furnaces, operated for a separation of the ingredients of the charge, produce slag, metallic sulphides (matte) and

---

* "Notes on a Part of the Huronian Series in the Neighborhood of Sudbury," *Quart. Jour., B.*, xliv., 1888.

† "The Nickel- and Copper-Deposits of Sudbury District," *Bull. Geol. Soc. of Am.*, ii., Rochester, 1891.

‡ *Hüttenerzeugnisse und andere auf künstlichem Wege gebildete Mineralien als Stützpunkte geologischer Hypothesen*, Stuttgart, 1858.

reguline metal. But the above hypothesis involves rather a common fusion of all, and a separation *in cooling* of slag (diorite) and matte (metallic sulphides). These authors should certainly not omit to explain further the principles upon which their explanation is based, taking into consideration at the same time the inner structure and other relations of the deposits in question, such as their conformity with the stratified rocks of the region; the occurrence of ore-channels, quite similar to those encountered in deposits formed by aqueous circulation, etc.

These pyritic deposits contain almost all the heavy metals, including platinum and gold, and it is remarkable that the latter here occurs in quartz, exactly as it does generally, throughout the world.

The untenable character of the explanations above quoted must be evident, and this brief mention of them will be sufficient. Yet it appears that there are other inquirers into the genesis of ore-deposits who purpose to take a similar standpoint.*

4. Hysteromorphous Deposits.

Under this title are included the deposits formed by the chemical and mechanical influences of the surface-region, from the original deposits of which the conditions of origin have been considered above. These formations have been considered and named from various standpoints. Thus the name "deposits of débris" emphasizes the idea of a mechanical crushing or disintegration; the German term *Seife*, like the Spanish and American "placer," is based upon the manner in which such deposits are often mined for their metallic contents, and so on. The expression "secondary deposits" satisfies, it is true, the definition given above, but is rendered ambiguous by its frequent use in other meanings connected with the genesis of ores. I feel warranted, therefore, in proposing for this group the more distinctly significant name "hysteromorphous" (later-formed).

The influences of the present surface upon deposits found in the deep region are so characteristic as to permit us to draw conclusions concerning the processes of earlier periods, when

---

* For instance, J. H. L. Vogt, of Christiania, "Bildung von Erzlagerstätten durch Differentiationsprozesse im basischen Eruptionsmagma."—*Zeitsch. f. prakt. Geol.*, 1893, i., p. 4.

the surface occupied a very different position. Unquestionably, effects similar to those of to-day were produced then also, and we must include in our consideration of the subject the hysteromorphism of former geological periods.

a. Chemical Effects.

The chemical effects proceeding from the present surface have been already discussed in many respects. They involve not only phenomena on the surface itself, but extend beneath it to the groundwater level, and even below that level, so far as the vadose circulation is traceable.

On the surface it is especially the oxidizing effect of the atmosphere, its contained carbonic acid, and the solvent and chloridizing action of atmospheric precipitation, simultaneously aided by the mechanical effects of wind and moving water, which bring about what Justus Roth* has called "simple weathering," to distinguish it from more complicated forms of decomposition. In considering not merely rocks, but outcrops of complex ore-deposits, we encounter what Roth calls "complicated weathering."

Decomposition underground, through the action of the same atmospheric constituents of the surface-water, extends, as is well-known, to the groundwater level, where it may manifest itself in a striking way by reason of the frequent occurrence at that level of the alternation of dryness with moisture, which is a factor greatly promoting decomposition.

A similar condition is presented, as was pointed out in Part I., by the workings of mines, where the water-level has been artificially lowered, and a zone of depth previously untouched by the vadose circulation is brought within the domain of that agency. Deep and old metal-mines especially exhibit in a striking way the effects of the vadose circulation, and, in addition, a phenomenon but seldom found in places under the influence of the natural water-level, namely, the effect of the mine-waters upon various surface relations and products.

Limonite-Deposit near Rio Tinto, Spain.—One of these rare instances is cited by J. A. Phillips† in his group, "Deposits

---

* *Allgem. u. Chem. Geologie*, vol. i., Berlin, 1879, pp. 69–159.

† *A Treatise on Ore-Deposits*, London, 1884, p. 15.

resulting from chemical action." Namely, in the vicinity of the great iron and copper pyrites-deposits of Rio Tinto, in Spain, there occurs a deposit of hydrated ferric oxide, shown by the fossils it contains (which correspond with species still living in the region) to be of recent origin, and undoubtedly produced by the weathering and decomposition of the neighboring pyritic deposit. It was deposited in a swamp-like basin with peaty matter, and subsequent erosion has left of it two remnants only, at Mesa de los Pinos and Cerro de las Vacas respectively. Evidently, in this case, the detritus of the pyritic deposit has not been mechanically swept away and collected elsewhere, but a chemical action has taken place, removing material in solution, exactly as in the formation of bog iron-ores. The formation here is certainly earlier than the Roman period, for Roman tombstones have been found, made of this recent iron-ore.

Mine-waters contain the solutions of all substances directly or indirectly dissolved by the vadose circulation, and some of these, encountering suitable precipitants, may be thrown down. Thus, ferrous oxide becomes by oxidation hydrated ferric oxide; many metallic sulphates are reduced by organic matter to sulphides; copper-salts may even be thus reduced to metal, etc. These new precipitates will mark the track of the mine-waters.

Finally, while the solutions formed by surface-waters, like those of the mine-waters, mostly find their way to the points where the water-level reaches the surface (drainage-points), yet as a part of the groundwater penetrates to greater depths, such solutions may very likely produce, in the deep region itself, impregnations, which must, however, differ in character from those produced by the deep circulation proper.

The primitive deposit from which such solutions have come will show remaining in it principally substances not easily soluble, together with such as, like precious stones, resist all atmospheric influences. Meteoric waters, carrying oxygen, some carbonic acid, and small quantities of chlorides, will first oxidize whatever is oxidizable, especially the metallic sulphides. On this subject S. H. Emmens* has published a clear statement,

---

* "The Chemistry of Gossan," *E. and M. J.*, 1892, liv., p. 582.

with some practical deductions. He distinguishes in the order of liability to decomposition the following degrees: (1) marcasite, (2) pyrite, (3) pyrrhotite, (4) chalcopyrite, (5) bornite, (6) folgerite, (7) millerite, (8) chalcosite, (9) galena, and (10) zinc-blende. The acid ferric sulphate formed from the first members of this series immediately attacks the latter members. The carbonic acid contained in the circulating waters has a high solvent power, and, among other things, dissolves the carbonate of lime as a bicarbonate, which reacts upon the basic sulphates, producing gypsum and free carbonic acid, and ultimately transforming lead sulphate into carbonate (cerussite). Copper oxide and, under some circumstances, native copper, may be formed from copper sulphate, and so on.

For the chlorine of the chlorides, lead and silver have the strongest affinity, and these metals will consequently be often found in the upper zone as chlorides.

The decomposition above water-level of gold- and silver-bearing deposits facilitates the extraction of these metals. Metallic gold can be extracted by simple processes of mechanical concentration and amalgamation from oxidized material, while gold in undecomposed sulphides, etc., must be roasted, smelted, or chlorinated with more or less cost and difficulty. Silver likewise occurs, as a rule, in this upper decomposed zone in the form of easily amalgamated combinations (free-milling ores), while the refractory ores of deeper zones are much harder to treat.

It is doubtless for these reasons that mining enterprises often come into very critical conditions when they reach water-level, and many mines even cease to be profitable. An important part, no doubt, is played by other causes, such as the necessity of hoisting increased quantities of water, the cost of the required machinery, etc.

It is remarkable that in western North America the groundwater level lies deeper than is generally the case in Europe. I suppose the reason to be, that the present area of the Interior Basin of North America, which has no surface-drainage to the ocean, was formerly cut by deep valleys of erosion, which made a deeper escape of the groundwater possible. This suggestion is confirmed by the level valleys of Utah and Nevada, several miles wide and filled with very recent sediments, between comparatively narrow mountain ranges, which seem to be, so to speak, the tops only of the former ranges.

In Europe, the upper zones of the ore-deposits were worked out long ago, at a time when the science of chemistry was in its infancy. But we know from the remnants in these workings that chlorides, lead and silver carbonates, and various sulphates, such as anglesite, occurred in them, though they were not recognized. In Transylvania the decomposed products of the outcrop-zone were called *Bräunen* ("browns"), with evident reference to the brown hydrated ferric oxide. The well-known maxim of the German miners concerning the "iron hat" is very ancient; and the same may be said of the Cornish proverb, "Gossan rides a high horse." Limonite is certainly a characteristic indication of the outcrop of an ore-deposit; and no doubt its reddish-brown color has chiefly suggested the South American miners' names, *pacos* and *colorados*.

In a few instances the "iron hat" has been actually mined as an iron-ore. As a rule it is the decomposed, porous and honeycombed vein-material of the upper zone, and is colored only with limonite. The part of the ore-deposit above water-level has a characteristic appearance. Quartz and other refractory gangue-minerals are surrounded and impregnated by earthy limonite masses. As a rule the original texture of the deposit has become obsure; and sometimes fragments of the mineral crusts, broken off and crushed through changes of volume, are found chaotically thrown together. Occasionally, however, the original structure may still be traced in the decomposition-products of the several crusts, unaltered nuclei of the ore being discoverable in them. Some substances (especially calamine formed from zinc-blende) display the stalactitic forms characteristic of the vadose region. Original druses as well as recently formed cavities are filled with new material; and in this way a secondary crustification may occur.

I must not forget to mention that there are some observations according to which gold has been precipitated chemically in hysteromorphous deposits. Oscar Lieber,* F. A. Genth and A. R. C. Selwyn expressed the opinion that detrital gold generally, or a portion of it, has been deposited from solutions.

---

* In Cotta's *Gangstudien*, and in *Geol. Rep. of S. Carolina*, 1860.

Laur, J. A. Phillips, Wilkinson, Newberry, Daintree,* Skey, Egleston,† etc., have accepted this view as more or less generally applicable. E. Cohen‡ has undertaken to examine it critically, and is inclined by his own experience in South Africa "to adopt the conclusion reached by Devereux for the Black Hills of Dakota, and to assume that by far the largest part of the detrital gold has been liberated by the mechanical destruction of older deposits and has been mechanically laid down; while, on the other hand, a precipitation from solutions undoubtedly takes place, but plays a very subordinate part only."

My own opinion on the subject is expressed in the above quotation.§ No doubt here and there, in the detrital deposits, traces of chemical activity are discoverable; but they are not sufficient to weaken the evident proofs of the mechanical origin of detrital gold.

b. Mechanical Effects.

The mechanical effects of moving air and water, of frost and ice, are grouped under the head of erosion, and are treated at length, so far as rocks in general are concerned, in the geological text-books. We are here concerned especially with effects of this kind produced upon those portions of ore-deposits which are exposed at the surface. We notice at once that mechanical, unlike chemical effects, are confined to the surface or a very small distance below it. In general, we must assume that the chemical changes took place first, but that the progress of erosion brings both to our view at the same time.

Verchoviky, or Surface-Deposits in Situ.—Not only water and ice (glaciers), but also wind, takes part in erosion. For instance, if an ore-deposit, by reason of its greater resistance, crops out above the level of the country, the wind will continually tend to blow away the finer and lighter portions of the detrites formed by chemical processes of weathering; so that, in the course of time, there must remain of the original outcrop only the heavier portions, so far as these are not carried

---

* See A. G. Lock's *Gold, its Occurrence and Extraction*, p. 746–800.

† "The Formation of Gold Nuggets and Placer-Deposits," *Trans. A. I. M. E.*, ix., 1881, p. 633.

‡ "Ueber die Entstehung des Seifengoldes," *Mitth. d. Naturw. Vereins f. Neupommern u. Rügen*, xix., 1887.

§ See my article, "Zur Genesis der Metallseifen," *Oesterr. Zeitsch. f. B. u. H. wesen*, 1887, xxxv., p. 325.

away by water. In fact, I have observed in the Urals that the gold-diggings of the valley, undoubtedly formed by water, extended up the slopes to points where this could not have been their origin. The gold-bearing weathering-detritus is then called *Nagornyje rozsypy* and *Verchoviky*.

A similar feature was observed by W. C. Kerr* in the auriferous deposits of North Carolina; and I have seen it in the old gold-workings of Bergreichenstein and Nesvacil, in Bohemia,† where flat mountain ridges are covered with old pits and dumps. It is impossible to consider them as diluvial terraces, for the alluvium passes over, so to say, into the solid gneissic rock, which is traversed by many quartz veins. The gold occurs concentrated in the deepest portion of the weather-detritus, that is to say, on the contact with bed-rock, and has penetrated all the open, loosely-filled fissures in the latter.

Cotta‡ speaks also of deposits of débris in place, which occur on high plateaus and mountain slopes, and consist of products of weathering which are not rounded pebbles or sand and slime, accumulated by water-currents. A. G. Lock§ speaks of surface-deposits being "a result of the disintegration of the rocks *in situ*," and says:

> "The gold it contains is quite angular, hackly, or crystalline, and is derived from auriferous quartz reefs or leaders, existing in the immediate vicinity."

Similar conditions obtain very significantly in the Kackar district, to be hereinafter more fully described.

Theory of the Sinking of Heavier Constituents.—But the great agent in the transportation and re-deposition of the metallic portions of original deposits has unquestionably been flowing water; and this is an equal factor in the removal of the rock-detritus of erosion, which it is constantly striving to carry to the ocean. River-sediments are notoriously unstable. What is deposited this year is carried further down stream in the years next following, and so on until it comes to comparative

---

* "Some Peculiarities in the Occurrence of Gold in North Carolina," *Trans. A. I. M. E.*, x., 475.

† "Zur Genesis der Metallseifen," *Oesterr. Z. f. B. u. H. wesen*, 1887, xxxv., p. 325.

‡ *Erzlagerstätten*, i., Freiberg, 1859, p. 100.

§ *Gold, its Occurrence*, etc., London, 1882, p. 828.

rest in the sea. The original deposits, furnishing the material thus transported over great distances and areas by water, are well called by the Russians *Korennyje mestorozdenyje*, or root-like deposits,—that is, as it were, the roots of the scattered hysteromorphous deposits.

The attempt has been made to explain the concentration, especially of heavy metals, like gold and platinum, in certain paying layers of the detritus, by a sort of natural concentration process. The circumstance that the richest gold-deposits most frequently lie in the lowest stratum of the detritus, immediately on the bed-rock, yet that several such horizons occur one over the other, is difficult to explain in this way; for Cotta's assumed separate periods of formation (*op. cit.*, i., p. 102) are scarcely satisfactory, involving as they do either periodic transportation or periodic deposition, neither of which is probable.

I believe that I have found in the Ural gold-placers a much more probable explanation, based on the principle that the specifically heavier elements of a loose mass are able, with the aid of water, to work their way down through the lighter portions. At the Przibram concentrating-works it is found that if the pulp is left standing for a considerable period, the galena will accumulate at the bottom. In gold- and platinum-concentrating establishments it may be often observed that these heavy metals find their way into the floor and woodwork of the mill, from out of which they are from time to time recovered by working up these materials. Why should this happen in artificial operations only, and not also under natural conditions, where the descent of the heavier portions is essentially aided by the percolation of atmospheric waters through the loose covering-material?

This view is supported by the features of all gold-placers, especially those of the detritus of weathering in place, where the agency of running water cannot be adduced, and the accumulations of gold at the contact of the loose and the solid material must be explained by its sinking through the former.

Stream-Detritus.—The detrital deposits produced by running water are generally characterized by the predominance of permeable material, such as sand, gravel, etc. Under this covering mass lies the solid, impermeable "bed-rock" or "rim-rock" of the Americans, the *plotik* or *posva* of the Russians; and in all the gold-fields of the world the richest pay-deposits are found, as a rule, at the border between the cover and the bed-rock. If the latter is decomposed, fissured, or otherwise loosened, the fine gold will sink into it, making it sometimes rich enough to be mined and concentrated; and this occurs without regard to the petrographic character of the rock. Thus in the Ural, palæozoic schists, limestone and eruptive rocks indifferently are charged with gold. This circumstance indicates also the error of the assumption that these bed-rocks originally carried gold.

But layers of impermeable material sometimes occur in the cover, as, for instance, lava-beds in Australia and California, or, in general, solid conglomerates and clays. In such cases there is often a concentration of gold on the more solid layer, called in America the "false bottom," and in the Ural *loznyj plotik*—that is, a material erroneously taken for the bed-rock. There are often in the detrital cover two or more such gold-bearing layers, which are easily explained on the theory above suggested. The hypothesis of a natural concentration in running water is embarrassed by the fact that the material of gold-placers shows no arrangement according to size, but consists, as a rule, of elements of all sizes.

The movement of the elements of a loose mass has been already pointed out by W. C. Kerr,* who admits the possibility, according to A. G. Lock, of the sinking of the heavier particles, though this is only in a passing remark, and without indication of its far-reaching importance. He says:

> "The superior weight of the precious atoms would cause them to sink through the moist surrounding matters till a hard layer was met with. The occurrence of this process would constantly add to the deposits, the gold always gravitating to the bottom, quickly or slowly, according to circumstances."

It seems to me that this idea must have impressed itself upon other impartial observers also; and I can only wonder that it has not been more frequently expressed.

R. Helmhacker has recently communicated some observations in the Altai region of Siberia, such as the sinking of heavy metallic objects in the loose wash, which confirm the

---

* "The Gold-Gravels of North Carolina," *Trans. A. I. M. E.*, 1880, viii., p. 462. *Gold, its Occurrence, etc.*, London, 1882, p. 916.

above views. Among other things, he identified grains of metallic lead formed in the gold-placers as shot, scattered in hunting, which had sunk into the earth.

As is well known, auriferous detritus occurs not only in present but also in ancient river-beds, long since dry; and since, in the latter, the remains of diluvial animals, such as the mammoth, etc., have been found, a distinction has been made between alluvial and diluvial gold-deposits. But discoveries of yet older organic remains have shown that such gold-deposits were formed in still more ancient periods. The old river-beds of California cross the present streams, and the auriferous detritus of the former is covered with thick lava-beds—a feature which may be observed in Australia also. During the deposition of the gold, therefore, conditions very different from those of the present day must have obtained.

In another respect, also, the relation between ancient and modern river-beds is sometimes peculiar. The late channels have been rendered by erosion deeper than the older ones. But on the eastern slope of the Ural this is almost totally reversed. The diluvial gold-deposits characterized by the remains of the mammoth often lie below the water-level of the present streams, so that the latter must be diverted in order to mine the ancient beds. This condition apparently extends throughout the whole Siberian plain, and may be taken as evidence that the erosive energy of its rivers has decreased since the Diluvial period, their fall having been reduced, either by the accumulation of the erosion-detritus or by changes in the relative altitude of the Ural range.

The eastern slope of the Ural is characterized by numerous lakes and swamps along the tributary streams, and a number of these contain auriferous detritus, which has been mined for gold.

Marine Detritus.—In some regions, the auriferous detritus, after being repeatedly deposited and again swept away, to be re-deposited further down the valleys, has at last reached the sea. The coast of Oregon, in western North America, and Vladivostock, in southeastern Siberia, are examples. Here the ebb and flow of the tide operate very nearly on the principles of artificial ore-dressing; and one would think that a concentration of the heavier particles might be thus effected. But it does not appear that such effects have been recognized hitherto.

Kackar District, in the Ural.—At the beginning of this section, in the discussion of features of auriferous erosion detritus, some characteristics of the Ural placers were described. A few additional particulars concerning them may be of interest. The gold-bearing stratum occurs at no definite depth. As a rule, the whole of the barren or poor cover is stripped off and thrown aside, before the auriferous layer, thus laid bare, is systematically attacked. Open cuts (*Razregy*) in the surface, of greater or less depth, are thus created, and are usually left to be filled up by the rivers. In the district of Kackar, already mentioned, in the Southern Ural, original gold-deposits ("root-deposits") of gold have been repeatedly found in the bottom of these cuts. They were well-defined quartz-veins, carrying in the upper zone free gold, but at greater depth sulphides and arsenides rich in gold. In the case I have in mind, the original open cut extended for a considerable distance along the strike of the vein; but the bed-rock (which was at the same time the country-rock of the vein) was much decomposed, so that the difference between detritus and bed-rock was not strikingly evident; and the placer-working passed only by gradual stages into vein-mining.

Hysteromorphous gold-deposits may thus be said, in a general way, to occur in the following positions:

1. In the simple detritus of weathering, immediately upon the original deposit (root-deposit).
2. Mixed with the sand and gravel of present streams.
3. At certain points, in the river-bottom, into the crevices and fissures of which the gold has sunk.
4. Mixed with the impermeable material of older water-courses, through which the gold could not sink.
5. On the false bottoms or bed-rocks.
6. On the true bed-rock.
7. In the decomposed bed-rock itself.

In considering the chemical changes of the outcrops of deposits (including, of course, those which give rise to hysteromorphous derivatives) we have seen that sulphides suffer total decomposition, and that of their constituents only the unoxidizable metals, such as gold and platinum, remain unaffected. Silver-ores and native silver, being attacked by the chlorides of the vadose circulation, are consequently not found in hysteromorphous deposits. But gold occurring in nature is for the most part alloyed with silver. The gold from the veins of Budweis, in Bohemia, contains by weight about two parts of silver, and that of Transylvania contains by weight more than three of silver, to ten of gold. Whenever I have had opportunity to compare the gold of an original or root-deposit with that of its derived placer, I have found the latter to be of greater fineness, that is, to contain less silver. I am strongly inclined to ascribe this phenomenon to the prolonged contact with water containing chlorides. The dull surface of placer-gold and its frequently spongy interior structure, as compared with the luster and solidity of "quartz-gold," favor this explanation.

Platinum-Placers.—Detrital deposits of platinum have been, until recently, particularly observed in the Ural only, from which the main supply of platinum was derived. Additional localities are now reported in the Altai district of Siberia and in Canada and British Columbia. In the Tulameen district, it is said, the hydraulic method of mining has been introduced for platinum. I have been unable to obtain detailed information concerning the features of these deposits.

In the Ural, and particularly in its most productive district, that of Niznyj Tagil, the conditions closely resemble those of gold-deposits. The richest platiniferous layers are on the true bed-rock. Platinum and its associates, palladium, nevjanskite and siserskite, being found to occur occasionally adhering to olivine and chromite, it was inferred that they were derived from the serpentine, which is itself a secondary product from olivine-rocks. More recently, platinum is said to have been found in an olivine-gabbro not yet metamorphosed; but whether the metal is a primary or an exotic constituent, can as yet scarcely be declared with certainty.

Formerly no other occurrence of platinum than the native metal was known; but now a platinum-ore has been found in the Sudbury district, Canada, namely, sperrylite, a compound of platinum and arsenic. Since this is certainly xenogenous, the question as to the original sources of platinum-deposits is advanced to a new phase by its discovery.

Tin-Placers.—In connection with the occurrence of tin as cassiterite in detrital deposits, the specific gravity (6.97) of this mineral, nearly equalling that of iron, and the great resistance which it offers to natural agents of decomposition, doubtless play the principal part. Of the numerous and various associates of cassiterite in its original deposits, none, except quartz, are equally able to resist decomposition; and the consequence is, that the detritus, both of weathering and of erosion, from the outcrops of such deposits, contains, besides the products of the decomposition of these other minerals, chiefly quartz and pieces of cassiterite. The latter, by reason of its high specific gravity, will tend to sink through the lighter detritus and be concentrated near the bed-rock.

The stanniferous detrital deposits of Bohemia and Saxony, as well as Cornwall, were long since exhausted; those of Australasia, the South Sea islands and South America are still worked. According to the special monograph of Dr. E. Reyer,* the richest layers are in fact found at the bottom of the detritus, immediately on the bed-rock.

With regard to the geological age of the detrital tin-deposits, the rule stated for gold generally obtains, namely, they are for the most part diluvial, yet have sometimes been formed in earlier periods. Thus, at Platten, in Bohemia, a tin-placer, which has been worked under a bedded flow of basalt, and the detrital deposits of Annaberg in Saxony, which underlie the basalt of the Scheibenberg, were doubtless formed in Tertiary times.

The original or root-deposits of tin have been hitherto quite generally considered as very old formations, connected with the eruptions of granite and felsite-porphyry.

Recently, however, tin has been found in the Mesozoic limestones of Campiglio Maritima; and it has been shown, moreover, that the root-deposits of tin in Mexico and Bolivia occur in trachytes and andesites, erupted during the Cretaceous or Eocene. Dr. A. W. Stelzner has recently published a notice of the latter occurrence,† and promised a more elaborate description. He says (p. 533):

> "The part played in geological history by the tin-ore of Bolivia contrasts sharply with that which has been observed in the Erzgebirge of Saxony and Bohemia, and in Brittany, Cornwall, East India, Australia, Tasmania, and the United States of America, and which has hitherto been willingly regarded as the exclusive method of tin-occurrence. The Bolivian tin-ore does not constitute

---

* *Zinn, eine geol.-montan.-historische Monographie*, Berlin, 1881, p. 208.

† *Zeitsch. d. deutsch. geol. Gesellsch.*, xliv., 1892, p. 531.

aureoles surrounding plutonic granite, and characterized by the contemporaneous presence of minerals containing boron and fluorine. On the contrary, it can only be considered as produced, simultaneously with precious silver-ores and sulphides of copper, iron, lead and zinc, by precipitation from mineral springs, which were connected in point of time, and perhaps also as effects, with outflows of Cretaceous or Lower Tertiary volcanic rocks."

c. *Hysteromorphous Deposits of the Older Geological Formations.*

Twenty-five years ago, at a time when no deposits of this kind were known, in an article on the continuance of ore-deposits (especially of gold) in depth,* I prophesied their discovery. They have since been observed in different gold-districts. I refer to the characteristic secondary deposits in quartz conglomerates, indicated by their stratigraphical positions and their contained fossils to be of considerable geological age. Such occurrences are often called simply cement-beds, as are the conglomerates of cemented gravel in recent placers; and it is difficult in cases where, as in Australia, this term is frequent,† to infer the age of the corresponding conglomerates. It is, however, in some cases unquestionable that these cements actually represent old formations—chiefly Palæozoic—and are therefore hysteromorphic products from still older primitive deposits.

Deadwood, South Dakota.—One of the best described occurrences is that of Deadwood and Blacktail gulches, in the Black Hills of Dakota.‡ It is a conglomerate bed, passing upwards into sandstone, and belonging, according to the contained fossils, to the Potsdam sandstone (Cambrian). It is by no means a river-deposit; on the contrary, the fossils indicate a shallow marine basin. The series lies very flat upon crystalline schists; is at most 100 feet (30 meters) thick, and is covered by a layer of porphyry, which has most probably protected it from erosion. Fig. 100, a section given by Mr. Devereux (*l. c.*, p. 468), shows how the deposit is exposed and rendered accessible on the sides of Deadwood and Blacktail gulches, which cut through into the underlying schists.

The conglomerates of pebbles of quartz, schist, and hema-

---

* *Oesterr. Zeitsch. f. B. u. H. wesen*, xv., 1867.

† See, for example, Mr. Lock's *Gold*, etc., already cited.

‡ W. B. Devereux, "The Occurrence of Gold in the Potsdam Formation, Black Hills," *Trans. A. I. M. E.*, 1882, x., 465.

tite which lie at the base of this Cambrian series carry partly coarse gold, under such circumstances that there can be no doubt of its secondary origin. It came probably from the Homestake vein near by. The auriferous detritus is about 2 meters (6.6 feet) thick, and the portions next to the underlying rock are the richest; so we have here the relation of the "true bed-rock." If my theory be correct, that the gold reached this position by sinking through the lighter detritus, it might be said that the gold was deposited not *with*, but *after*, the detritus, and consequently that the Cambrian fossils do not prove the Cambrian age of the gold-deposition. Such an objection might perhaps have weight in other cases of the kind, but in this case, the bed being covered by a porphyry overflow, and hence not at all exposed to later deposits, the objection has no force.

The Black Hills contain representatives of the three principal types of gold-occurrence, namely, gold-bearing veins and ancient and recent detrital deposits. The paper of Mr. Devereux is also very interesting in other respects—for instance, with regard to the explanation of the differing fineness of vein- and detrital-gold, and with regard to the traces of chemical action in the detrital deposits.

Australasia.—The data from Australasia concerning this class of deposits are less conclusive. In 1876 Wilkinson observed in the Talhawang district of New South Wales that the Tertiary detrital deposits received their gold from Carboniferous conglomerates. These conglomerates were associated with sandstones and slates, in which occurred a fossil plant peculiar to the Carboniferous of New South Wales. The gold occurred in pretty coarse, rounded grains, and on one occasion a nugget was found weighing 5 ounces (155 grammes). Similar conditions are said to obtain in the Hawkesbury rocks, at the North Shore, Sydney, at Govett's Leap, and in the conglomerates of the Coal-Measures in the southern district. Gold is also reported in the Coal-Measures at Peak Downs in Queensland, near Hobart Town in Tasmania, and in New Zealand.*

The question, whether these deposits of gold were really made simultaneously with that of the detritus in the Carbon-

---

* Lock's *Gold*, etc., pp. 515, 516. See also R. Daubrée's "Note on Certain Modes of Occurrence of Gold in Australia," *Quart. Jour. Geol. Soc.*, 1878, xxxiv., p. 435.

iferous period, may be decided by the circumstance that the conglomerates are or are not covered by Carboniferous strata. In the latter case, it is possible that the gold may have sunk into the gravel at a later period.

South Africa.—In South Africa, at Witwatersrand in the Transvaal, ancient detrital deposits have yielded a considerable gold-production. According to E. Cohen,* the Witwatersrand consists of sandstones (which resemble closely that of Table mountain at the Cape of Good Hope) and dolomites of high age—undoubtedly Palæozoic. Conglomerates of the same age, intercalated among these strata, occur in the vicinity of Johannesburg in several nearly parallel outcrops, and are for certain distances tolerably rich in gold. They are composed mostly of quartz pebbles, sometimes with fragments not entirely rounded, which are united by a strong, ferruginous, arkose-like cement. The quartz pebbles are sometimes porous and impregnated with hydrated ferric oxide, thus presenting the peculiar corroded appearance so characteristic of auriferous quartz. The gold occurs chiefly in the cement, immediately next to the pebbles. It is mostly coarse-grained, and sometimes even crystalline. The latter circumstance has raised the question whether the gold has not here been chemically precipitated, and hence, whether these are detritus-deposits at all. My standpoint in this discussion, as I have remarked at the end of the section on chemical effects in the upper region, is like that of E. Cohen. I do not deny the presence of chemical influences in the detrital deposits, although I have personally not happened upon them. So far as I can judge from the treatises of A. R. Sawyer† and Charles A. Alford,‡ and from a specimen of the Witwatersrand conglomerate, kindly sent to me by A. H. Halder, of Pietersburg, it is my opinion that the gold was mechanically brought into the conglomerates from still older auriferous quartz-veins occurring in the rocks which form the basis of this Palæozoic formation; and since the idea of a later entrance of the gold is excluded by the almost vertical position of the

---

* "Goldführ Conglom. in Sudafrika." *Mitth. d. naturw. Ver. f. Neupommern*, etc.

† "The Witwatersrand Gold-field." *Trans. N. Staffordsh., Inst. M. and Mech-E.*, 1839.

‡ *Geological Features of the Transvaal*, London, 1891.

conglomerate beds near Johannesburg, I suppose the gold to have been deposited at the same time as the detritus. The greater part of the gold, as has been said, occurs in the cement. There are no vein-like deposits whatever in the conglomerate; and the only chemical changes which could be presumed are confined to the decomposition of pyrites and the segregation of its contained gold.

According to a foot-note in Phillips's *Treatise on Ore-Deposits* (p. 2), gold is washed out of granular conglomerates of the Lower Carboniferous at Bessèges, Department du Gard, France.

Bohemia.—In the region of Trautenau, in Bohemia, I observed at Gabersdorf and Goldenöls considerable traces of ancient placer-mining, partly in the valley-bottom, partly on the slope, which consisted of old Permian and Carboniferous conglomerates. These remains looked exactly like other gold-workings in Bohemia, and I could only explain their situation by supposing that this was another case of auriferous Palæozoic detritus. The same may be said of another enigmatical gold-occurrence, at Stupna in Bohemia, where in 1593 a gold of unusual fineness (0.954) for Bohemia was produced, and must have come from a detrital deposit. The ancient miners penetrated through bedded flows of melaphyre. The waste-dumps are composed of pebbles from Permian conglomerates. It is therefore possible that these mines were operated upon auriferous Permian conglomerates.*

---

* F. Pošepný, "Ueber einige wenig bekannte, alte Goldbergbaue Böhmens." *Oesterr. Zeitsch. f. Berg. u. H.-wesen*, xxxvii., 1889.

DESCRIPTION OF FIGURES.

FIG. 1.—Erosion of a channel in rock-salt, at Máros Ujvár, Transylvania. I, impermeable rock; S, rock-salt; H, hydrostatic head of vadose circulation.

FIGS. 2 and 3.—Course of vadose circulation, as affected by the nature of the rocks. S, soluble, I, insoluble rock; H, hydrostatic head; *a*, entrance; *z*, outlet; *a b c z*, natural curve of water-circulation, if I did not intervene; *a d z*, actual path under or over I.

FIG. 4.—Geode of *Eisenopal* (jasp-opal), showing the filling of a cavity in which air or gas is present, besides the liquid.

FIG. 5.—Diagrammatic representation of deposits in a limestone cavern. (Deposits white; empty space, black.)

FIG. 6.—Division of ground-water by fissures and permeable strata.

FIG. 7.—Conventional representation of an artesian well.

FIG. 8.—Spring-mounds at Arczó near Korond, in Transylvania.

FIG. 9.—Upward erosions in building-stone in the walled pit of a spring at Bourbonne-les-Bains.

Fig. 1

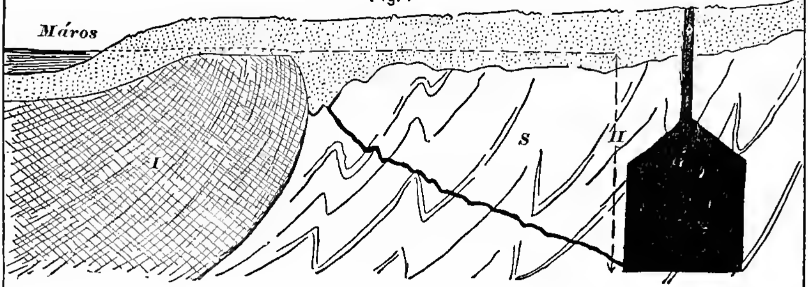


Fig. 2

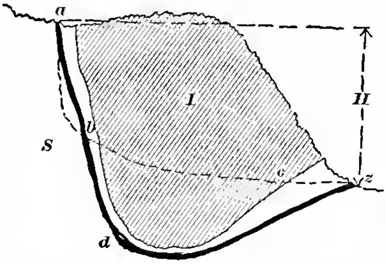


Fig. 3

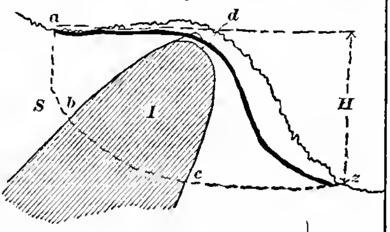


Fig. 6

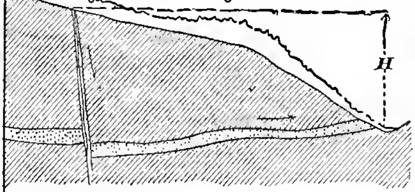


Fig. 7

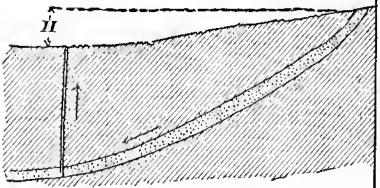


Fig. 4

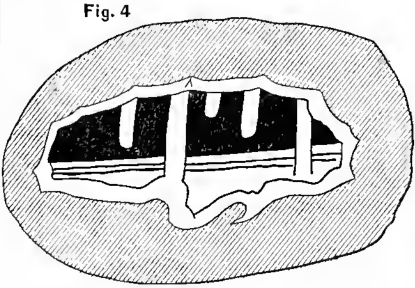


Fig. 5

Fig. 8

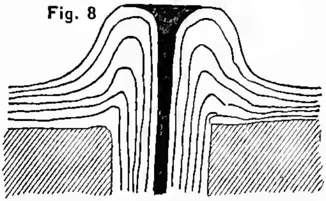
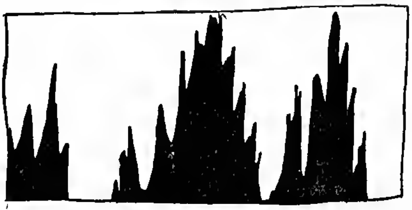


Fig. 9



Bradley & Poates, Engr's, N. Y.

Description of Figures.

Fig. 10.—Deposition of cinnabar and opal in basalt at Sulphur Bank, Cal. Sketch at the surface by F. Posepny.

Fig. 11.—Similar deposition at the same mine, in sandstone, at greater depth (J. Le Conte).

Fig. 12.—Carlsbad *Sprudelstein.*

Fig. 13.—Pisolite with pyrite crusts, from Hammam Mesoutine.

Figs. 14, 15 and 16.—Pisolites formed by dripping solutions at Offenbánya.

Fig. 17.—Sphere-ores, a correction of the illustrations of Cotta (Erzl. *Lehre*, I., 33) and Daubrée (*Les eaux aux époques anciennes*, p. 64).

Fig. 18.—Gold specimen from the Katrontza ore-body, Verespatak.

Fig. 19.—A crusted rock-nucleus, from Raibl.

Fig. 20.—Boiler-scale.

Figs. 21 and 22.—Fragments of rock and older crusts, surrounded by later crusts, from Zellerfeld (J. C. L. Schmidt).

Fig. 24.—Gold-aggregates, surrounded by crusts of calcite, rhodonite, siderite and quartz, from the Rákosi Mangan ore-body, Verespatak.

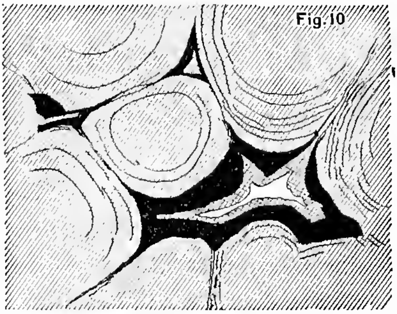


Fig. 10

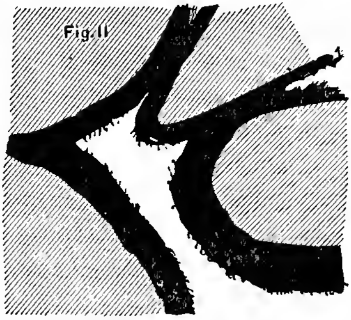


Fig. 11

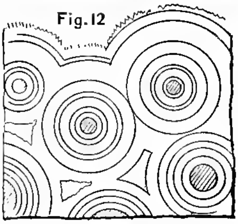


Fig. 12

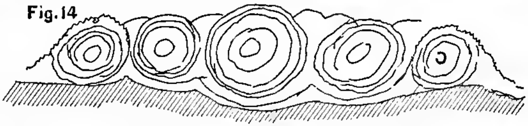


Fig. 14

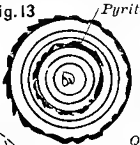


Fig. 13

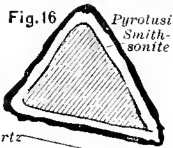


Fig. 16

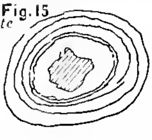


Fig. 15

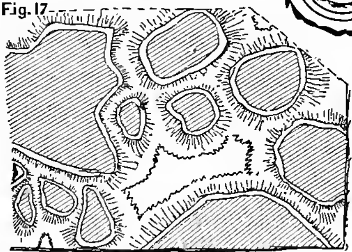


Fig. 17

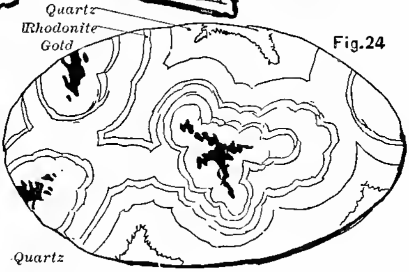


Fig. 24

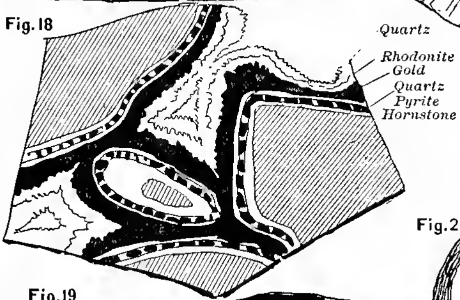


Fig. 18

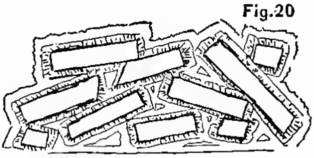


Fig. 20

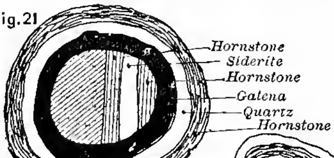


Fig. 21


Fig. 19

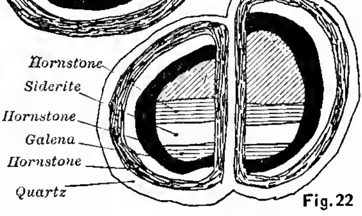


Fig. 22

Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIGS. 25, 26, 27 and 28.—Sections of stalactites of galena, blende and pyrite, so-called "pipe-ores," with hollow axis, from Raibl.

FIG. 29.—Section of rhodonite stalactites, with axis of gold-aggregates, from the Hungarian National Museum.

FIG. 30.—View of the same.

FIG. 31.—Section of a similar stalactite in the author's possession, from the Råkosi Mangan ore-body. Enlarged to twice the natural size.

FIGS. 32, 33, 34, 35.—Sections of ore-channels in the limestone of the Vallé mines, Missouri (J. R. Gage).

Fig. 25

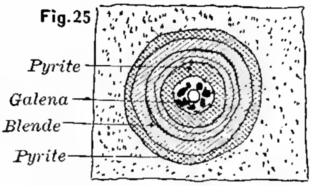


Fig. 26

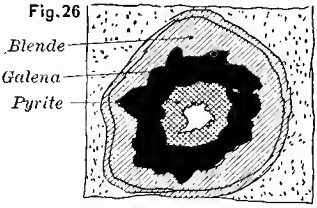


Fig. 27

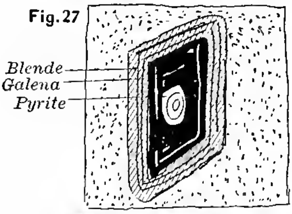


Fig. 28

Fig. 29

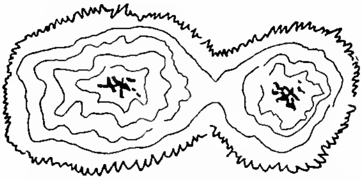


Fig. 30

Fig. 31

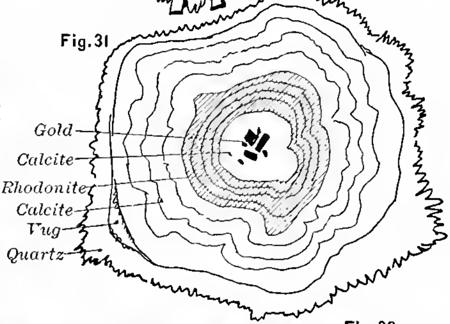


Fig. 32

Fig. 33

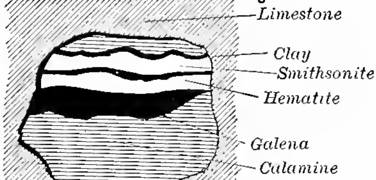


Fig. 34

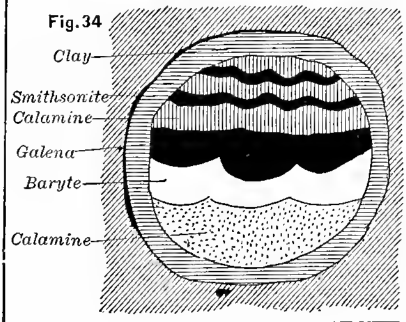
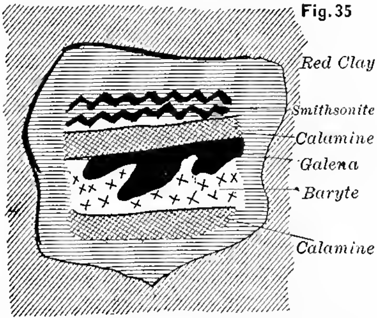


Fig. 35



Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 36.—Plan showing gold-bearing veinlets, striking E. to W., in granite (berezite) striking N. to S., at Berezov.

FIG. 37.—Network of veins and vein-clay-slates in the Clausthal district. Localities: *a*, Lautensthal; *b*, Bockwiese; *c*, Festenberg; *d*, Ober-Schulenberg; *e*, Wildemann; *f*, Zellerfeld; *g*, Clausthal.

FIG. 38.—Network of veins and *Ruschel* in the St. Andreasberg district. *Ruschel: a b*, Neufang; *a c*, Edellent; *d f e*, Silberberg; *f g h*, Abendroth Veins: *l l*, Samson (*i*, Samson shaft); *k k*, Bergmannstrost.

FIG. 39.—Section through the Franz Josef shaft, Przibram, Bohemia. A B, sea-level, heights above and below which are given in meters on the left. The Roman numerals on the right indicate the vein-levels. *a*, post-Cambrian slates; *b*, Cambrian sandstone; *c c*, faulted stratum of adinole; *d d*, diorite dikes; *m*, Martyr vein; *u u*, Marie Hilf vein; *v v v*, Sefcin vein; *w w*, West-dipping vein; *s s*, Franz Josef shaft.

Fig. 36

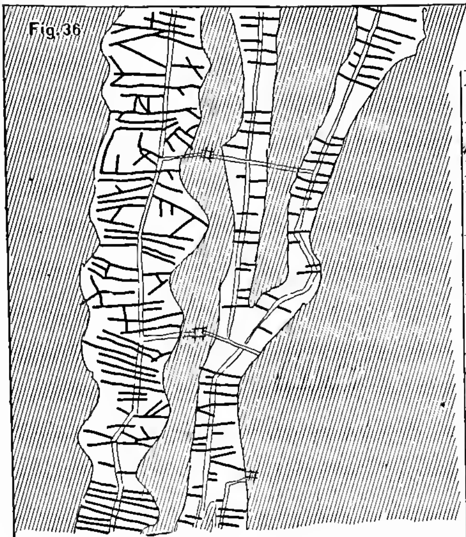


Fig. 39

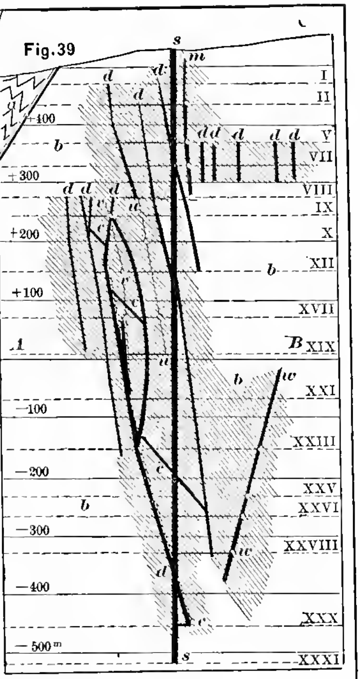


Fig. 37

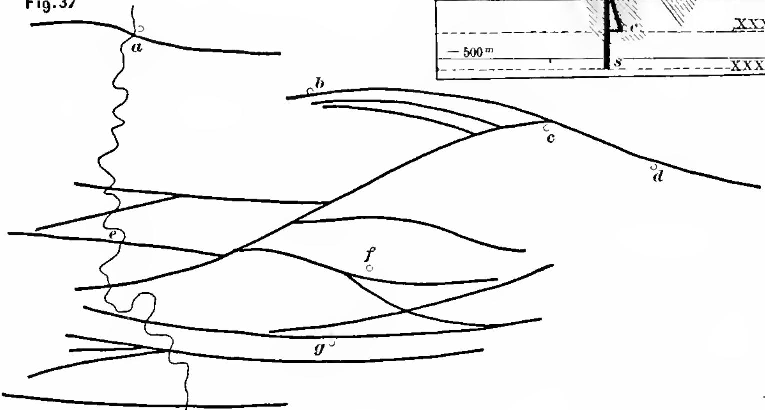
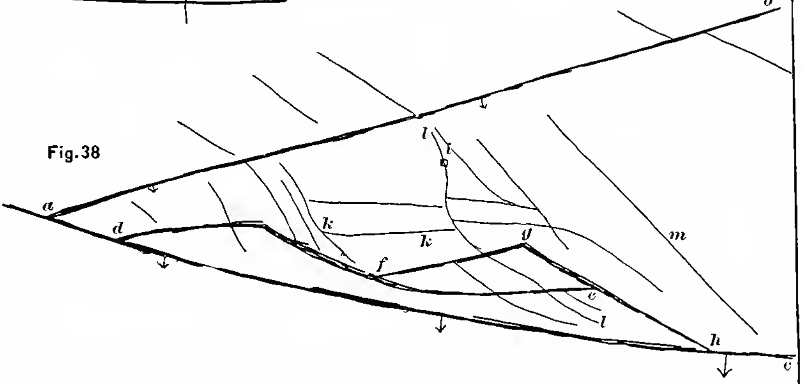


Fig. 38



Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 40.—Ideal section through Bohutin, near Przibram. *a*, Cambrian sandstone; *b*, pre-Cambrian schists; *c*, granite; *d*, main fault-fissure; *e e*, diorite dikes. (NOTE: At Przibram itself the pre-Cambrian schists constitute the hanging-wall of the main fault-fissure to the entire depth of the mines—about 1100 meters, or 3600 feet.)

FIG. 41.—Diagrammatic representation of the structure of the Verespatak ore-bodies (Volbura), showing the ore replacing the washed-out cement of a breccia, mostly of porphyritic fragments.

FIG. 42.—The same, only conglomerate instead of breccia.

FIG. 43.—Vertical S. to N. section through the Vulkoj mines, showing the supra-position of andesite upon the shaly sandstone. *a a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *e*, Jeruga adit; *f*, Peter-Paul adit; *g*, Hermann adit.

FIG. 44.—Vertical E. to W. section through the gold-mines of Botesiu and Vulkoj. A, Botesiu; B, Vulkoj; *a*, Nepomuk adit; *b*, sandstone; *c*, andesite; *d*, Corabia open-workings; *j*, Jeruga vein.

Fig. 40

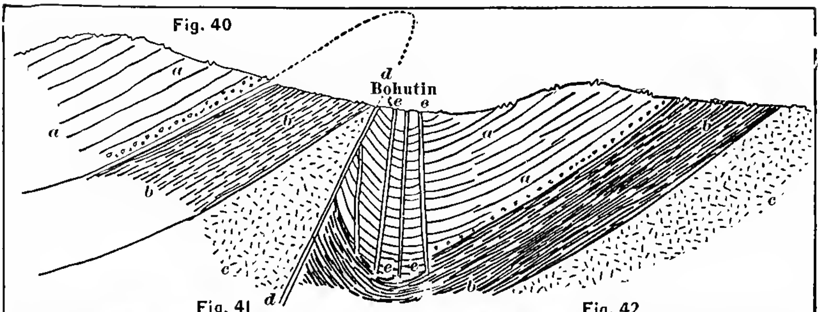


Fig. 41

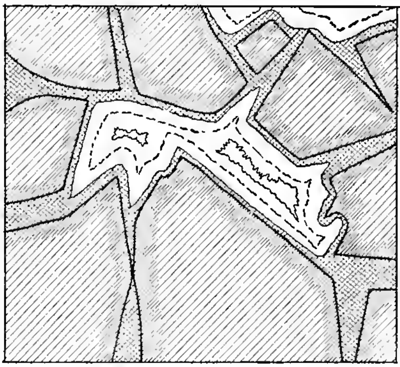


Fig. 42

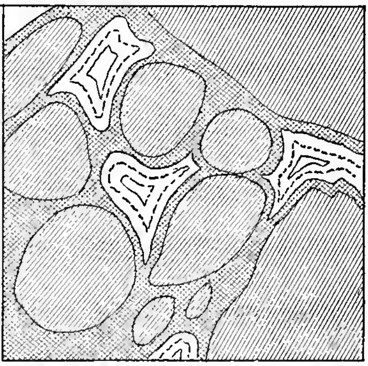


Fig. 43

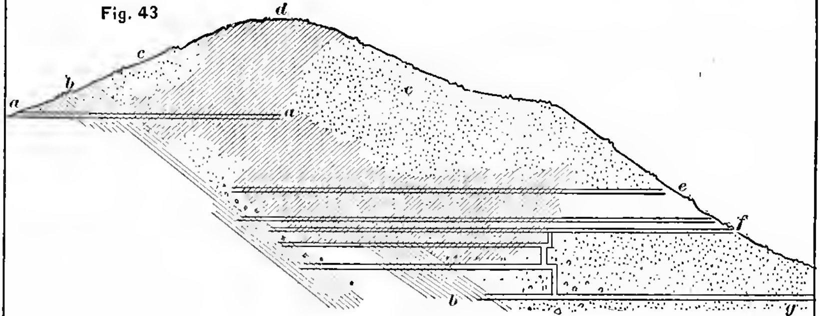
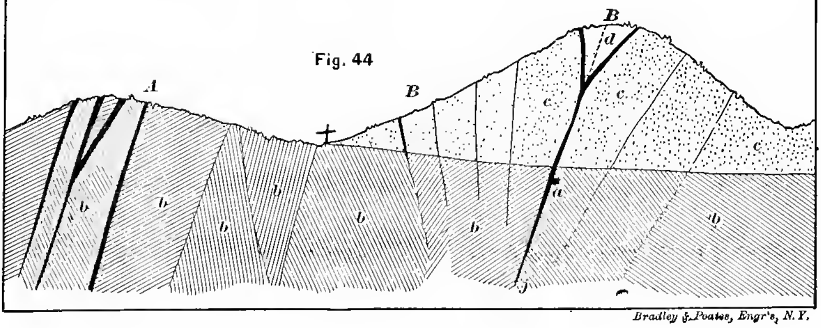


Fig. 44



Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 45.—Section in fourth level of Peter Stehend vein, Freiberg. *a*, decomposed country-rock; *b*, quartz, with brown-spar, pyrites, blende, and silver-ores. (G. A. Von Weissenbach, No. 2 in his work.)

FIG. 46.—Section on third level of Adlerflügel Stehend vein, Freiberg. *a*, gneiss fragments; *b*, older vein-formation; *c*, later quartz-vein matter; *d*, gneiss. (Weissenbach, No. 21 in his work.)

FIG. 47.—Section on third level of Gnade Gottes Stehend vein, Freiberg. (Weissenbach, No. 22.)

FIG. 48.—Section on thirteenth level of Adalbert Liegend vein, Przibram. *a*, galena and calcite; *b* (or, more precisely, the irregular mass shown to the right of *b*), zinc-blende; *c*, sandstone. (J. Zadrazil, No. 52.)

FIG. 49.—Section on thirteenth level of Adalbert master-lode, Przibram. *a*, siderite; *b*, calcite; *c*, quartz; *d*, galena; *e*, diorite. (J. Zadrazil, No. 5.)

FIG. 50.—Section on twenty-ninth level of Adalbert master-lode, Przibram. *a*, calcite; *b*, silicified (*verquarzte*) vein-matter; *c*, quartz; *d*, diorite. (J. Zadrazil, No. 21.)

FIG. 51.—Section on adit of Hildebrand vein, Joachimsthal. *a*, mica-slate; *b*, dolomite; *c c*, proustite; *d*, dolomite with pyrite; *e*, uranite. (J. Nemecek, No. 11.)

FIG. 52.—Section on tenth level of Junghäuerzechen vein, Joachimsthal. *a a*, dolomite and calcite; *b b*, mica-schist; *c*, basalt-wacke; *d*, chalcopyrite; *e*, prousite. (J. Nemecek, No. 5.)

Fig. 45

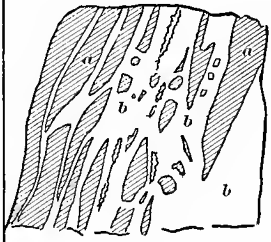


Fig. 46

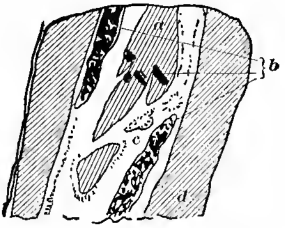


Fig. 47

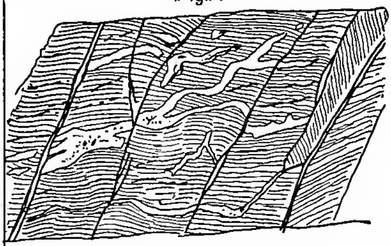


Fig. 48

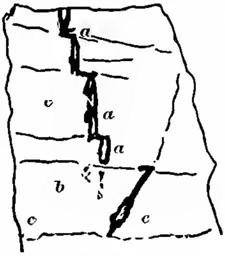


Fig. 49

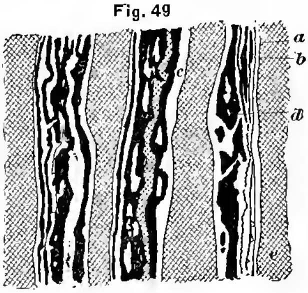


Fig. 50

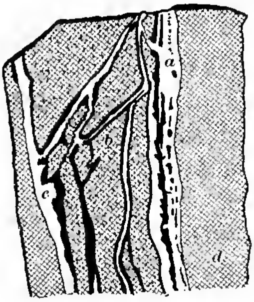


Fig. 51

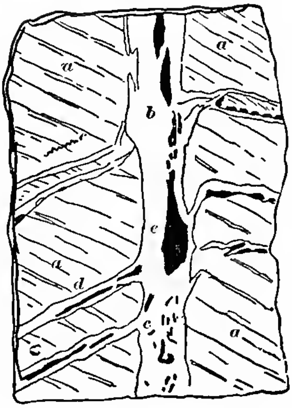
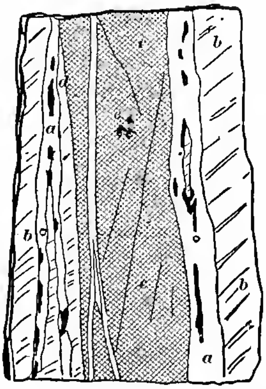


Fig. 52



Bradley & Poates, Engr's, N. Y.

DESCRIPTION OF FIGURES.

FIG. 53.—Specimen from the Drei Prinzen Spat vein, in the eighth level of the Churprinz Friedrich August mine, Freiberg, Saxony; $\frac{1}{6}$ nat. size; *a*, quartz with disseminated galena and blende, indistinctly crustified—from the older vein; *b*, fluorite with quartz; *c*, barite in thin crusts; *d*, gray earthy mass of the later vein, very distinctly crustified; *e*, the latest fault fissure.

FIG. 54.—Copper-deposit at Prettau in Tyrol. Sketch of the roof the Ottilie level.

FIG. 55.—Ditto; side of the same level.

FIG. 56.—Ditto; vertical section in the plane of the pitch, which descends nearly westward, the course of the strata being E. to W., and the dip steep to South. Adits and levels: *a*, Peter; *b*, Jacob; *c*, Marx; *d*, Johann; *e*, Kristof; *f*, Nikolaus; *g*, Ignatz. The three levels below *g* are the Ottilie, Karl, and Hugo.

FIG. 57.—Ditto; horizontal projection, showing approximately the position of the ore-bodies on the different levels; *a* to *g* as in Fig. 56; *x y*, strike; *y w*, true dip of strata; *y z*, pitch of ore-shoot.

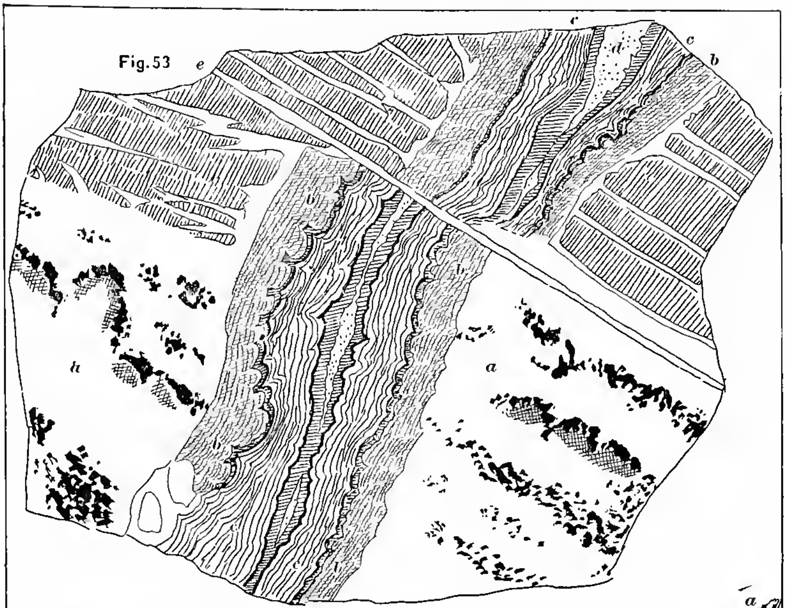


Fig. 53


Fig. 54

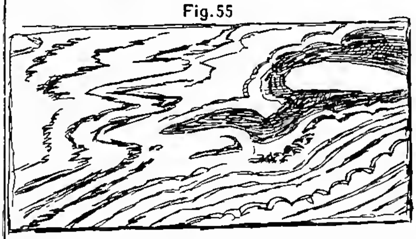


Fig. 55

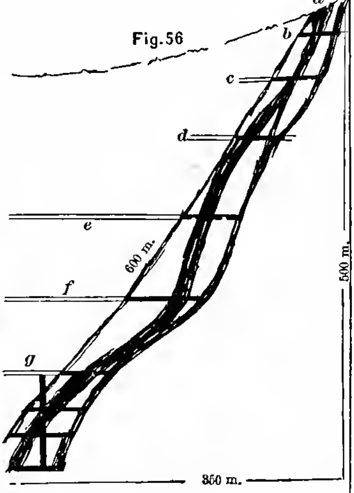


Fig. 56

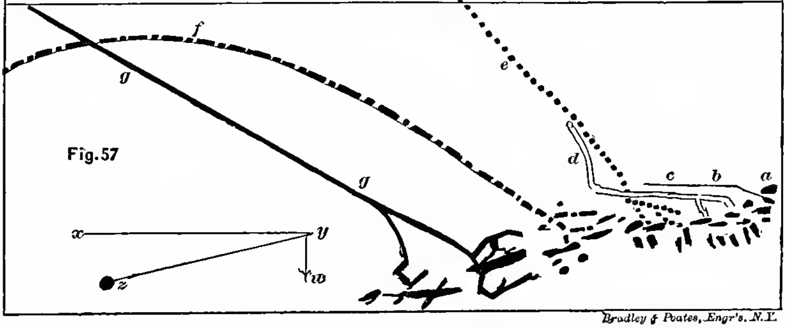


Fig. 57

Bradley & Poates, Engr's. N.Y.

DESCRIPTION OF FIGURES.

FIG. 58.—Surface-geology of the vicinity of the Comstock lode. B, basalt; L H A, later hornblende-andesite; A A, augite-andesite; E H A, earlier hornblende-andesite; L D *b*, later diabase (black dike); E D *b*, earlier diabase; Q P, quartz-porphyry; M D *r*, metamorphosed diorite; P D *e*, porphyritic diorite; G D *r*, granular diorite; M, metamorphic rocks; G, granite. (G. F. Becker.)

FIG. 59.—Vertical cross-section through Union shaft. (G. F. Becker.)

FIG. 60.—Vertical cross-section through C. and C. shaft. (G. F. Becker.)

FIG. 61.—Vertical cross-section through Yellow Jacket shaft. (G. F. Becker.)

FIG. 62.—Vertical cross-section through Belcher shaft. (G. F. Becker.)

FIG. 63.—Vertical section on line of Sutro tunnel. I, II, III, and IV, Sutro tunnel shafts; *s s*, lines of solfataric action; *v*, vein-material. (G. F. Becker.)

Fig. 58

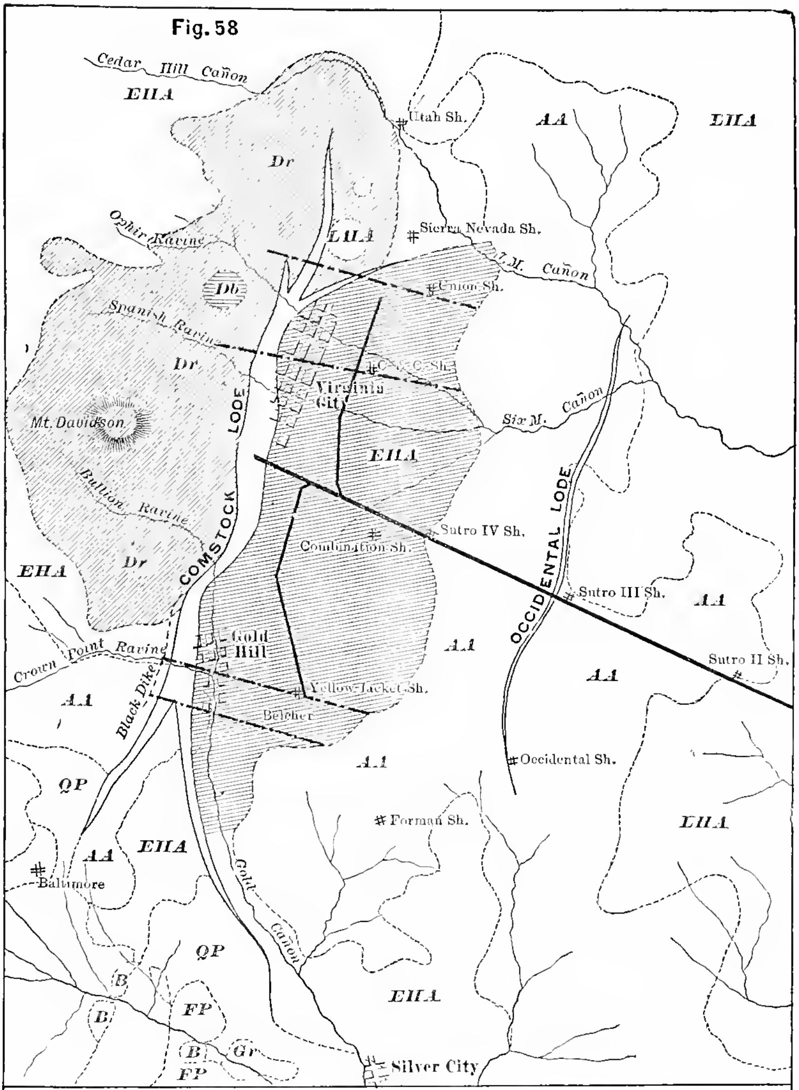


Fig. 59

Fig. 60

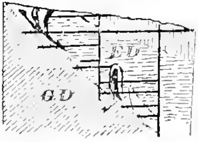


Fig. 61

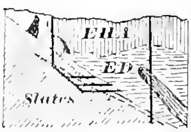
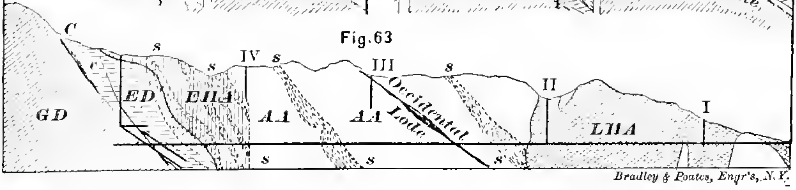


Fig. 62

Fig. 63



Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 64.—Vertical E. and W. section through the mines of Valle Sacca, near Rèzbânya, Hungary. *a*, sandstone; *b*, Jurassic limestone; *c*, Liassic limestone; *d d*, crystalline limestone; *e*, syenite; *f*, 3d adit; *g*, 4th adit; *h*, new Anton adit; *i*, Juliana ore-body; *k*, Marianna ore-body; *l*, Anton ore-body; *m m*, parallel intercalated dike; *n n*, Reichenstein ore-body; *o o*, dikes.

FIG. 65.—Vertical longitudinal section of Reichenstein ore-body, Valle Sacca, Hungary. *n n*, ore-body; *b*, limestone; *d*, 1st adit; *e*, 2d adit; *f*, 3d adit.

FIG. 66.—Diagram showing the S. W. pitch of the Reichenstein ore-body, the dikes dipping W. *x y*, course of dikes; *x w*, dip of dikes; *x z*, pitch of ore-shoot.

FIG. 67.—Vertical N. and S. cross-section of the Government mine at Raibl, Carinthia. *a*, Raibl slates; *b*, ore-bearing limestone. Adits: *c*, Johann; *d*, Frauen; *e*, Sebastian; *f*, Franz II., IV., VI. and VII.; positions of levels numbered upwards from Johann adit.

FIG. 68.—Vertical N. and S. section through the Struggl mine at Raibl. *a*. slate; *b*, ore-bearing limestone; *f*, Franz adit; *g*, Einsiedl level.

FIG. 69.—Faulting of the contact by a "Blatt." *a*, slate; *b*, limestone.

FIG. 70.—Vertical N. and S. cross-section through the Benyes mine, Rodna, Transylvania. *a*, mica slate; *b*, andesite; *c*, limestone. Adits: *d*, Amalia; *e*, Zap Peter; *f*, Anton; *g*, Nepomuk; *h*, Teresia.

FIG. 71.—Section through the "New Lead-Mass," in Mt. Ambree, Offenbânya, Transylvânia. *a*, mica-slate; *b*, andesite; *c*, limestone. Levels: *d*, Segen Gottes; *e*, Glück auf; *f*, ore-shoot.

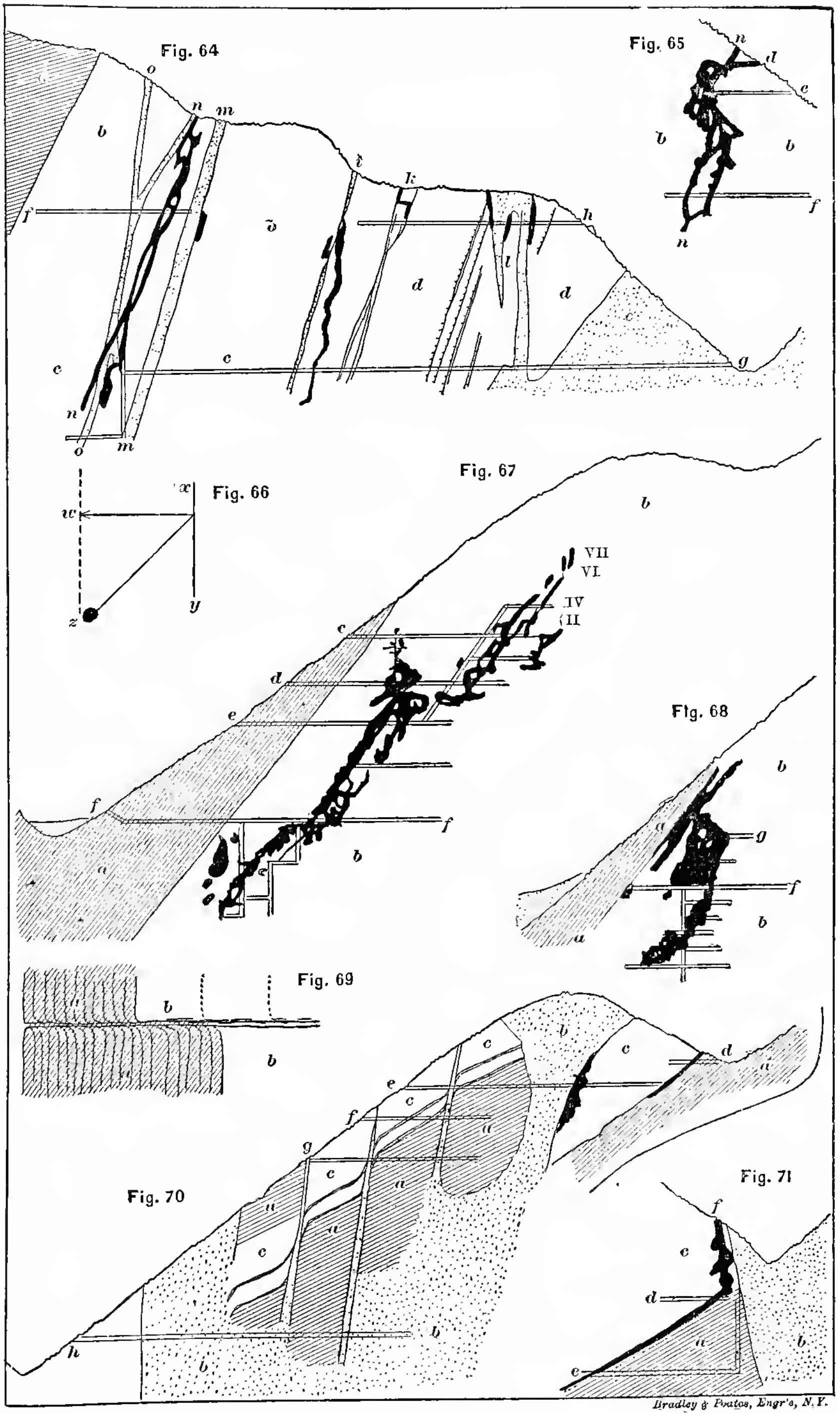


Fig. 64

Fig. 65

Fig. 66

Fig. 67

Fig. 68

Fig. 69

Fig. 70

Fig. 71

Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 72.—Face of level on the *Josephiblatt*, at Raibl, where the ores occur in the country-rock.

FIG. 73.—Vertical E. and W. section through the McKean shaft, Iron Hill, Leadville, Colo. W. P., white porphyry; B. L., blue limestone; G. P., gray porphyry; W. L., white limestone; L. Q., lower quartzite; G., Granite. (A. A. Blow.)

FIG. 74.—Sections from the Red Mountain district, Colo. A., andesite; P. Q., pink quartzite; L., limestone; L. Q., lower quartzite; *a*, Batavia shaft; *a b*, Jackson tunnel; *c*, adit; *o o*, ore. (G. E. Kedzie.)

FIG. 75.—Section across Longfellow Hill and Chase Creek, Clifton district, Arizona. A, Longfellow Hill; B, Chase Creek; *a a*, felsite; *b*, limestone; *c*, sandstone; *d*, porphyry; *e*, upper adit; *f*, deep adit. (A. F. Wendt.)

FIG. 76.—Ideal sections at Eureka, Nevada. A, Ruby Hill; *a*, Prospect Mountain quartzite; *b*, crushed limestone; *c*, limestone; *d*, shale; *e*, stratified limestone; *f*, Secret Cañon shale; *g*, Hamburg limestone; *i*, Logan shaft; *p*, Lawton shaft. (J. S. Curtis.)

FIG. 77.—Combined section at Eureka for comparison with Fig. 76. *a, b, c, d, e, f*, as above; *k*, Windsail shaft; *l*, Bell shaft; *m*, Richmond shaft; *x y*, east ore-body; VII., Richmond 7th level. (J. S. Curtis.)

FIG. 78.—Sketch of face of 310-foot level. Old Telegraph mine, Utah, showing texture of the filling (altered to cerussite). *a*, hanging-wall clay; *b*, quartz; *c*, quartzite.

FIG. 79.—Section from the lead-region of Wisconsin, in the neighborhood of Dubuque, Iowa. (J. D. Whitney.)

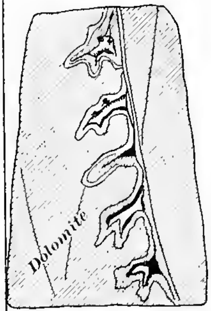


Fig. 72

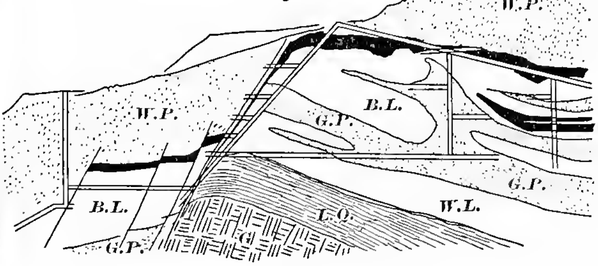


Fig. 73

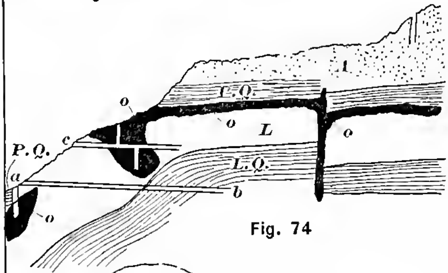


Fig. 74

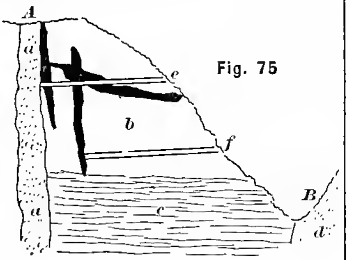


Fig. 75

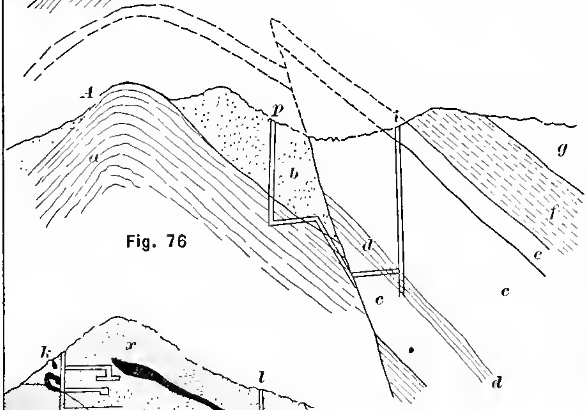


Fig. 76

Fig. 78

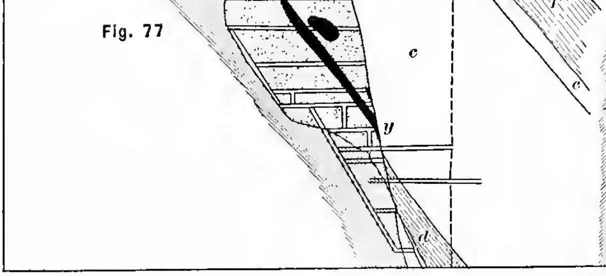


Fig. 77

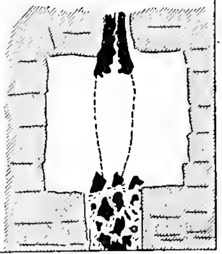


Fig. 79

J. F. Bradley & Co., N. Y.

Description of Figures.

Fig. 80.—Plan of ore-deposits at Wallerfangen and St. Avold, near Saar Louis. (C. Simon.)

Fig. 81.—Cross-section of 81. H, hanging-wall; F, foot-wall.

Fig. 82.—Cross-section of the Mechernich deposits, showing irregular faulting of the *Knoten* sandstone beds.

Fig. 83.—Cross-section of the Vesuv mine, Freihung, Bavaria. *a*, Keuper clay; *b*, variegated sandstone; *c*, ore-beds; *d*, engine-shaft.

Fig. 84.—Section of a tree-stem, replaced with galenite, from Freihung.

Fig. 85.—Calamine veinlets in the limestone at Raibl; *a*, limestone.

Fig. 86.—Cellular calamine of Raibl.

Fig. 87.—Section through the Laurium district, Greece; *a*, limestone; *b*, schist; *c*, Hilarion shaft. (A. Cordella.)

Fig. 88.—Section through the Laurium district; *a*, limestone; *b*, schist; *d*, porphyry dikes. (A. Huot.)

Fig. 89.—Limonite-deposit in West Cumberland; *a*, millstone grist; *b*, mountain limestone; *c*, Silurian schist. Hematite in place. (J. D. Kendall.)

Fig. 90.—*Bohneisenstein*-deposit of Wochein, Carniola; *a*, limestone; *b*, iron-ore. (A. v. Morlot.)

Fig. 80

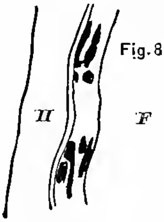


Fig. 81

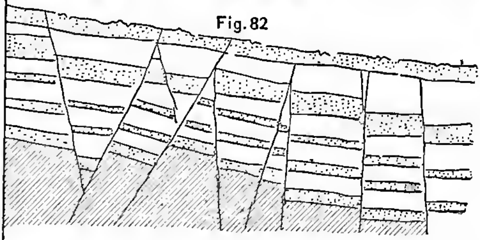


Fig. 82

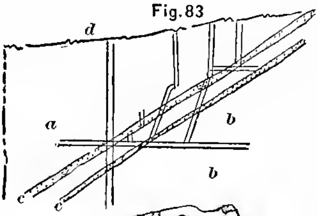


Fig. 83

Fig. 85

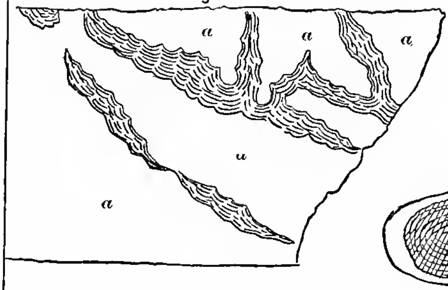


Fig. 86

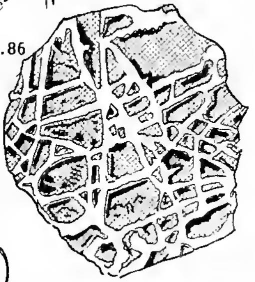


Fig. 84

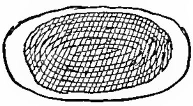


Fig. 87

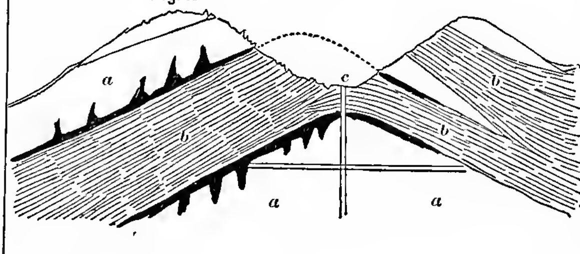


Fig. 89

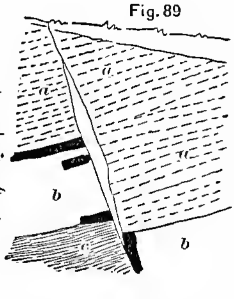


Fig. 88

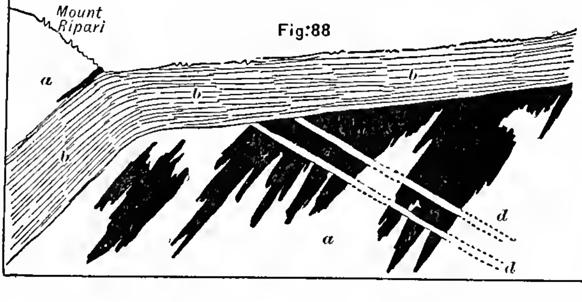
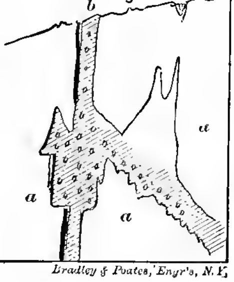


Fig. 90



Bradley & Poates, Engr's, N.Y.

DESCRIPTION OF FIGURES.

FIG. 91.—Tin-vein in Cornwall, with pseudomorphs of cassiterite after feldspar in the granite country-rock. (C. Le Neve Foster.)

FIG. 92.—Tin-vein in Cornwall, showing "capel" or altered "killas" country-rock. (C. Le Neve Foster.)

FIG. 93.—Impregnation of the granite with tin-ore at East Wheal Lovell, Cornwall. (C. Le Neve Foster.)

FIG. 94.—Specimens of ore from the Kongens mine at Röras, Norway. (Th. Kjerulf.)

FIG. 95.—Specimen of ore from the Mug mine, Trondhjem, Norway; *a*, pyrrhotite; *b*, mica; *c*, quartz; *d*, chalcopyrite. (Th. Kjerulf.)

FIG. 96.—Polished section of ore from Åmmeberg, Sweden.

FIG. 97.—Ditto, showing leaf-silver in fissures in zinc-blende.

FIG. 98.—Section through the Copper Falls mine, Lake Superior; *a*, trap; *b*, ash-bed at depth of 80 feet; *c*, amygdaloid; *d*, sandstone at depth of 420 feet.

FIG. 99.—Nagynyerges vein at Kisbánya, Transylvania.

FIG. 100.—Section through Palæozoic detrital gold-deposit of the Black Hills; *a*, porphyry; *b*, schist; *d*, Potsdam (old contact-lines dotted); *e*, cement-mines; *ff*, placers, the one on the left in the drawing being in Deadwood gulch at Central City; the one on the right, in Blacktail gulch. (Devereux.)

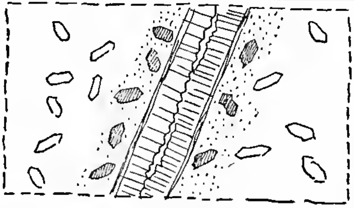


Fig.91

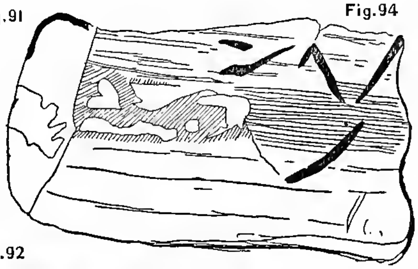


Fig.94

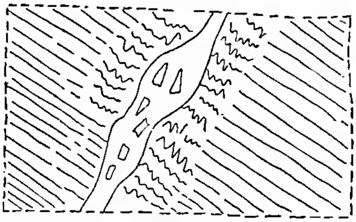


Fig.92

Fig.95

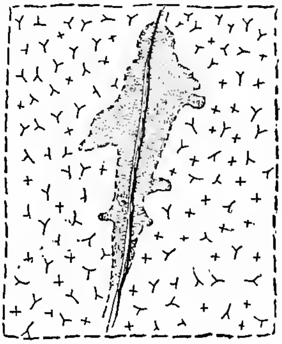


Fig.93

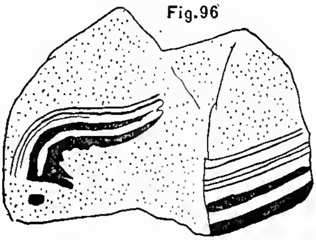


Fig.96

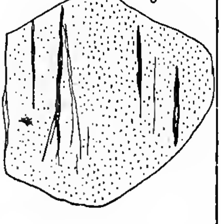


Fig.97

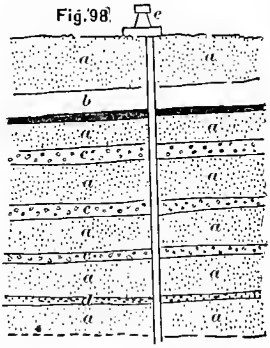


Fig.98

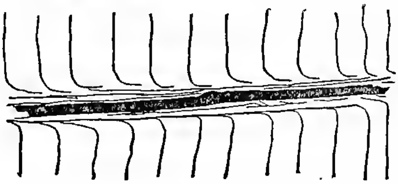


Fig.99

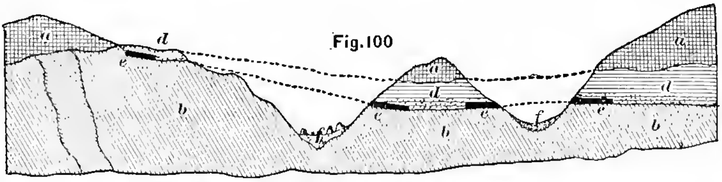


Fig.100

Bradley & Poates, Engr's, N.Y.

Discussion at the Chicago Meeting, August, 1893, Including Communications Subsequently Received.

W. P. Blake, Shullsburg, Wis.: I desire to express my admiration of Prof. Posepny's memoir, and particularly of the charming manner and spirit of the introduction.

With respect to his mention of the ore-deposits of Missouri and Wisconsin, reference may be made to my paper presented at this meeting (*Trans.*, xxii., 621), showing the existence of dislocations and breaks in the bedding, and their apparent close relation with the localization of the ore-deposits as claimed by Dr. James G. Percival, and also so claimed by Dr. Jenney in his paper before us (*Trans.*, xxii., 171). I have in my paper given reasons for believing that the zinc- and lead-ores in the strata above the compact Trenton limestones were formed by lateral secretion and concentration from above downwards, substantially as shown by Prof. J. D. Whitney, and not by the ascent of solutions through the fissures, as Prof. Posepny (p. 118) seems inclined to believe.

In regard to the contemporaneity of the ore and the rocks, and in favor of a later introduction of ore through fault-fissures, Prof. Posepny (p. 124) cites the influence of these fissures. In my paper, already referred to, I have endeavored to show how faults may have influenced the deposition of ore without being themselves channels for the flow of mineral solutions, and how they may have caused the contemporaneous formation of metallic sulphides from sea-water in the body of a forming rock; the faulting fissure being formed at an early period in the foundation-rocks, and probably continuing to be a plane of break and movement in the deposits of later formation.

Arthur Winslow, Jefferson City, Mo.: The results of extensive and long-continued studies, such as are here presented by Prof. Posepny, deserve most careful consideration before one should undertake to criticise the general conclusions or judge of the broader bearings of his work. I shall not attempt anything of the kind. The remarks made by me (*Trans.*, xxii., 634,

735) in the discussions of Mr. Emmons's and Dr. Jenney's papers, presented at this meeting, are to a great extent applicable here; but I wish to add a few more words bearing directly upon Prof. Posepny's statements concerning the Missouri and Wisconsin ores.

On page 117 he says that while the deposits, away from the granite and porphyry "islands" of southeastern Missouri, consist chiefly of lead- and zinc-ores, "other metals, such as copper, cobalt and nickel, occur as the Archean foundation-rocks are approached." This circumstance, he says, is "an indication that the source of the lead-deposits also is to be sought in depth." Whatever may be the value of this indication, I do not think the facts as stated hold generally. I judge that Prof. Posepny reasons from his observations at Mine La Motte, where such conditions exist. At other points, however, these changes in composition are not observed as the crystalline rocks are approached. At Doe Run, a mine recently opened, work is prosecuted along the old water-worn pre-Cambrian surface of the Archean granite, among the conglomerate boulders themselves; and few or no copper-, cobalt- or nickel-ores are found. Again at other localities, in St. Genevieve, Franklin, Crawford and other counties, copper-ores occur remote from any granite or porphyry outcrops and well above the basal beds of the Cambrian.

With reference to the Wisconsin deposits, our author seems to think the absence of ores, in the great thicknesses of limestones and sandstones which underlie the productive horizons, by no means conclusive as an argument against their deep-seated source, and suggests that the solutions may have come up through a passage not yet exposed, and even that fault-fissures and eruptive dikes may exist which have not been discovered. From the fact that he refers in this connection only to Whitney's report of 1862, I conclude that he has not had access to the later and more exhaustive works of Strong and Chamberlin. Perhaps with the full light conveyed by these reports and accompanying maps, Prof. Posepny might have attached more importance to the objections raised. For my own part, I do not see how such a passage for the solutions as he suggests could possibly exist without its presence having been revealed and its course traced through the widespread mining and exploring which has been conducted in this region during the past seventy years. Neither do I yet see how the solutions could traverse the intervening great thicknesses of water-soaked sandstones without becoming diffused, in great part at least. The failure to find such a passage and the absence of the ores in the beds assumed to have been traversed, though evidence of a negative character, is so strong that it becomes of almost positive value in support of the theory of lateral segregation.

T. A: Rickard, Denver, Colo.: The distinguished author of this paper has referred to the Leadville monograph of Emmons as "epoch-making." This judgment has been anticipated, I believe, by most of us. It serves, however, very well to recall the fact that the publication of that particular monograph marked the high-tide of the lateral-secretion theory, which owed its importance more to the fact of its acceptance by certain distinguished geologists than to its incomplete demonstration by Sandberger.

What Prof. Posepny said of the work of our American geologist we can say, with even greater force, of his present contribution. His dissection of the theory promulgated by Sandberger is most effective. The sympathies of the miner are with him in that demolition of the lateral-secretion theory; for the latter was an explanation which never found much favor underground, with the miner, but had its stronghold in its own particular *habitat*, the professor's *sanctum*. Here I would throw out the suggestion to my fellow mining engineers, whose business is to observe rather than to theorize, that these distinguished scientists must, after all, look to the men who spend much time underground for the accumulation of evidence whereon to found their hypotheses. If the genesis of ore-deposits is to be unravelled, more particularly if this study is destined to be capable of further practical and economic application, it must be through the gathering of facts and not the mere building of theories. Prof. Posepny has very properly pointed out that Sandberger's views gained many disciples because they permitted extensive generalizations to be made above ground, and in comfort, but did not so much require a descent underground and the making of observations under conditions of discomfort. Therefore, I would say, let those of us who have the opportunity aid in the elucidation of truth by the collection of the facts and observations without which speculations regarding the origin and formation of ore-deposits are worse than vain.

Prof. Posepny emphasizes the fact of the ascension of mineral solutions. I venture to suggest that these terms—"ascending," "lateral," and "descending"—may all be applied to mineral solutions at various periods and under various conditions. It is the great fact of *circulation* which covers all. The water which comes up must have first gone down; its original descent was as necessary to the process of ore-formation as its subsequent ascent. When and where in its journeying it became a solvent and when and where it became a precipitant—that is what the miner wants to know. The ultimate formation of an ore-deposit is dependent more upon conditions favoring precipitation than upon those determining solution.* Prof. Posepny points out more than once that the two great factors which increase the solubility of all substances are heat and pressure. We know by observation that these conditions are increasingly obtainable as we go downward. The deep region is one that favors solution, just as the shallow zone, because it is characterized by lessened heat and diminished pressure, favors precipitation. It is this simple fact which helps to explain the ordinary non-persistence of ore in depth. It is this which explains the comparatively late origin of ore-deposits. The general non-persistence of ore in depth is a fact capable of proof; the comparatively late origin of most ore-deposits is a hypothesis which is founded upon observation and confirmed by the consideration that the older geological formations were at some time overlaid by an enormous thickness of later sediments, and therefore existed under conditions favoring solution, and not that precipitation to which ore-deposition is more directly due.

One more point I would wish to refer to. Prof. Posepny demonstrates that at Przibram the metal of the ore-deposits could not have come from the eruptive rock in the immediate vicinity of the lodes. This is most interesting. For many years

---

* Reference is intended particularly to the metals.

we have been accustomed to references to dikes and other bodies of eruptive rocks as being the source of the precious metals of certain lode-formations. In fact, a "dike" was almost as necessary as a "true fissure-vein," a good climate, plenty of timber, fine scenery and other factors, which, in a prospectus, are requisite to the making of a good mine. In my Bendigo paper* I have already suggested that the vicinity of eruptive rocks need not necessarily indicate that they were the source of the metals, but that their extrusion afforded the heat which made the underground waters active. I would add that the contraction, due to cooling, following the extrusion of a sheet or a mass of igneous rock may have afforded a line of least resistance or—as Prof. Posepny would put it—"a line of maximum circulation."

In closing I would express the indebtedness which we must all feel to Prof. Posepny for so extensive and so valuable a contribution. In my own case I would express it as the gratitude of an apprentice to a master.

Horace V. Winchell, Minneapolis, Minn. (communication to the Secretary): It is an interesting fact that the opinions here so ably advanced by Prof. Posepny were partially stated as long ago as the end of the seventeenth century. A few quotations from "An Essay Towards a Natural History of the Earth," by John Woodward, will make this plain. I quote from the third edition, published in 1723, the date of the first edition being 1695.

> "That there is a perpetual and incessant circulation of water in the atmosphere; it arising from the globe in the form of vapour, and falling down again in the form of rain, dew, hail and snow. That the quantity of water thus rising and falling is equal; as much returning back, in rain, etc., to the whole terraqueous globe, as was exhaled from its vapours. That tho' the quantity of water thus rising and falling be certain and constant as to the whole, yet it varies in the several parts of the globe; by reason that the vapours float in the atmosphere, sailing in clouds from place to place, and are not restored down again in a perpendicular upon the same precise tract of land, or sea, or both together, from which originaly they arose, but any other indifferently" (pp. 132, 133).

As to the cause of the circulation of waters beneath the surface of the earth he speaks as follows:

---

* *Trans.*, xxii., 289.

"That there is a nearly uniform fire or heat disseminated throughout the body of the earth, and especially the interior parts of it; the bottoms of the deeper mines being very sultry and the stone and ores there very sensibly hot, even in winter, and the colder seasons. That 'tis this heat which evaporates and elevates the water of the Abyss, buoying it up indifferently on every side, and towards all parts of the surface of the globe; pervading not only the fissures and intervalls of the strata, but the very bodyes of the strata themselves, permeating the interstices of the sand, earth or other matter whereof they consist, yea even the most firm and dense marble and sandstone. . . . That this vapour proceeds up directly towards the surface of the globe on all sides, and as near as possible, in right lines, unless impeded and diverted by the interposition of strata of marble, the denser sort of stone, or other like matter, which is so close and compact that it can admit it only in smaller quantity, and this very slowly and leisurely.

"That where the vapour is thus intercepted in its passage, and cannot penetrate the stratum diametricaly, some of it glides along the lower surface of it, permeating the horizontal intervall which is betwixt the said dense stratum and that which lies underneath it. The rest passes the interstices of the mass of the subjacent strata, whether they be of laxer stone, or of marle, or the like, with a direction parallel to the site of those strata, 'till it arrives at their perpendicular intervalls" (pp. 136, 137).

Woodward entertained the idea that "the whole terrestrial globe was taken all to pieces and dissolved at the deluge."

"That at length all this metallick and mineral matter, both that which continued asunder, and in single corpuscles, and that which was amassed and concreted into nodules, subsided down to the bottom; at the same time that did the shells, teeth, and other like bodyes: as also the sand, cole, marle, and other matter whereof the strata of sand-stone, cole, marle, and the rest are for the most part composed; and so were included in, and lodged amongst, that matter. . . . And the case of metalls and minerals being the same, 'tis for that reason that in some places we now get iron, or vitriol, but no copper or alum: in others we find these, but not those: and in others both these and those, and perhaps many more. . . . Thus we sometimes see whole strata compiled of metallick and mineral nodules: others of pebles, and of flints, without the interposition of other matter. . . . Thus likewise we find strata consisting almost entirely of common salt: others of ochre: and others of several metalls and minerals, tin, lead, vitriol, nitre, and sulphur promiscuously, without any considerable mixture of coarser terrestrial matter."

Of the origin of veins he speaks in these words:

"That the metallick and mineral matter, which is now found in the *perpendicular intervalls* of the strata, was all of it originaly, and at the time of the deluge, lodged in the bodyes of those strata; being interspersed or scatter'd in single corpuscles, amongst the sand, or other matter whereof the said strata mainly consist. That it was *educed thence* and *transmitted into these intervalls*, since that time; the intervalls themselves not existing till after the strata were formed, and the metallick and mineral matter was actualy lodged in them; they being only breaches of the strata, and not made till the very conclusion of the catastrophe, the water thereupon immediately withdrawing again from off the earth.

"That the water, which ascends up out of the Abyss, on all sides of the globe, towards the surface of the earth, incessantly pervading the pores of the strata, I mean the interstices of the sand or other matter whereof they consist, detaches and bears along with it all such metallick, mineral, and other corpuscles which lye loose in its way, and are withal so small as to be able to pass those interstices; forcing them along with it into the perpendicular intervalls; to which it naturally directs its course, as finding there a ready exit and discharge, being partly exhaled thence up into the atmosphere, and partly flowing forth upon the surface of the earth, and forming springs and rivers.

"That the water which falls upon the surface of the earth in rain, bears also some, tho' a lesser, share in this action; this, soaking into the strata which lye near the surface, straining through the pores of them, and advancing on towards their perpendicular intervalls, bears thither along with it all such moveable matter as occurs in those pores in much the same manner as does the water which arises out of the Abyss with only this difference, that this passes and pervades none but the superficial and uppermost strata, whereas the other permeates also those which lye lower and deeper. (*The vadose and deep underground circulations of Posepny.*)

. . .

"That therefore the metalls and minerals which are lodged in the perpendicular intervalls of the strata do still grow [to speak in the mineralogists' phrase], or receive additional increase from the corpuscles which are yet daily borne along with the water into them. Nay they have grown in like manner ever since the time of the Deluge, in all such places where those intervalls are not already so filled that they cannot receive any more: or where the stock of metallick and mineral corpuscles, originally lodged in the strata, is not quite exhausted, and all borne thither already. . . .

"That the metallick and mineral matter which lyes in the bodyes of the strata does not grow, . . . but on the contrary, hath been diminished and lessened by so much as hath been conveyed into their perpendicular intervalls, and as hath been brought forth upon the surface of the earth by springs, rivers, and exhalations from the Abyss, since that time. That notwithstanding there have and do still happen, transitions and removes of it, in the solid strata, from one part of the same stratum to another part of it, occasion'd by the motion of the vapour towards the perpendicular intervalls of these: and in the laxer strata, such as sand, clay, and the like, *from the lower ones to those which lye above them,* and even to the very surface of the earth" (pp. 208–216).

Although the paragraphs quoted lead us to infer that Woodward thought veins were filled by the mechanical transportation of matter in small grains, yet there are in other places indications that he also had an idea of their formation by the deposition of minerals from solution. Thus, nearly a century before Werner and Hutton, were expressed ideas which were the results of long and careful observation and study which, though tinged with the theological and so-called philosophical doctrines of the day, were yet true to nature and of universal application, and which strike us as extremely valuable and original when put in modern logic and phraseology.

John A. Church, New York City (communication to the Secretary): I cannot agree with all the *dicta* of Prof. Posepny's valuable paper. He says (page 14, and see page 74) that in fissures "only the places remaining open would permit an active circulation of solutions and a regular deposition from them." The idea of deposition in a free space runs through the whole of the paper, and is applied not only to the ore-deposits of the vadose circulation but with equal uniformity to those of the deep circulation. Such ideas seem to me to be incompatible with the crushing pressure which all agree must be found at depths of 10,000 and 15,000 feet. We have in metasomatic replacement an explanation of ore-formation which accords so well with the conditions supposable at great depth that it seems unnecessary to add to it a requirement that is certainly contradicted by those conditions.

I believe I was the first in this country to ascribe the formation of an important vein (the Comstock) to metasomatic alteration, which I then called "substitution," the term metasomasis being suggested in the same year. The character of the Comstock ore forbids the supposition of deposition in an open space; for it is not quartz but a mixture of quartz and fragments of the wall-rock. In the opinion of experienced men more than half of the rich ore mined from the heart of the great ore-bodies was "porphyry," and at least the proportion was great. My conclusion was disputed by Mr. Becker; but one of the surest advances which vein-geology has made in the last fifteen years has been the steady growth of the idea that the thickest ore-bodies may have been formed by the replacement of masses of wall-rock fragments, or by the spread of siliceous replacement from a narrow crevice through the walls.

In deep-seated formations this method of deposition is necessarily supposed; for there are not only no open spaces there, but the situation is not even what I conceived it to have been in the Comstock. Nearer the surface there might be partings which, though minute, would be real openings, while at great depth such partings must be so closely appressed as to be no more than mere breaks of continuity.

The tendency of opinion in this country is toward metasomasis acting upon masses of crushed rock in crevices which they completely fill; and I find nothing in Prof. Posepny's paper which need cause a retreat from this view.

Prof. Posepny appears to place great reliance upon the appearance of the ore and the walls enclosing it, and I suppose it is because deep-seated deposits in limestone have some strong resemblances to those of the upper circulation, that he concludes that the former must be laid down in "spaces of dissolution," like some of the latter. To me these facts point rather to an identity of active agent than to identical circumstances of its action. To make my meaning clearer I will recall some well-known facts and theories.

We know that the limestone rocks, in proportion to their amount, carry more ore-bodies than the siliceous rocks, though the latter have actually the greater number. The suitability of limestone for the deposit of ores is usually made to depend upon its solubility in water charged with carbonic acid, which is supposed to be derived from the soil by descending waters. It is carried into the interior of the earth and again discharged, for the earth being a closed vessel already full of water into which a new supply is constantly poured, it is clear that as much must be discharged into the atmosphere by springs as the atmosphere supplies by rain. I find fault with the usual view upon this subject, which apparently assumes that the deep waters must be highly charged with CO_2 derived from the surface. On the contrary, it seems to me that the discharging water must bring out as much CO_2 as it takes in, for neither water nor gas can be lessened in quantity except by the comparatively small amount that enters into fixed combinations in the rocks. Since the solubility of gas in water is increased by pressure we must suppose that the dissolved CO_2 remains with the water that absorbed it throughout the whole range of circulation and that there cannot be any discharge of surface CO_2 in the interior. Yet we know that large quantities of CO_2 are discharged from the earth as gas not dissolved in water, besides that which is dissolved; and this gaseous discharge must be in excess of the CO_2 carried in. May we not find the source of this excess in deep-seated metasomatic replacement?

The operation of solutions whose composition we do not know can be judged only by their effects. When metasomatic replacement takes place in limestone it is generally assumed that lime carbonate goes into solution, while its place is taken by the ore-substances, that is to say, that the action is molecular substitution and not atomic; but it is conceivable that the change should begin by an interchange of acidic elements—that SiO_2 should drive out CO_2. Subsequent changes might remove the lime silicate by another process of substitution, since it is more soluble than silica; but the point is that CO_2 would be liberated, and though the original ore-solution were free from CO_2, it would immediately become charged with that agent and exert the well-known dissolving power of carbonic acid solutions. In this way a solution which would have but feeble power in other rocks may in limestone set up a chain of reactions that would intensify its effects. These considerations lead to interesting conclusions.

We have a source of CO_2 in rocks, however deep-seated, and consequently effects may be produced at any depth, which simulate those of surface-waters, though probably without the production of caverns. Since the mode of solution is the same, the appearance of the walls lining an ore-body and the appearance of the ore itself may be almost precisely the same as in the vadose region.

Limestone contains the elements for self-destruction, since the breaking up of one lime-carbonate molecule may cause the solution of another; and, as this cannot be said of any other rock, we reach a possible explanation of the comparative frequency of ore-bodies in limestone. The dolomites would, of course, present similar reactions.

There are two questions which are distinguished, even in the difficult study of veins, by the obscurity which hangs over them. One is the selection of a favored stratum for ore-deposition. In some situations the solutions, before reaching the stratum of actual ore-deposition, must have passed several strata suitable for their action, if they had possessed from the beginning the power of solution which they showed ultimately. I believe this objection has been urged against the lateral-secretion theory as applied to Leadville. Ore-solutions exhibit a selective power which is extraordinary in a water fully supplied with dissolving qualities, but quite explicable in a solution which lacks this power. I suppose it is impossible at present to determine why the rocks now exposed at Leadville were selected for attack by the solutions; but I think it is comprehensible why that action, however extensive, should be localized by the development and action of CO_2 in the neighborhood where it began.

An obvious consequence of these considerations is that the aqueous circulation of the earth becomes, through the medium of metasomasis, a means for restoring to the atmosphere accumulations of carbon that represent the organic life of past times.

The second obscure question is logically one which ought to be answered before we discuss the origin of ore at all. It is the secondary alteration of already-formed ore-deposits. I have no doubt that some of the deep-seated deposits which we see are actually a product of the vadose circulation. Formed ten thousand feet below, they have been raised until they are now ten thousand feet above the sea-level, and, during the immense period through which they have been subjected to the surface circulation, they have not only been re-arranged but may have actually lost their ancient origin. Even the rock in which they were deposited may have been removed and the ore transferred to another member of the series. Structural facts may prove deep-seated deposition, but actually the ore-bodies we see are often in whole or in part hysteromorphs. This is especially true in limestone deposits. Though these facts are well-known, they do not exert the controlling influence upon opinion which I think they deserve, probably because of the extreme difficulty of separating the primary from the secondary phenomena. No writer that I have seen has given to this subject half the importance which a mining engineer must give it.

I cannot agree with the author in giving so much importance to crustification, as he describes it. Certainly a banded structure can arise from the replacement of fragments arranged in layers by pressure and friction, as well as in many other ways, and does not prove deposition in a cavity, whether filled by water or air. He has misunderstood me in saying that I found crusts of quartz alternating with calcite in the Justice mine (Comstock). I said the thick masses of calcite in that mine rested on a thin layer—an inch or two—of quartz; but this is not crustification in the author's sense. My view of that occurrence was that an insignificant quartz seam, probably belonging to the last period of the Comstock, was first produced, and that the calcite was formed by replacement of the wall-rock at a later period. There is not the least evidence of deposition in a cavity. If there is crustification, that appearance does not have the significance which our author gives to it.

I have not attempted to particularize the many points in which I find myself in agreement with the author; and since my remarks have been rather in criticism, I desire to express, in conclusion, my high appreciation of his admirable treatise.

S. F. Emmons, Washington, D. C. (communication to the Secretary): Prof. Posepny's paper, or treatise, as it rather deserves to be called, is a most important contribution to the theory of ore-deposits. His wide personal observation of most of the important mines in so many different parts of the world and his critical acumen as an observer, combined with his long-continued studies of the subject, give to his words an exceptional authority. Whatever might be said, therefore, in praise of his article (and it would take much time to say it all) would hardly add to its value. But the very high quality of his work renders any errors in it exceptionally hurtful, and I shall therefore confine my remarks mainly to what seem to me to be erroneous teachings, and to points in which I differ with him either wholly or in part. I would first say, however, that to the greater part of the views put forth in this paper I most heartily subscribe, especially to those on underground circulation, and on the great rarity of ore-deposits which have been formed contemporaneously with the enclosing rocks.

It is well known that for some years past there has been a very warm discussion between Posepny and Stelzner on the one side, and Sandberger on the other, in regard to the derivation of the material of ore-deposits, the former holding to the ascension, the latter to the lateral-secretion theory. Without attempting to determine the merits of either side of the controversy, which it would be unwise to do without examining personally the deposits in question and their geological surrounding, one is inclined to believe that the views of either of such able geologists must have scientific value, whether one or the other may be proved to be erroneous in a particular instance. I regret, however, to see this controversy brought into what should be a broad and impartial discussion of the facts of nature, and to detect in certain cases what appears to be a tendency on the part of Prof. Posepny to adopt a rather forced construction of these facts, in order to make them support his views rather than those of Sandberger.

The lateral-secretion theory, which Posepny ascribes to Sandberger, is much narrower than that which I, and I think most American geologists, hold. It confines the derivation of the vein-contents to the wall-rock in immediate contact with the deposit; whereas, in my view, a derivation from rocks within reasonable proximity, as opposed to a source at unknown depths ("in the barysphere"), would constitute lateral-secretion, and ore-bearing currents may in such cases have had an upward, downward or lateral motion, according to differing local conditions of rock-structure. Prof. Posepny himself admits, in his admirable discussion of vadose or shallow and deep underground circulation, the possibilities of such lateral-secretion when he describes the latter (p. 28) in the following words:

> "The ground-water descends in the deep regions also through the capillaries of the rocks; at a certain depth it probably moves laterally towards open conduits, and reaching these, it ascends through them to the surface."

The distinction between the action of surface and that of deep-seated waters is an important one in the study of ore-deposition; but I do not think that Prof. Posepny is justified in assuming, as he does, that only ascending waters are capable of depositing ores. Furthermore, the necessary derivation of metallic minerals by these ascending waters from the "barysphere" seems too far-fetched. At what depth the barysphere will be found, meaning thereby the part of the earth's interior where the rocks have a much higher specific gravity than those that come under our observation, is purely a speculative question; but as our surface observations extend over a thickness in round numbers of about 100,000 feet of rocks, and show no appreciable difference of specific gravity between the deeper and more shallow rocks, except such as is due rather to different degrees of density than to heavier mineral constituents, it seems safe to assume that such a barysphere must exist, if at all, at such great depths as to be beyond the reach of any mineral-bearing waters. If such a zone rich in heavy metals exists in depth, as there is some reason to believe, my own view, as expressed in my paper read at this meeting, is that the heavy metals which constitute the ore-deposits were brought up from it into the outer crust of the earth by the various eruptive rocks, and were partially concentrated in certain parts of these eruptive rocks by differentiation during the process of cooling. In this view I agree with Vogt, whom Prof. Posepny mentions (p. 147) in a somewhat slighting manner. I differ with Vogt, however, in that I consider the greater part of our ore-deposits, all certainly that have come under my limited observation, to be due to further concentration, perhaps many times repeated, both chemical and mechanical; and I am entirely at one with Prof. Posepny in considering their final concentration into their present form to be due to the action of circulating waters.

Prof. Posepny's belief in the capabilities of an ascending current of heated waters or thermal springs seems to me, in some instances, as exaggerated and unreasonable as his rendering makes Sandberger's disbelief, in the instances he cites. He quotes a single observation by Nöggerath in 1845 on the finding of vertical channels in limestone 8 to 35 inches in diameter, near Aachen, which are supposed to have been eaten out by the ascending spring-waters, and from this draws the wide-reaching conclusion that ascending waters may actually force their way up through rock masses without the necessity of pre-existing cracks or channels. Among instances where he uses this explanation to account for the formation of an ore-deposit the most remarkable is that of Laurium (p. 135), where the ore-deposits as shown by the diagrammatic section (Fig. 87) are funnel-shaped bodies extending outward from the contact of flat-lying schists into subjacent and superjacent limestones, that is both upwards and downwards. My own explanation of this section, deduced by observations in limestone-deposits in this country, would be that the ore-bearing currents circulating along the contact-planes had eaten outward into the more soluble rock, upwards from the upper contact, and downwards from the lower contact. But Prof. Posepny explains the funnel-shape of the ore-bodies on the upper contact as produced "by the pressure of the ascending solutions." The lower contact he offers no explanation for, but says "it is perhaps somewhat ideally sketched."

It is unprofitable, however, to discuss deposits which neither of us have seen; for nothing is so liable to misconception as the description of ore-deposits one has not seen by a person with whose qualifications and accuracy of observations one is not familiar. This is shown in Prof. Posepny's remarks upon the Leadville deposits, in which he concludes that I must acknowledge that my views in regard to the downward course of the ore-bearing solutions were incorrect, because several mining engineers have shown them to be untenable. It does not seem to occur to him that the views of a mining engineer (who is not necessarily a geologist) based upon studies of a single mine or set of mines would be of less value as applied to such theoretical questions than those of a trained geologist who had made a study of all the geological conditions and mines of a district. Of the three articles quoted by him, that of Mr. Freeland offers no opinion upon the subject in question. Both this and Mr. Rolker's article were written before my monograph was published, otherwise Mr. Rolker would have found his objections on these points foreseen and accounted for there (p. 490).

In the summer of 1890 I spent nearly two months at Leadville studying the recent developments with the special purpose of testing the correctness of my former deductions, and Mr. Blow accompanied me through the workings of North Iron Hill, with which he is so familiar. While I naturally found many details of geological structure which were not, and could not have been, correctly represented on the underground sections accompanying my report, I found no reason to change my views of the manner of formation of the ore-deposits, and I convinced myself (and I think Mr. Blow also) that his objections were based on a misapprehension of certain geological phenomena. It were too long to give here all the results of my observations, which I regret that circumstances beyond my control have as yet prevented me from publishing. I will say, however, as bearing upon this point, that in no case did I find any convincing evidence of the action of ascending solutions. The ore-bodies occur in two general forms, either on the approximately horizontal contact-planes of porphyry and limestone, or along nearly vertical fissures crossing the limestone beds. In either case, wherever the form of the ore-body was such as to throw any light upon the probable direction of the ore-forming currents, it showed that they must have descended, for they all terminated more or less in a point or wedged out downwards.

Before discussing this further, it may be well to repeat my statement given in the monograph (p. 379) which has evidently been overlooked or misapprehended by my critics. I say, with regard to the *immediate* source of the ores:

> "1. That they came from above. 2. That they were derived mainly from the neighboring eruptive rocks.
>
> "By these statements it is not intended to deny the possibility that the materials may originally have come from great depths, nor to maintain that they were necessarily derived entirely from eruptive rocks at present immediately in contact with the deposits."

I do not maintain, as many have assumed, that the ore was derived from the white porphyry. I do not pretend to be able to determine what particular body of porphyry it came from. The objection of Mr. Blow that it could not have come from the white porphyry because this is not all decomposed (*not* " not at all decomposed," as Prof. Posepny puts it), is based upon a misapprehension of what constitutes decomposition. If Prof. Posepny will read the description of the eruptive rocks in my chapter on rock-formations, he will see that all the Leadville porphyries are more or less decomposed within this district; when Mr. Cross and I were making our geological studies we had to go several miles away before we could find a specimen of unaltered white porphyry for microscopical study.

My contention with regard to the ores of this district, as opposed to the theoretical views of Prof. Posepny and those of his school, would not have been essentially affected, however, if it had been shown that the solutions had ascended to reach the *locus* of the present deposits. The fissures across the limestone which gave access to the solutions forming the ore-shoots of North Iron Hill described by Mr. Blow are, as I showed in my monograph, faults with only a few feet of displacement, and can extend to only limited depth; in some cases their lower limit could be detected. The great faults which extend several thousand feet in depth are not ore-bearing, except in so far as ore has been dragged into them in the movement of their walls, one upon the other. But the extent in depth, even of these great faults, must be extremely limited as compared with the distance of the barysphere. I believe that the eruptive rocks originally brought up the heavy metals from the depths into the general region in which the ores are now found. Some of these eruptives still contain over four per cent. of them, in spite of all the leaching to which they have been exposed. The ore-deposits are concentrations of these materials by deep underground waters, flowing along natural channels, and depositing along those which admitted a comparatively free flow, as compared with a capillary circulation. Such a flow may have been upward, downward or lateral, according to varying structural conditions. The ascending solutions which Prof. Posepny contemplates, however, could not have formed ore-bodies of the form of those found in Leadville; and it was for that reason that I laid stress upon the evidence of their probable downward course.

As regards the phenomena of "crustification," I may not have been explicit enough in stating its absence. In my original examination I searched in vain for any evidence of it. In my second examination, almost entirely in bodies of unaltered sulphides, I found overwhelming evidence that the ore was not deposited in pre-existing cavities, but by metasomatic replacement of the limestone. In the great bodies of the A. Y., Minnie and adjoining mines not only could every detail of the granular structure, joints and cleavage of the original limestone be detected at times in the sulphide ore, but even the cracks in the top of the ore-body through which the ore-bearing solutions had descended were often visible. In abandoned drifts, where the limestone dust had accumulated on the walls, one would have supposed the walls to be all limestone until the breaking off of a fresh fragment by the hammer showed the metallic gleam beneath.

G. F. Becker, Washington, D. C. (communication to the President from Newport, R. I.): The paper of Prof. Posepny is a very valuable contribution to the science of ore-deposits, and deserves a more careful critical discussion than I am able to assist in giving to it at this time, in the absence of facilities for reference to authorities, etc. A few general observations, therefore, must suffice at present to indicate my views.

The theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement. Prof. Posepny is very clear on this point (p. 13), and I have insisted upon it in my memoir on quicksilver-deposits and in a paper on quicksilver about to be distributed. Prof. Posepny appears to me, on the other hand, to lay too much weight upon the structure which he calls "crustification," as indicating exclusively the filling of open cavities and the absence of replacement. Metamorphic processes are very frequently accompanied by the formation of layers similar to stratification and crustification, and, indeed, from similar causes. Strata are distinguishable only because the circumstances of deposition undergo more or less marked variations, and the banded structure of agate or hematite is also due to variations in conditions of deposition such as the strength of the solutions, or the rapidity of their flow, or temporary changes in the composition of the fluid. It appears to me that the banded structure attending metamorphism, as a matter of observation in many cases, is due to entirely similar causes. Thus a mass of iron immersed in a copper-solution will precipitate the copper as a laminated mass, unless great precautions are taken to secure uniformity of temperature, etc. In short, lamination is an ordinary attendant of processes of deposition, whether by replacement or otherwise, whenever they are so slow as to be subject to changes of condition. Hence crustification seems to me an insufficient guide to genetic diagnosis.

The indications of replacement which I should rely upon are twofold: crystalline pseudomorphosis and the irregular enlargement of fissures in the replaced mass. Of the latter, Prof. Posepny gives a good illustration (Fig. 85). As for pseudomorphosis, it has a very important bearing on the work of Mr. Emmons and of J. S. Curtis, for it appears to be thoroughly well established that galena forms pseudomorphs after calcite; and, therefore, the theory of replacement of limestone which they advocate is, to say the least, possible. The studies of these observers at Leadville and Eureka tend to show that replacement has been the chief process; but so far as I can recall their remarks they do not assert the entire absence of deposition in pre-existing openings; so that even if crustification were an infallible sign of filling, the detection of crusts (Posepny, p. 114) would not invalidate their position. Another objection to Mr. Emmons's views is expressed by Prof. Posepny in the sentence (p. 109), "It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville." I cannot share this view, for replacement, like solution, must occur along fissures or channels, and metasomatic ore-bodies will present analogies in form to the open spaces of caves of solution.

It seems substantially certain that open cavities in limestones can form only above the permanent water-level of a country, since in such a country the water below this level must be approximately saturated with calcium carbonate. On the other hand, replacement may take place at any depth. Now, in the Great Basin, the Tertiary and Early Quaternary were very wet periods, and if the Eureka limestones have been excavated by surface waters, the excavation and subsequent ore-deposition, according to Prof. Posepny's view, must be crowded into the late Quaternary. The present precipitation of that region would seem insufficient to bring about much cave-formation, while a greater precipitation would raise the water-level. Thus, so far as Eureka goes, the hypothesis of subsequent filling raises distinct, though perhaps not insuperable, difficulties as to the formation of the cavities.

The foregoing notes should be reinforced by examples and citations which I cannot now furnish.

F. M. F. Cazin, Hoboken, N. J.: If I venture to add a few lines to Prof. F. Posepny's treatise on the genesis of ore-deposits, my justification is derived from practical work done and consequent opportunities enjoyed in a region to which the learned author personally has remained a stranger, and of which in existing literature no such account is available as would afford to him the powerful argument in favor of his theories really presented by the region itself, to a degree of importance beyond any other mentioned by him.

The region to which I refer furnishes a demonstration of the xenogenous origin of ore-deposits, heretofore considered as idiogenous, which I may properly call gigantic, and which is equalled nowhere on the face of the earth as far as known. I refer to the region so tersely described by James Douglas (*Trans.*, xix., 694) in these words:

"In the Appalachian chain from Vermont to Georgia there are imbedded in the crystalline schists large masses of pyrites, some consisting of ordinary bisulphide of iron but most of them of pyrrhotite, and all carrying more or less copper."

There is, on the long stretch from Vermont (Mr. Douglas might have truly said "from Canada and Maine") to Georgia, no older mine, and none with more important development on the ore-deposits thus described, than that which has been called by State-legislative act "the Vermont Copper Mine." Its history began before the world knew about copper on the shore of Lake Superior. For many years it produced at the rate of 3,500,000 pounds of copper per annum, and, with adequate improvements, could do so to-day. I have seen its developments on a deposit dipping 24° N.E. to a distance of 2350 feet from the surface, and to a vertical depth below sea-level of several hundred feet, the lateral expansion of stopes ranging between 50 and 350 feet. Having been connected with this mine from early in 1882 to June of 1888, I have had opportunity to search for the origin of the ore-body there exploited.

Having discovered unmistakable local evidence as to the true nature of such origin, it remained to ascertain the identity or uniformity of effect from identical causes or other deposits falling under the description above quoted; and it was not difficult to establish such identity and harmony.

At a distance of ten miles in a northerly direction another mine in the same geological position, at Corinth, offered evidence leading to the same conclusions, and in a southern direction at a distance of four miles, the Strafford mines, and at a further distance of sixteen miles the Pompanoosuc mine, all similarly situated, demonstrated the same effects under similar causes. And a visit to many other localities within the Huronian Appalachian region could confirm only the conclusions to which the observations in the Vermont mine had been leading me.

Except as to dip, topography and shape of workings, Fig. 56 in Prof. Posepny's paper might well serve as the image of the

Vermont ore-deposit, represented on a vertical plane along its dip. And Figs. 54 and 55 may well serve as a representation of horizontal and vertical planes, as they are seen inside and outside of the Vermont, Corinth and Strafford mines, where the designs shown in these figures not only occur in dimensions varying from a few fathoms to many hundreds of fathoms, but also in varying material. In the mine, this consists of the sulphides of iron and copper, and outside and at distant points therefrom, in an admixture of carbon-matter (graphite) in the country-rock. This rock is a micaceous schist, the graphitic part varying in proportion from a mere trace to 100 per cent., becoming marketable plumbago in many localities, though without sufficient extent, as a rule, for exploitation.

But it is not on the similarity of design between sulphide and carbon admixtures in the rock alone that my conclusions were built, as a description of the mine will further show.

In their lateral expansion the ore-stopes in the Vermont mine present a figure very similar to the one presented in Prof. Posepny's Fig. 93, if the longitudinal extent be assumed as 2350 feet, with the lower part broadened. But similar figurations are also presented on a smaller scale, where in quarries the rock is laid bare on one of its dark seams.

The roof and floor of the Vermont ore-deposits are virtually impenetrable to water; the mine at 1000 feet vertical depth being dry. But there is uncovered at a distance of a few hundred feet from the outcrop an almost vertical cross-fissure or fault (without perceptible faulting), filled with calcareous spar containing sparsely distributed small seams of galena, which cross-fissure allows a few hundred gallons of water a day to percolate into the workings. Some of this water finds its exit through an abandoned adit. Where it reaches the surface, and where its flow is slow, allowing evaporation, it deposits a slime of virgin-white carbonate of lime; and as it passes down into the valley, it deposits for miles a mixture of carbonates of lime and iron, giving to the creek-beds their peculiar coating of color, as a result of atmospheric reduction of the iron carbonate.

The ore of the Vermont in its mineral character has one main peculiarity, which is common to the deposits as described from Canada to Virginia and Georgia, namely, that quantitative analysis shows neither the figures required to constitute the one of its components as ferro-sulphide, nor those required to show it as ferri-sulphide, these figures varying all the way between those applying to FeS and those applying to FeS_2.

The structure of the ore is the same as that of the graphitic rock, with the same variations in the ore as to contents in sulphides, as there are in the country-rock as to contents in carbon-matter. That in no case I have met with a nucleus of carbon in a body of sulphides, I have attributed to a full completion of the metamorphosis.

Yet another feature is common to the ores of the described deposits. For a long distance on the northern part of these continental deposits, wherever they occur in the Huronian schists, their ores carry nickel in proportions varying from a mere trace in the copper-metal made therefrom to an available percentage in the ore itself.

Although much disinclined to draw generalizing conclusions from isolated geognostic phenomena, I claim justification in the case at hand for the following conclusions, because the evidence is such as repeats itself on a large area, and once understood presses itself upon our attention, so as to be no longer ignored:

1. The iron and copper sulphides occurring in the Huronian crystalline schists on the eastern part of the North American continent have locally displaced carbonaceous matter, where faulting of strata aided water-circulation, such water containing sulphate salts of the metals in solution.

2. The metamorphic action of absorbing mineral carbon and of setting free CO_2 is continuous to the present day.

3. The product of such action extending below sea-level being observable in lines nearly parallel with the coast-line of an entire continent, and showing equal peculiarities in composition on the entire line, it is reasonable to assume oceanic action.

It is true that the ocean of our period evinces the presence of copper only by its presence in maritime organisms. But when, on the shores of a once existing Triassic sea we find embedded in massive but porous sand-rock an entire palm-vegetation, that has turned into copper-glance, as my eyes have seen it (compare p. 131 of Prof. Posepny's paper), then we may well assume the presence of a perceptible quantity of copper in a

Triassic sea, though not necessarily sufficient to destroy animal life. It is even a matter of time only for an ocean like the one of our own period to provide Pecillopora and Heteropora corals with their copper, or to be the means of metamorphosis of carbon-deposits into copper-sulphides in part; the percentage of copper in these deposits being in general not above three per cent. of the deposits as a whole.

I find a further justification for stating these facts and the conclusions to which they lead in the circumstance that the learned author, although mentioning the occurrence of graphite in crystalline schists, does not mention that this graphite anywhere accounts for the origin of ore-beds.

The description of the Sudbury ore-beds deals with a case far more complicated than those considered by me, because there Huronian strata similar to those met at the different mines in the Appalachians have been disturbed by more recent dioritic eruptions, which subjected the pre-existing ore-beds to a new partial or second metamorphosis, by which the true state of affairs is very materially obscured, misleading the describers into the untenable assumptions, so justly controverted by the learned author. Had he been informed of the facts, as I have described them above, the author of this eminently interesting and progressive essay on the genesis of ore-deposits would have been able to knock the last crutch from under the theory of an eruptive origin of the ore-deposits at Sudbury and elsewhere in the crystalline rocks of the Huronian period.

I take this opportunity to furnish, on another point, information for which Prof. Posepny apparently calls (p. 132).

A few months only after my report on the Nacimiento copper-occurrence was published, with the consent of those interested, in the *Engineering and Mining Journal*, Aug. 7 and 14, 1880, the United States surveyors, who were commissioned by the Surveyor-General of New Mexico to survey the twenty-one mining claims described by me, were driven off these claims by a numerous band of jumpers, who had swarmed into those parts as the usual *avant-garde*, indicating, as stormbirds the storm, the approach of a new railroad line in those remote parts. To reinstate the legitimate owners either brutal force or litigation had to be employed. The ill-success of other copper-enterprises in New Mexico, though quite foreign to all natural conditions, caused them to resort to neither. When, in 1891, I again visited the upper Rio Grande valley, I found on the platform of the railroad-station at Bernalillo, N. M., about a car-load of the precise cuprified palm-vegetation formerly described by me, showing that there had survived some activity at Nacimiento; but, as stated in my first report, profitable operations are possible only on a scale like that on which lead is obtained from a similar sand-rock at Mechernich in Rhenish Prussia.

Discussion at the Virginia Beach Meeting, February, 1894, Including Communications Subsequently Received.

T. A. Rickard, Denver, Colorado (communication to the Secretary): The paper of Professor Posepny was printed so short a time before the Chicago meeting that it could not receive at that meeting the thorough discussion, based upon careful study, which its great importance and value deserved. In the remarks which I made on that occasion, I could do little more than express, with others, our thanks to the distinguished author for this admirable treatise on a subject of such general and permanent interest. Further examination of it has confirmed the opinion that its appearance marks an epoch, particularly in this country, in the study of ore-deposits and their origin, and has led me to feel that our appreciation of it will be best expressed in aiding its purpose and widening its usefulness by the free contribution of facts and interchange of views which it invites.

I have, elsewhere,* expressed some dissatisfaction with the new names introduced in this paper; and it has seemed to me, also, that the classification of ore-deposits, which it proposes, is unnecessarily complicated. From the stand-point of a mining engineer, we have had, in my judgment, no classification more practical and sensible than that suggested by Dr. Raymond, twenty-five years ago (outlined on page 7 of Professor Posepny's paper). If any modification of it be permissible, I would suggest the following:

---

* *Eng. and Min. Jour.*

- I. Surface-Deposits.
    - A. Due to mechanical agencies.
    - B. Due to chemical agencies.
- II. Inclosed Deposits.
    - A. Bedded.
        - *a.* Contemporaneous, in origin, with country-rock.
        - *b.* Subsequent, in origin, to country-rock.
    - B. Not bedded.
        - *a.* Due to dislocation.
        - *b.* Due to impregnation.

Surface-deposits have no regular form, and are, therefore, distinguished primarily by their origin. Class A would be typified by gold-bearing placers, and Class B by deposits of bog iron-ores.

When we come to inclosed deposits, we find an extreme complexity; but, we readily recognize that some are conformable to the bedding of the country-rock, while others are independent of it. We can further distinguish those which are of contemporaneous origin, such as the coal-beds, from those which were formed after the deposition of the country-rock. To this class belong ore-deposits which have replaced beds of limestone; and another pretty example is afforded by the Bendigo saddle-reefs, which are conformable to the anticlinal curves of the country-rock, but were clearly formed after both the original sedimentation and the subsequent folding.

Among the non-bedded deposits there is no limit to diversity of structure and of origin. We recognize, however, that the fissure-veins which cut across the bedding, but retain a definite position due to their formation along lines of original dislocation, may be distinguished from the irregular impregnations, due as much to the chemical composition of the country-rock as to its structure. These two types, however, are forever intermingled. It is seldom, indeed, that an ore-deposit has not some features, however faint, of form and structure dependent upon those of the country-rock, while, on the other hand, it is not often that a fissure-vein is found which does not exhibit, in places, a lack of definition, due to metamorphic action upon its inclosing walls.

In the discussion of the origin of fissures, Prof. Posepny has touched upon a point which has been the subject of frequent debate. I fully believe that dislocation accompanies the formation of a fissure, and that a movement of its walls is often evinced by slickensides and striæ. Yet, this has been questioned by one or two members of the Institute who are known to be both accurate and experienced observers. The question at issue is a vital one, if we desire to obtain a clear idea of the mode of formation of mineral veins. It has been denied that the striæ and slickensides observed upon the walls of lodes necessarily prove that movement has taken place; but it has never been clearly shown what other agency did form them. Prof. John A. Church has discussed this matter in a most interesting way,* and has pointed out that slickensides may be formed, not only by rubbing but also by "deformation, as when a plastic substance like clay is forced through an opening," and again by deposition in fine parallel lines. Recently, Prof. Daubrée has experimentally proved that gases under high pressure are capable of producing striæ upon rock-surfaces.† It is true that a distinction is made between striæ and slickensides, but I look upon the two as the work of the same agency. In the former case we have coarse rubbing due to large particles, and in the latter, fine polishing due to minute particles. There is no doubt, however, that certain structures are called striæ, which are to be ascribed to causes other than those usually supposed to produce striæ and slickensides. As I write I have before me a large piece of rock, the surface of which exhibits fine parallel lines, which, at the mine (the Hillside, in Yavapai county, Arizona), were called striæ. The rock was part of the casing of a cavity found in the hanging-wall of the lode, which traversed a quartzose talc-schist. Its surface has been covered‡ by a series of siliceous coatings, doubtless deposited by the mineral-bearing waters which circulated over it. The precipitation took place along certain parallel lines, probably marking the direction of flow of the circulating waters, and the resulting appearance is to be regarded as a pretty example of a variety

---

* *Eng. and Min. Jour.*, April 30, June 11 and 18, 1892.

† *Bull. Soc. Géol. de France*, 3 serie, Feb., 1891, t. xix., p. 313. *Comp. rend. Acad.*, t. cxi., séances du 24 Nov. et 4 Dec., 1890. *Compt. rend. Acad.*, t. cxii., séance du 19 Jan., 1891.

‡ As shown by viewing the broken edges of specimens.

of crustification, but, coming as it does from a lenticular hole, cannot have been due to rubbing caused by faulting.

In the accompanying drawing (Fig. 1), reproduced from a sketch made underground, the cavity above referred to is marked A. There are two others, B and F, of the same kind. D is a seam 6 inches thick, of white talcose gouge, lining the foot-wall, and separating it from C, which is the lode itself.

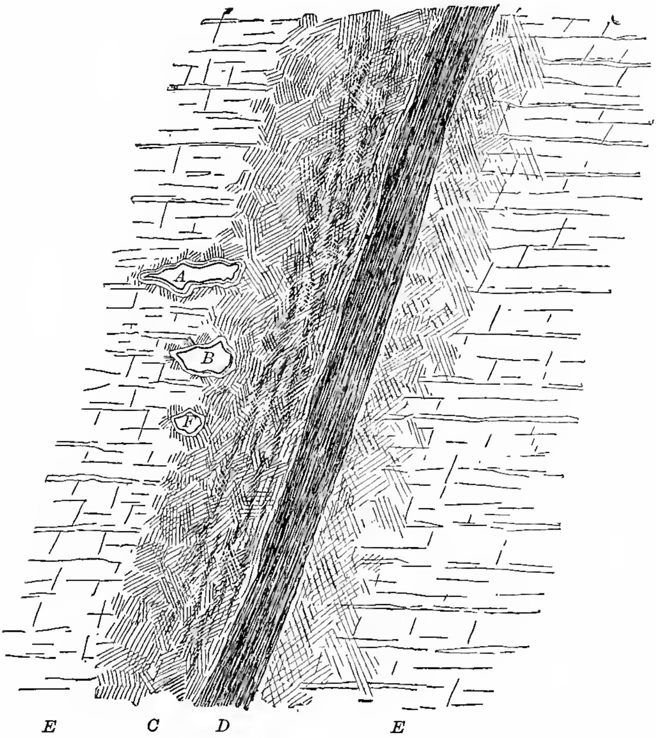


Fig. 1
HILLSIDE MINE, ARIZONA

The latter is 15 to 18 inches wide, and consists of quartz, iron-pyrites, zinc-blende, and a little galena, very much intermingled, and carrying gold and silver in almost equal proportions. The lode itself reproduces to a noticeable extent the structure of the country-rock which it has replaced. The cavities in the hanging-wall are also surrounded by talc-schist, which is mineralized to such a degree as to constitute "low-grade ore." The vein cuts clear through the foliation, nearly horizontal, of the talc-schist, and the alteration of the country-rock, while most marked in C, extends to a varying distance on either side.

Not infrequently the quartz of a lode has striated markings which are but the negative of those occurring on the wall-rock.* In such cases the quartz is sometimes entirely solid and unbroken, suggesting that it was deposited upon the previously striated surface, and that it has not only replaced the substance but also reproduced the structure of the rock once inclosed by the fissure-walls. On the other hand, one instance may be cited where it seems necessary to suppose that movement took place subsequently to the deposition of the quartz. At the 1800-foot level in the Great Extended Hustler's mine† at Bendigo, Australia, the quartz lying against the hanging-wall of the reef exhibited a surface as smooth as polished ivory, but distinctly grooved, and also marked with fine, dark lines, parallel to the grooves. The latter had, I believe, an origin similar to that of ordinary striæ, while the dark lines were due to the grinding of particles of pyrite observable in the quartz. Though this quartz seemed to the eye as hard as adamant, it would readily crumble away when pressed between the fingers. It had been crushed to the consistency of common table-salt, which, save for the presence of occasional crystals of pyrite, and for its highly polished surface, it much resembled.

Objection has been raised to accepting the occurrence of clay, striæ and slickensides as necessary evidence of faulting, because they are occasionally absent where movement may be supposed to have taken place. In such instances, it is reasonable to infer that they have been destroyed by agencies identical with those to which the lode-formation is due, namely, the replacement of country-rock, often in a crushed and shattered condition, by ore, through the metamorphic action of percolating solutions.

There is a fanciful notion current among miners that a smooth wall and a thick gouge are the necessary adjuncts of a productive " true fissure-vein." Experience does not confirm this belief. A defined wall and a soft seam of clay are natu-

---

* Instances of such are to be seen in the gold-quartz veins of California.

† See *Trans.*, vol. xx., 512, *et seq.*

rally welcome to the miner, because they facilitate the actual breaking down of the vein-stuff; but they are no more characteristic of productive than of barren lodes.

The irregularity in the dip of some veins has been cited as disproving the possibility of their formation along lines of faulting. Occasionally mine-workings show that the dip of a vein is reversed; and the formation of the fracture which it occupies cannot be referred to a continuous line of movement, because that would have involved the shearing-off of the opposing angle. But it is not necessary to suppose, nor do facts suggest, that lodes are generally formed along continuous or single lines of movement. As Prof. Posepny has well shown, it is the study of the circulation of underground waters which affords the key to much that is perplexing in ore-deposition. In such cases as are here referred to, it is rational to suppose that the mineralizing solutions searched out the easiest way which offered itself. They did not necessarily percolate along a single definite straight line of fissuring, but often deviated from it, whenever it afforded a less ready passage than was offered by other fractures which united with it or crossed it. An instance which occurs to me as I write, is furnished by the Seven-Thirty mine at Silver Plume, Colorado. The lode consists of a system of veins carrying rich silver-ore, the most productive of which is that which bears the name of the mine. It rarely has any considerable width ; it is often only a thread traversing the coarsely crystalline granitoid gneiss and porphyritic microcline granite of the region. At the third level, about 280 feet from the surface, there is a very marked irregularity in the course of the vein, presenting some interesting features, which the accompanying sketch (Fig. 2) will help to explain.

From the shaft eastward for several hundred feet (A to B) the vein carries ore; but its width is small and irregular. The lode widens rapidly at B, where it also meets with a sudden deviation in its course. At a first glance, this looks very much like a fault, but subsequent examination will correct such a view. The fissure continues in a straight line from K to L, after the ore has swerved to the south. Instead of maintaining its eastward course, the ore is disposed in two cross-veins, CD and EF, nearly at right angles with that course, which unite with a fissure, MQ, similar in character and parallel in strike to that from which they sprung, AL. Both AL and MQ are continuous so far as they have been followed in the mine-workings. The walls are well-marked, even after they cease to enclose ore. The cross-veins CD and EF lack well-defined boundaries. The western branch, CD, is a streak, about 3 inches wide, carrying ore of a tenor of 300 ounces of silver per ton, while the eastern branch, EF, is larger, about 1 foot wide, and carries ore of lower grade, about 100 ounces per ton. The latter is accompanied by much more galena than the former. The distance between the two is 10 feet; their length is 44 feet. The country separating them is not noticeably altered or mineralized.

This is not an instance of faulting; the ore is found in connection with a system of fractures AB, CD, EF and MQ, the varied structure and arrangement of which modified the circulation of mineralizing solutions, and so brought about the irregularity in the deposition of the various minerals comprising the ore. The mineralizing waters met with diverse conditions. From A to B the fissure was tight, and its boundaries were distinct, limiting the circulation to a narrow channel; hence a small streak of ore was found. At B the shattering of the country-rock accompanying the formation of the cross-fractures, CD and EF, offered facilities for the ready penetration of the solutions and for chemical interchanges. From C to D and from E to F the irregular fracture across the foliation of the country-rock produced irregular but rich streaks of ore. On meeting with the other main line of fissure the solutions again found well-defined boundaries which put a check to the metamorphic replacement of the country-rock, and it was not

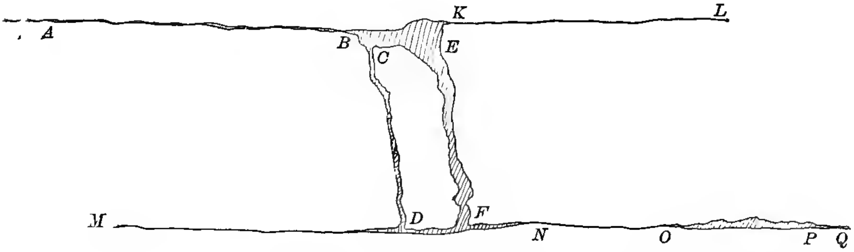


Fig. 2
SEVEN THIRTY MINE, COLORADO.

till the conditions changed (at O), that a notable width of ore was again deposited.

Many supposed faults found in mine-workings are really of this character. There has been a deviation in the course, and a marked diminution or increase in the amount of ore-deposition, because the mineralizing solutions have circulated along those fractures which presented the easiest passage and offered the conditions most favorable to chemical interchanges.

Returning to the subject of striæ, slickensides and clay-seams, I must say, that while the questioning of accepted theories is wholesome, and the views quoted above deserve respectful consideration, it seems to me that observed facts warrant the general belief that these phenomena have usually been produced by the rubbing of two faces of rock which have undergone movement; and I do not sympathize with those who consider that the ordinary explanation is far-fetched. We know that the rock-formations of the upper earth have undergone movement, for this is proved by all geological investigation. Further, we have every reason to believe that movement among beds of rock of unequal flexibility must cause some to break. Facts confirm such a belief. Again, every break must be coincident with a movement: for a fracture can hardly be said to exist until made evident by movement however slight. At any rate a fracture unaccompanied by movement would not give the relief required by a series of beds exposed to such strain as necessitated a rupture. Such movement must be accompanied by friction, due to the tendency to smooth down the irregularities of the two opposing rock-faces. Where movement has once occurred, a line of less resistance is established, and a repetition of movement is likely. The result is to break small particles from off projecting points and so form a dust which water makes into mud or clay, also to scratch the surfaces in contact, forming striæ, and to polish them, forming slickensides. Why therefore deny the probability, even the necessity, of the movement of the walls of a fissure, and why endeavor to give to the markings of rocks underground an origin other than the one which would certainly be ascribed to them if they were found on rocks* at the surface?

---

* No one questions, for instance, that the scratching seen on boulders from a glacial moraine are the result of rubbing due to movement.

The pages which Prof. Posepny devotes to an inquiry into the conditions governing the flow of underground waters are among the most valuable of his treatise. His explanations will do much to clarify our conceptions of the mode of behavior of underground waters, and will doubtless suggest further inquiry in the same direction. The word "circulation" is the key to the whole matter. There has been a tendency to speak of descending, lateral and ascending currents, as though the one adjective would cover the manner of movement of all mineral solutions. An ascending flow was supposed to have formed this lode, descending that one, while others again, steering a middle course, have imagined that ore-formations derived their origin from solutions having a lateral flow. In each case a narrow view of the subject is both unphilosophic and unscientific; it has too often been the obstacle to progress in this branch of geology. One great fact confronts us, and that is circulation.

The distinguished author is himself carried away by his prejudices, and in the latter portions of his treatise* allows his ascensionist views to lead him too far and in part to forget the very forcible teaching given in the earlier pages. Much will be done to explain the many puzzling and apparently contradictory features exhibited by the ore-deposits of different regions if we remember that mineral solutions both descend and ascend, that occasionally they may have an approximately lateral flow, and that in each instance their circulation is governed by a diversity of ever-changing conditions.

Water must first descend in order to afterwards ascend. The known density of the earth precludes the supposition that its interior contains any reservoirs of water; the sinking of deep wells and bore-holes has indicated that at a comparatively short distance from daylight the temperature is so high that water could not exist as such, but would be dissociated into its constituent gases; while actual mining exploration has shown that in the deepest mines there is less water encountered in depth than in proximity to the surface. These facts all confirm the every-day observation that underground waters originate from the rain and snow precipitated from the atmosphere.

---

* As on page 57.

We may compare the circulation of water up and down, through the earth's rocky exterior, to that of the ordinary heater in a house. The water circulates because, when hot, it rises through the length of pipe, and, when cool, it falls back to be reheated. Using this analogy to explain Nature's operations, we have at one end the condensation and precipitation of moisture due to a fall of temperature, while at the other, and deep down in the earth's rocky confines, we have a heat which sends the water back to the surface. In this matter of ore-deposition we are not concerned with the two ends of the circuit. We have no particular interest for the moment in that part of the water-circulation which intervenes between its elevation by evaporation from the earth's surface and its return as rain; nor, on the other hand, can we see what goes on at the other end of the circuit. We can only guess what conditions obtain and what phenomena occur at depths inaccessible to man. All our investigations must concern themselves with the intermediate stage, that stage which is most particularly marked by the transition from higher to lower temperatures, and, inversely, from increasing to diminishing pressures. It is the nice adjustment of these conditions which, on the one hand, favors precipitation, and, on the other, compels solution. To the miner, therefore, it may appear most important to investigate those factors which bring about precipitation, because to them must be ascribed the immediate agency of ore-deposition. It would simplify his ideas if he could speak of an upper zone of precipitation, where the temperature is low and the pressure light, in contradistinction to a lower region of solution, where the heat is great and the pressure intense. Such attempts to separate the locality of the two processes, however, must not be carried too far. Precipitation has no sooner ceased than solution begins. It is the excess of the one over the other which causes the deposition of ore in one place and its removal to another. Similarly, in our talk of "primary" and "secondary" deposits of ore, while some such distinction may be necessary for the purpose of explaining differences of immediate origin, we must not fail to recognize that all the ore-deposits within the ken of man are essentially secondary. There has been nothing original since the world was first evolved from chaos. We have to deal with a continuous rearrangement of material.

The ore of one place came thither by removal from another. Whether it be present in minute microscopic particles or in blocks as big as a house, is a distinction more economic and commercial than scientific and philosophic. The decomposition of one mineral is required for the composition of another. Ore-deposits are in their nature concentrations, whether by the mechanical accumulation of disintegrated fragments of older deposits or by the local regathering or segregation by chemical agencies of minerals previously widely and minutely disseminated, or finally by the addition, bit by bit, through mechanical and chemical force, of the matter brought from above or below by circulating waters.

The frequent occurrence of thermal springs in the neighborhood of later eruptive rocks is very properly emphasized by Prof. Posepny, and is of immediate importance to the student of ore-deposition because the eruptive rocks are in turn found so often in close association with lode-formations. That thermal springs, eruptive rocks and ore-deposits are intimately inter-related in their origin is generally accepted. In this connection I may be permitted to contribute some additional facts.

Besides the localities quoted by Prof. Posepny, I would mention the Hauraki or Thames gold-field, in the North Island of New Zealand, where a good opportunity is offered for the study of this subject. In the Coromandel peninsula of the North Island there is a gold-bearing belt extending for nearly a hundred miles, from Cape Colville to Te Aroha. The prevailing country-rock consists of Tertiary eruptives, through which patches of Carboniferous slate occasionally appear. There are thermal springs scattered throughout the region. At the principal mining center, the Thames, the escape of carbonic acid gas has often caused a temporary cessation of work in the mines. There are soda-water springs in the vicinity of the Thames. At Te Aroha, at one end of the gold-belt, there is a group of celebrated medicinal hot springs. This last locality is connected by a continuous chain of thermal springs with Rotomahana, about 45 miles distant, the famous hot-lake region, the pink and white sinter-terraces of which were known for their beauty throughout the world until Mt. Tarawera broke out in sudden eruption and destroyed them in 1884.

Veins of gold-bearing quartz, recent eruptive rocks, thermal springs, dying solfataric action, and active volcanic force, are all intimately associated in this corner of the world.

At the Thames, the leading mining town of the island, bodies of gold-ore of unusual richness have been found. In 1871, the Caledonia mine produced 10 tons of gold and paid three million dollars in dividends. In 1878, at the Moanataeri, 5400 pounds of quartz yielded 14,600 ounces of gold. The prevailing country-rock is an andesite breccia, traversed by zones of decomposition, in which the gold-veins occur. At Rotorua, in the hot-lake district already referred to, the plain is in part covered with fragmentary andesite. This material is usually loose and unconsolidated. Near the edges of the fumaroles, which are numerous, it has, however, become cemented, and then very much resembles the country-rock of the mines. The rims of the fumaroles also exhibit products of decomposition, which are similar in character to those observed in the lode-channels at the Thames, and which, because they are soft and granular, have been termed "tufaceous sandstone." Quartz closely resembling that of the gold-veins of the mines can also be seen to be deposited around certain of the fumaroles and hot springs referred to above. My examination of the ore-occurrence and vein-structure, though incomplete, led me to conclude that the deposition of the gold and its associated minerals had followed certain lines of altered country-rock which had been exposed to the effects of dying but lingering solfataric agencies.*

Another district which affords evidence to help us in studying this subject is that of Pontgibaud, in south-central France, among those volcanic peaks of Auvergne which have been rendered classic by the work of Poulet Scrope. The silver-lead lodes of this district have been very extensively developed, and their geological structure has more than once received notice at the hands of competent observers.† The country-rock consists of gneiss and mica schist, penetrated by dikes of granulite.‡

---

* See also "Certain Dissimilar Occurrences of Gold-Bearing Quartz," by the writer, in the *Proceedings of the Colorado Scientific Society* for 1893.

† *Annales des Mines*, M. Guényveau, 1st series, t. vii., p. 162 to 188. MM. Rivot and Zeppenfeld, 4th series, t. xviii., p. 137 to 257, 361 to 446. Also recently M. Lodin, April, 1892, in a paper entitled "Etude sur les gites métallifères de Pontgibaud," also published in the *Annales des Mines*.

‡ If it were in our West it would be called "porphyry"—a term which has gradually been losing its distinctive meaning through careless use.

The lodes are of later date than the dikes, but older than the Pliocene flows of basalt which cover their croppings. The period of their formation is considered to have been between the middle Miocene and the middle Pliocene, very probably contemporaneous with the extension of the acid eruptives of Mont Dore, which took place at the beginning of the middle Pliocene. The lodes generally follow the veins of granulite, and are productive only when so associated. When the dike-rock in which the lode occurs is most feldspathic, the metalliferous filling is most valuable.

In this region mineral springs are abundant, and the escape of carbonic acid gas has frequently put a temporary stop to underground work. This applies particularly to that part of the district through which the river Sioule flows between the town of Pontgibaud and the mines at Pranal. Often, while fishing along the stream, I have noted places where there is a constant escape of carbonic acid gas from its bed to the surface. At Pranal there appears to be an intimate connection between the lode-fissures and the volcanic vents. One of the mineral veins has been traced to its connection with what appears to be a vent of the extinct volcano of Chalusset. Powerfully carbonated springs exist close to the mines and on the slope of Chalusset.

In both of the two districts above cited, the one in New Zealand and the other in France, note has been made of the escape of considerable quantities of carbonic acid gas. It is scarcely necessary to emphasize the fact that this is a most common and powerful agent in bringing about changes in rocks and minerals. The action of carbonic acid, and of the alkaline carbonates which it forms, have been recognized by all petrographers. To it we owe the salts occurring in ordinary mineral springs; to it are due the pseudomorphic replacement of feldspar with chlorite*, and the alteration of olivine into serpentine, and of

---

* And the chlorite afterwards gives place to tinstone. This is a subject much studied by Mr. Richard Pearce, at a time when its importance was not so well recognized as now. — See "The Influence of Lodes on Rocks," *Proceedings of the Mining Association of Devon and Cornwall*, September 8, 1864. Mr. Pearce directs attention to the difference between the granite encasing the lode and that found at some distance from it. He makes note of the joints in the granite, and remarks upon the difference in the minerals found in two well-marked systems of joints having contrary directions. He shows that the changes observed in the rock adjoining the lodes have their origin in the lodes. Emphasizing the metamorphism

limestone into dolomite. Even at ordinary temperatures, carbonated waters extract magnesia from complex silicates. In this way, biotite loses magnesia and iron, becoming converted into muscovite.

The subject of the close association of ore-deposits and igneous rocks is a most important one to mining engineers. The detailed geological surveys of several of the most productive mining districts of the West, carried out during the past few years, have done much to emphasize the relation which seems to exist between bodies of eruptive rocks and deposits of gold- and silver-ore found close to them. It has become the fashion, especially since the publication of Emmons's masterly monograph on the Leadville region, to suppose that the precious metals of the lodes were derived from the leaching of the adjacent eruptives; and some mining engineers have gone so far as to consider the neighborhood of dikes necessary to the occurrence of a productive lode. This latter notion may be classed with the supposition, now slowly passing away, which, not long ago, was so strong, that a "true fissure-vein" was the only permanent depository of the precious metals.

In the United States, in Europe, and in most of the Australasian mining regions, the close association of dikes, or other forms of intrusive eruptive rocks, with lode-formations is so marked, that it is not surprising to find such rocks considered as necessary adjuncts to the occurrence of valuable ore-deposits. But generalizations are proverbially dangerous; and, that this is an illustration of the proverb, the following facts may show.

The gold-mining region of the province of Otago, in the South Island of New Zealand, is confined, for the most part, to a great series of foliated quartzose schists of an age considered Archæan by some,* and Silurian by others.† These rocks have

---

of the granite, he shows that the lodes consist essentially of altered granite, the most important alteration being the replacement of the feldspar by chlorite, by tinstone and by schorl. He discards the idea of an igneous origin of the tin-ore, and declares that aqueous agency alone can satisfactorily account for the changes in the rocks and the formation of the lodes. He expresses the belief that the subject of the metamorphism of the country-rock, if "diligently investigated, must assist in explaining some of the laws which regulate mineral deposits." This was said thirty years ago!

[*] "On the Foliated Rocks of Otago," Professor F. W. Hutton, F.G.S. *Trans. of the New Zealand Institute*, vol. xxiv., 1891.

[†] "The Gold-Fields of Otago." *Trans. A. I. M. E.*, xxi., 412.

an enormous thickness over a large area; the thickness has been estimated at 50,000 feet, while the area is fully 10,000 square miles. This has been a very successful gold-mining region, although the gravel-deposits have, so far, been more productive than the quartz-veins. The lodes have certain well-marked structural peculiarities, resulting from the foliated arrangement of the country-rock which they traverse. In a previous contribution, incidental reference was made* to the fact of the remarkable absence, in this auriferous area, of eruptive rocks. It is interesting to recall so marked an exception to what is often held to be a general rule.

That the quartzose schists of Otago are simply altered sedimentary beds of very early geological age, there is little reason to doubt. The quartz folia are arranged along the lines of original sedimentation, and not along cleavage-planes. It is a case of "stratification-foliation," as distinguished from "cleavage-foliation."† The only rock likely to be a metamorphosed eruptive is the chlorite schist of Queenstown.‡ The mining regions of Otago do not exhibit any of the phenomena of contact-metamorphism; and the changes which have been produced may be ascribed to what we call "regional" metamorphism, a vague way of describing those alterations which are forever taking place in rocks wherever there is heat and pressure, alterations which are, therefore, most evidenced by the oldest rocks, which have necessarily been overlaid by a great thickness of later-deposited formations.§

A treatise which covers so wide a field as that of Professor Posepny can, of necessity, devote but scanty attention to some mining regions which, to those who know them, appear to afford important evidence on the subject of ore-deposition. In this regard, it is to be regretted that Professor Posepny does not seem to have had his attention drawn to certain very excellent geological reports contained in the blue books of the

---

* *Trans.*, xxi., 413.

† Prof. T. G. Bonney uses these terms in the *Quarterly Journal of the Geological Society*, vol. xlix., part i., p. 95.

‡ As pointed out by Prof. Hutton. *Op. cit.*

§ I do not lose sight of the fact that igneous rocks may become schistose by metamorphism, especially through pressure, as a dolerite becomes a hornblende schist. There is no reason to suppose that such a metamorphism has occurred in these rocks of Otago.

mining departments of Victoria, New South Wales, and New Zealand. Australasia has many object-lessons to offer to the student of economic geology, and the Colonial geological surveys have published several accurate and most interesting descriptions of them.*

In concluding this contribution to the discussion of Prof. Posepny's paper, I may be permitted to express again the belief that his destructive criticism of the lateral-secretion theory is most opportune, and that his investigations into the flow of underground waters will do much to illuminate our views of the methods of ore-deposition. At the same time, I cannot but hold that his accumulation of facts and observations will show that neither the lateral, nor the ascensionist, nor any other one narrow theory can cover the multitudinous diversity of the ways in which ore-deposits are found to occur.

R. W. Raymond, New York City: Concerning Mr. Rickard's proposed classification, I beg to say, while recognizing its convenience for mining engineers, that it cannot be considered as a substitute for that of Prof. Posepny, for the simple but conclusive reason that it is not genetic. Its fundamental division is based upon the position of the deposits, which should be, in a genetic classification, a subordinate consideration; and the most profound genetic distinction presented by nature, namely, the distinction between contemporaneous and subsequent formation, appears in this scheme as a division of the third degree, affecting only inclosed bedded deposits. If I were inclined to criticize names, as Mr. Rickard has elsewhere done with regard to Prof. Posepny, I might point out that the word "contemporaneous" does not describe coal-beds, which Mr. Rickard mentions as typical examples of it. Whatever may be said of a coal-bed, it is not contemporaneous in origin with the country-rock above it or below it. But this is a small matter. The point I make is much more important, namely, that the classi-

---

* I would more particularly instance *The Geology of the Vegetable Creek Tin-Mining Field,* by T. W. Edgworth David, and the recently published *Special Report on the Bendigo Gold-Field,* by E. J. Dunn, together with the numerous observations made by R. L. Jack, in Queensland; H. Y. L. Brown, and H. P. Woodward, in South Australia; G. H. F. Ulrich, and F. W. Hutton, in New Zealand; Wilkinson and Liversedge, in New South Wales; Murray, Sterling, and Howitt, in Victoria.

fication itself is neither based on genetic distinctions nor on any other logical arrangement. I say this all the more frankly, because, as Mr. Rickard declares in complimentary phrase, he has largely followed the classification given by me in 1869. But that was, as Mr. Rickard's is, merely a convenient miners' arrangement. Now that Prof. Posepny comes forward, proposing for the purposes of science, not of mining, a truly genetic classification, a critic may fairly demonstrate its logical defects and suggest remedies, or declare remedies to be impossible. In the latter case, his contention would be that a genetic system cannot be constructed, and that the attempt had better be abandoned. But to say that one prefers, as a mining engineer, the handy non-scientific arrangement of ore-deposits hitherto in use, is no criticism at all. It is as if a botanist, considering a natural system in botany, should say that it was discouragingly complicated, and that he preferred the simple and convenient arrangement of Linnæus, by which one could identify a species from the number of petals and stamens and other arbitrary signs.

H. V. Winchell, Minneapolis, Minn.: While heartily agreeing with the frequently-expressed opinion that Prof. Posepny's paper is a masterly and exceedingly important discussion of ore-deposits, it still appears that there may be room for differences of opinion on some points. Indeed, they necessarily follow from such decided statements on so important and interesting a subject.

Those of us who live in the Lake Superior region are wont to believe that we have some conception of the meaning of the term "ore-deposits." We can, and frequently do, point with pride to the great value of our production of iron-ore and the fact that we furnish nearly two-thirds of the total product of the United States. It is an industry employing about 30,000 miners and involving capital to the amount of fully $100,000,000. But when we come to treatises on iron-ore deposits we are always disappointed. We find that, while speaking generally and theoretically, iron-ore deposits may be mentioned, yet when it comes to critical discussion, and the illustration of theories by examples, they are omitted. We are constrained to protest that "ore-deposit" does not signify merely a vein of gold-, silver- or lead-ore or a stockwork of tin- or zinc-ore, but that hematite and magnetite form ore-deposits of a commercially important and genetically highly interesting class.

The value of the raw iron-ore produced in this country in 1889 was equal to the value of the gold bullion produced in the same year. And if we take the value of the pig-iron, which more nearly corresponds with bullion in the degree of removal from the raw material, we find it equal to the value of the gold and silver combined. And yet our author dismisses the entire subject in a couple of pages, and of Fuchs's and DeLaunay's 2000 pages only two are devoted to the most important iron-ore district on the globe.

It would not be fair to suggest that iron-ores are overlooked because they do not seem to be explainable by the theories adopted for other classes of deposits. If that were the case, all the more need of giving them attention. It is more probable that it is because of the recentness of their development and the comparatively scant literature on the subject in the libraries of our foreign colleagues.

That the circulation of waters carrying different chemical reagents is the all-important factor in the genesis of ores, as we find and mine them, is clearly shown by Prof. Posepny, and is accepted by the majority of writers on the subject. But the prominence which is given to ascending waters and the insignificant effects ascribed to descending solutions will not find such ready acquiescence. It seems likely that ascending waters are the more likely to be effective and to predominate below the ground-water level than in the vadose circulation. But it can be conclusively demonstrated that many of the immense iron-ore lenses of the Lake Superior region owe their present state of concentration, even to the depth of many hundreds of feet, to the action of the descending waters. Aside from the Mesabi range, the proofs lie partly in the following well-known facts:

1. The ore is a product of concentration *in situ*, whether the original rock or lean ore was an oxide, a silicate, or a carbonate, or whether it was oceanically or otherwise precipitated.

2. The ore-bodies have the shape of highly-inclined lenses, and frequently have an unaltered "capping" of jasper partially covering their upper ends.

3. When this capping is present, it can be traced downward into the ore through changes which are clearly the result of oxygenated atmospheric waters.

4. The downward course of the waters is further shown by the protecting action of dikes and other impervious barriers, below which the ore is not found.

5. The ore-lenses lie in basins of greenstone-schists or other rocks, and occur at various depths to at least 2000 feet.

6. At the lower edges of some of these lenses are found deposits of silica, kaolin, etc., which have plainly been removed from the ore-body above in the process of concentration.

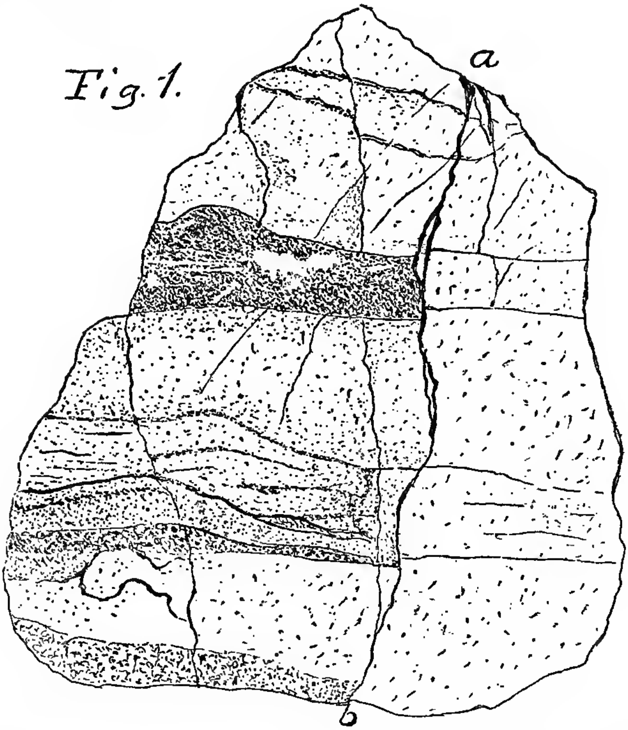
This is much below the vadose circulation, as the immense pumping engines and the rivers of water which they throw the year round testify; but it is an instance of the formation of ore-deposits on the largest scale by descending waters.

The circumstances are somewhat different on the Mesabi range, but the proof is no less clear that the ore has been formed by solutions percolating downward. There the mines lie along the south side of the continental divide or water-shed, from which waters flow north to Hudson Bay and south to the Gulf of Mexico. They thus occupy the highest regions of the northern part of the State. Moreover, the shape of the strata, and the presence of a conglomerate beneath them, indicate that there was a shore-line there when the rocks were deposited. These facts, with the comparatively undisturbed condition of the strata, lead us to believe that the conditions have remained during many geological ages as they were originally and as they are now, viz., such that the inevitable direction of water-circulation would be downward and following to a certain extent the gentle dip of the rocks to the south.

Although of remarkable magnitude and chemical purity, these deposits are essentially surface-products and are at present largely above the ground-water level. The processes of replacement by the removal of silica, and of concentration by the addition of sesquioxide of iron, can be seen in progress in a hundred places. The rock which undergoes this change is a gray, reddish or greenish chert ("taconite") banded with iron-ore. Figs. 1 and 2, taken from specimens from the Mesabi, illustrate the change mentioned, and show the downward course of the ferruginous solutions.

Since we have here examples of iron-ore deposits, both above and below the ground-water level, which have been formed by descending waters, the thought naturally arises that the solutions may not have been so universally ascending, in the case of other mineral deposits, as our author would have us believe.

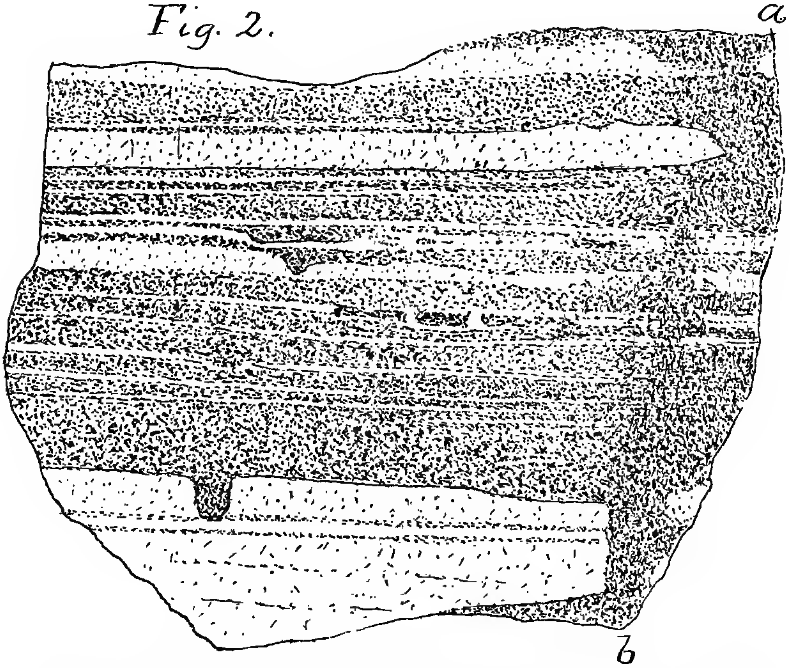
Fig. 1.



Taconite from the Mesabi range changing to iron-ore by solutions moving from left to right. *a b* is a fault line which conducted the descending waters downward and prevented the right half of the specimen from undergoing the ferrification which is seen in the left half.

Another idea on which undue stress seems to have been laid is the correctness of the "ascension theory," and the absolute error of that of "lateral secretion." A consideration of these two ideas leaves me with the impression that they are not in reality so diametrically opposite that if one is true the other can have no scintilla of truth in it. In the deep region the circulating waters are supposed to be under considerable pressure, from which they escape by flowing in the direction in which they meet the least resistance. Even if the solution were on the whole ascending, still it must often happen that cracks and fissures would be encountered, leading in a lateral direction into some main fissure, full of ascending waters under slightly less pressure than that behind the waters which entered laterally. In that case it is also quite likely that there would be a different chemical reaction at or near the junction of these two circulating fluids from that produced by the action of either one of them on the rocks through which it passed. This might result in the precipitation of certain minerals on the walls of the main fissure near the subsidiary fissure, and thus the resulting ore-deposit would owe fully as much to lateral secretion as to ascension. And if these lateral joints and cracks (or even more porous rocks) were sufficiently numerous, the whole

Fig. 2.



Another instance of partial alteration of taconite to ore. There was a joint here along *a b* whence downward moving waters effected a more rapid change for some distance laterally than the solutions percolating toward this joint along the strata from left to right were able to produce in the solid rock. Specimen collected by J. E. Spurr.

vein, when formed, would be due to the combined actions of lateral secretion and ascension.

Moreover, it seems almost necessary for the ascensionists to borrow aid from the lateral secretionists, whether they will or no. For the question arises: Where do the ascending solutions come from, anyhow? Is there an inexhaustible reservoir at the bottom of each vein-fissure which supplies a ceaseless flow of carbonated and mineralized waters carrying precious metals in solution? Or does the water start from the surface and percolate downward until it is forced by heat and generated gases to rise again? If the latter is the true supposition, is it not evident that the fissures which conduct these ascending waters must receive them from all sides through a thousand small crevices and pores, thus making again a combination of both lateral and ascending motions and depositions?

If ascending waters come from a great depth, descending waters must reach to the same great depth, and since the solutions cannot traverse the same path in their ascent that they do in their descent there must be a certain amount of lateral motion at the moment when these solutions are the most dense and carry their heaviest burden of dissolved material. And it is evident that, whatever the depth from which the metallic elements come, there is as much chance for one mode of deposition as for the other.

SECRETARY'S NOTE.—The remaining contributions to the discussion published in this volume were presented at the Bridgeport Meeting, October, 1894, or issued with the papers of that meeting, having been received before the Florida Meeting of March, 1895.

PROF. POSEPNY (communication, translated by the Secretary): First let me express my warmest thanks to all those who have so favorably judged my paper on the "Genesis of Ore-Deposits," and likewise to those who have taken this occasion to bring forward, whether in support of my views or in opposition to them, various observations and opinions, whereby our knowledge of ore-deposits has been unquestionably increased.

It is exceedingly difficult—indeed, almost impossible—to make a correct comprehensive statement of a subject, the separate fundamental data of which are scattered throughout the world; and my treatise must, of course, be considered as merely an attempt in that direction, inspired by the purpose of contributing to this theme an element not yet sufficiently recognized, namely, the logical application throughout of the genetic principle. As I indicated on p. 9 of this volume, I expected as a result neither a simplification of systems nor a direct benefit to practice. My object was, irrespective of such considerations, to approach more nearly to the truth.

A single observer may be able to establish a few more or less important facts; but the great mass of the knowledge required he cannot personally possess. In the most favorable case, government institutions, established to benefit single nations, or scientific or business associations, may procure accurate knowledge of the mineral resources of separate countries, and these may be combined to increase the knowledge of a considerable territorial complex; but the question still remains, whether the developments and natural exposures in a given region are really typical and conclusive as a basis for general scientific deductions. In this respect, an international union of such endeavors, devoted to the advancement of this branch of geology, would be a decisive gain.

When the United States Geological Survey began the study of the geological relations of ore-deposits, there was ground for hope that a new era in the knowledge of this subject would be thereby inaugurated. In fact, several monographs of inestimable value concerning the most important ore-deposits had been published, when, for reasons unknown to me, the whole activity of the survey in this direction was interrupted—an event much to be lamented.

Yet a monograph can give only what is revealed by the developments accessible at the time it is written; and since mining continually makes new exposures, and for the most part obliterates the old ones, a complete scientific inquiry should involve provision for the repeated examination of a given mining district, and for publication, at intervals of, say, five or ten years, of the new knowledge thus acquired.

It is scarcely to be doubted that the investigation of the genetic relations of a thing is necessary to complete our knowledge of it, and that this inquiry is therefore obligatory as a part of the study of anything which we desire to know exhaustively. Dr. Raymond (discussion at the Virginia Beach Meeting, p. 226) has defended the introduction of this principle into the science of ore-deposits, for which I thank him heartily.

Messrs. W. P. Blake and A. Winslow have controverted my views concerning the original source of the lead- and zinc-deposits of Missouri and Wisconsin, condemning at the same time the similar views brought forward at the same Chicago meeting in the paper of Dr. W. P. Jenney. Since I am personally acquainted only through a tourist's journey with the relations of these deposits, which extend over so large a region, and am, moreover, not master of the wide literature of the subject, I must leave the defence of the principles asserted to Dr. Jenney, and will here simply refer to his reply, contained in the present discussion.

With regard to Mr. Winslow's observations, I must confess that I am acquainted neither with the mine at Doe Run nor with the publications of Messrs. Strong and Chamberlin. But I know that concerning every region where lead- and zinc-ores occur in limestone and dolomite, the two opposite theories as to their origin invariably appear; and that in terranes consisting of structural plateaux, with nearly undisturbed position of strata, the representatives of the view that these ores were deposited simultaneously with the country-rock have the great advantage that the conditions of stratification are in their favor.

Besides the paper here in discussion, I have lately devoted to the deposits of lead- and zinc-ores in soluble rocks a special treatise,* in which I have compared the occurrences of such deposits in plateau-regions with the conditions obtaining in mountain regions with already disturbed stratification. This publication originated in an address delivered by me at a miners' congress in Klagenfurt, that is to say, in the center of a mining industry based upon mineral occurrences of this class.

In order to counteract a conception based upon local conditions, I have placed side by side the various alpine occurrences of Carinthia with those of the plateaux of Upper Silesia and North America, illustrating them, according to my custom, with

---

* "Ueber die Entstehung der Blei-und Zinklagerstätten in auflöslichen Gesteinen."—*Jahrb. d. k.k. Bergakademien*, 1893.

drawings of the typical features. Among others, the occurrences in Sardinia and in the North of England are discussed, and use is made of recent literature concerning the Upper Silesian plateau. In this place, I can only remark that some of these occurrences in the mountain terranes carry evident traces of the subsequent derivation of the ores from below; and that this fact alone is an argument for the similar origin of the plateau-deposits, which so closely resemble the former in all other respects.

The treatise I have mentioned does not include the observations made by me in the spring of the present year upon the analogous deposits of Laurium in Greece, which are likewise in a structural plateau; but I can assure the reader that the developments of that region also indicate the derivation of the ores from below.

So far as Mine la Motte is concerned, I can attach no great weight to the observations which I made there, upon a hasty journey. Nevertheless, the specimens of ore disseminated in sandy dolomite which I brought away show distinctly upon the surfaces, after polishing, the secondary intrusion of the ore into the country-rock.

With regard to Mr. T. A. Rickard's criticisms, I would observe that formerly the theories of ascension, descension and lateral secretion were generally spoken of without the assignment of any cause for the assumed movements of the subterraneous liquids. I think, however, that I have secured some definiteness of conception by showing the actual descent of the vadose circulation and the ascent of the deep circulation, and by interpolating the lateral movement between the two. This gives reality to the processes formerly conceived abstractly, and makes it possible to discuss them.

Mr. Rickard observes that, with reference to the formation of ore, I have laid special emphasis upon *ascending* mineral solutions (p. 191 of this volume). I meant to do this, however, only with regard to the sulphides. These certainly were not produced from the *descending* solutions, which carry oxygen now, as they unquestionably did in former geological periods also, and which invariably decompose sulphides wherever (as is the case in the vadose zone) they come into contact with them. With regard to the sense in which I use the terms *ascending* and *descending*, I will say something below.

Mr. Rickard suggests (*loc. cit.*) that, since the increase of pressure and temperature favors solution, while their decrease favors precipitation, precipitated ores are to be expected rather in the shallow zone; and that this might explain the circumstance that (as he believes) ores do not continue in depth. Without going into the latter question in detail, I would point out that the conceptions of shallow and deep are only relative, and that in my discussion I could only have in mind the conditions existing at the time of the formation of the ores, and not at the present time. What was once shallow may now lie very deep, and *vice versa*. In this respect, the character of the ores is, I think, the decisive fact. Oxidized ores must have become such in a zone then shallow, and original sulphides must have been deposited in a zone then deep, and beyond the reach of oxidizing agencies. For the present, only the extreme of these processes can be clearly recognized; but it is not impossible that future studies in this direction may distinguish the characteristics of the intervening stages of formation, such as the deposits made during lateral movements of the mineral solutions.

It would certainly be a step backward to allow the established characters of the two extremes to disappear under the general term "circulation." In my description of the vadose circulation I have pointed out that, notwithstanding its course at the ground-water level appears to be almost horizontal, and notwithstanding an actual ascent of the liquid may be locally brought about by siphon-action, nevertheless a decided prevailing descent can be proved for the vadose currents. The terms "descending," "ascending" and "lateral" are not applied to a portion, but to the whole line of the current; and to its cause, as both theoretically and empirically determined. I cannot admit that this is "a narrow view of the subject," likely to hinder progress in this branch of geology; on the contrary, I believe it expresses a series of observed facts, calculated to increase our knowledge.

Mr. Rickard seems to look at every new conception in this department from the sole standpoint of its immediate usefulness in mining, and not to reflect that the scientific investigator has simply to seek the truth, without regard to such considerations. His criticism might have been more favorable in some particulars (*e.g.*, Virginia Beach Discussion, p. 219, with reference to p. 59 of my paper), if I had taken pains, in many cases in which I was speaking of "ore-deposits," to explain that under this phrase, used for brevity, I was referring to deposits carrying metallic sulphides.

Mr. H. V. Winchell complained, at the Virginia Beach meeting, that under the head of ore-deposits the deposits of iron-ore are too often either meagerly or not at all considered. This complaint would be well founded as against a report on the mineral resources of a given region, in which the economic importance of the deposits is a controlling element; but it is scarcely just in its application to a paper like mine, which was intended only to give single instances in illustration of certain genetic theories. The reason that iron-ore deposits generally receive comparatively little attention in genetic discussion is, I think, the simplicity of their conditions, the knowledge of which is to some extent assumed to be familiar, so that authors interest themselves much more in the discussion of the more complicated occurrences, which have rarely, as a rule, been correctly interpreted.

I am indebted to Mr. Winchell for making good my omission by adding to my paper his account of iron-ore deposits known to him. Since the deposits he cites consist of oxidized ores only, they may well have been formed by an originally vadose circulation. I must, however, point out that some iron-ore deposits may be of idiogenous origin. Thus, I consider the oölitic structure of some deposits (*e.g.*, those of hematite in the Silurian of Central Bohemia) as a sign of their original deposition in the basin. I have had, however, far too little to do with these deposits to be able to determine more closely the significance of the remains of brachiopods (*e.g.*, orthis shells), which occur, transformed into hematite, together with the oölites.

The iron-ore beds of the Silurian basin of Bohemia have a certain analogy with those of the Huronian basin of Michigan, especially as regards the length and continuity of their outcrops, and their connection with tufas of the eruptive rocks. In the latter, as is indicated by the beautiful pseudomorphs of chlorite after garnet, considerable metamorphosis must have taken place.

Concerning the Mesabi iron-ores, I am indebted to this critic for the illustrations of two specimens which he has published. They, indeed, suggest reflections as to their probable genesis, upon which, however, I do not trust myself to venture at this time.

In reply to Mr. Winchell's criticism that, while laying unnecessary emphasis upon the correctness of the ascension-theory, I appear to concede to the theory of lateral secretion not an atom of truth, I beg to observe:

1. That I deem lateral secretion, in the sense in which it is defined by Professor Sandberger, to be possible only in the zone above the ground-water level, and, therefore, in the formation of oxidized ores only, and not for sulphide-ores.

2. That I am, indeed, obliged (as I have shown on page 28) to assume a lateral movement of liquids in the deep zone. But this is a region in which present processes cannot be directly observed, and, therefore, no clues to the conditions of deposition are found. Hence, I was not able to describe such conditions in my paper. It is possible that, in the course of time, conditions of deposition may be discovered which can best be explained in this way. I have not yet encountered such a case.

The same is true as to regions in which the two extreme branches of the subterranean circulation take on a lateral course. The case supposed by Mr. Winchell, in which a deposit can be ascribed to ascension and also to lateral secretion, I do not clearly understand, since a physically weaker current is not capable of displacing a stronger one. While the extreme forms of circulation—that is, both the ascending and descending branches—possess a pronounced character, it must be expected that the character of the branches connecting these extremes will be less distinct.

Mr. John A. Church does not agree with me regarding ore-deposits in open spaces as a very frequent phenomenon, and expresses the opinion that open spaces cannot exist at great depths (such as 3 to 5 kilometers). I must remind him that in order to establish the first proposition the most important observations of a great number of observers for more than a century must be disproved. He cannot have failed to notice that ore-deposits of that form which has been relatively most thoroughly studied, namely, fissure-veins, consist predominantly of separate crusts, often marvellously distinct, covering what were once the walls of the fissure-space. Even if his proposition be confined to deposits of great thickness and extent in depth, which are deemed to have been formed (as, for instance, the Comstock lode, which he has studied) by substitution, replacement or metasomasis, he cannot possibly deny the existence of other thick and deep deposits, the structure of the ores of which evidently represents the filling of open spaces. For instance, some of the Przibram veins, which have been worked to the depth of more than 1100 meters, and the ore of which often exceeds 10 meters in thickness, must certainly be reckoned as wide and deep; yet the ores from their deepest portions do not differ in the least, so far as structure is concerned, from those which occur in the shallower parts. Both regions present fragments of the country-rock of all sizes, surrounded by the vein-material. Moreover, these fragments surrounded by quartz usually predominate in one or the other of the crusts of the vein-filling.

Mr. Church seems to allow small value to the observations which it is possible to make upon the ores themselves and the adjoining country-rock. This is equivalent to the rejection of the only means of obtaining data concerning their probable genesis. It is difficult to discuss such an objection, particularly in its bearing upon the phenomenon of crustification, which I consider one of the most important genetic factors, and concerning which I will speak further in connection with my reply to other critics.

Mr. Church declares the Comstock vein-mass to be the product of substitution—that is, of metasomatic alteration — and denies entirely that it is a fissure-vein. He says I have misunderstood him in saying (p. 92 of this volume) that he found crusts of quartz, alternating with calcite, in the Justice mine. The passage to which I referred was the following:*

> "The ore of the Justice is not quartz but calcite, with but an insignificant amount of silica, and it is noteworthy to find these two components of the lode dispersed in that banded arrangement, which is another of the accepted proofs of a true fissure-vein. The quartz is always on the propylite and the cal-

---

* *The Comstock Lode*, etc., by John A. Church, New York, 1870, p. 173.

cite on the quartz; but there is no comparison in respect to quantity. The quartz is always insignificant in thickness, never reaching a layer more than an inch or two, so far as noticed, except in the dyke-vein, while the calcite forms masses which are several yards in thickness," etc.

Why is this not what I call crustification? It is certainly conceivable that the Comstock was formed by the opening of a space of discission at the contact of diorite and diabase, the filling of this space by the deposition of silica and carbonate of lime from solutions, and the repetition of these processes until the deposit had attained its present thickness. There is, for example, in the collection of the University of Vienna, a large slab from the Adalbert vein at Przibram, showing a series of thin galena-veinlets, the crystals of which meet in the axis of each several veinlet, showing that each was separately filled, and hence that the process of opening and filling, regarded with reference to the Adalbert vein as a whole, was repeated many times, until the aggregate thickness of about one meter, shown by this slab, had been attained. The Comstock might have been formed likewise by repeated opening and filling, only the several fillings would have to be thicker, and (since the material varied little) the result might be too indistinct to attract the attention of the miner.

Mr. Church regards the ore-body of the Justice mine as a deposit separate from the Comstock; but it is, nevertheless, a branch of the Comstock lode, and certainly has an analogous origin.* The occurrence of a crustified portion, which I think the text of Mr. Church's description indicates, possesses, therefore, significance for both branches of the Comstock.

By crustification, however, I do not mean merely a "banded structure." This may indeed originate, as Mr. Church says, in various ways, but crustification cannot; for true crusts are predominantly chemical precipitates, the crystal-aggregates of which present a certain arrangement. For instance, the quartz-crystals usually stand perpendicular to the former cavity-wall, directing their pyramidal surfaces towards the central druse. Incrusted fragments exhibit the same crusts as the cavity-walls, which is, at the same time, an additional proof of the existence of an open space, etc. It is true, that among these chemical

---

* See Becker's *Geology of the Comstock Lode*, p. 30.

precipitates there sometimes occur mechanical sediments, such as frictional detritus, which may be enveloped by one or another of the crust-substances; but this is by no means a case under Mr. Church's statement (p. 198 of this volume):

> "Certainly, a banded structure can arise from the replacement of fragments arranged in layers by pressure and friction, as well as in many other ways, and does not prove deposition in a cavity, whether filled by water or air."

Pressure and friction can give rise to no arrangement of xenogenites in separate crusts; in other words, no crustified quartz and calcite filling, such as I suppose to exist in the Comstock. I possess, for example, besides the ores from the Consolidated Virginia bonanza, mentioned in my paper (page 92), some quartz specimens from the 1500-foot level of the Belcher mine, in which separate dark ore-bearing zones may be distinguished, running parallel with each other, even to the repetition of minute undulations. This is, I confess, not such a convincing case as that of the specimen shown in Fig. 53 of my paper, which exhibits numerous successive crusts of baryte, fluorite, etc., no thicker than paper; or those of the Raibl specimens, which consist of thousands of thin layers of zinc-blende (whence the name *Schalenblende*); but it indicates, at least, the probability of a similar origin. It is, of course, not in every ore-deposit that such incontrovertible proofs as those last mentioned are found and preserved for science.

Mr. Church points out (pages 196 and 197 of this volume) that metasomatic processes effected in limestones through the expulsion of the carbonic acid by a stronger acid, may also explain the exhalations of carbonic acid so frequent in certain localities. I much prefer, however, to avoid the adoption of such a purely speculative standpoint, and would only suggest that, upon that view, the enormous volume of such exhalations in volcanic regions would require us to conclude that in those regions immense masses of limestone are undergoing the metasomatic process referred to.

As regards, finally, the subsequent alteration of the original ore-deposit, which, according to Mr. Church, partially passes into hysteromorphism, it is undoubtedly true that mineralogists, devoted to the study of pseudomorphs, have collected already valuable data in this field; yet, I think, prolonged investigation will still be required before general deductions can be profitably discussed.

Mr. S. F. Emmons, whom I have to thank warmly for his favorable judgment upon several portions of my paper, naturally does not concur in the views I have expressed concerning Prof. Sandberger's lateral-secretion theory, to which he was himself at one time more or less committed.

He objects, for instance, to my reference to the barysphere. This is a part of my conception of our planet as consisting outwardly of several successive, and more or less connected, spherical envelopes—atmosphere, hydrosphere, biosphere, lithosphere, and barysphere—of which only the exterior ones are open to our direct observation. In discussing the mutual reactions of these great geological factors, which we may briefly call aggregate-spheres, it is unavoidably necessary to refer to the barysphere, which is beyond our observation; and, according to my habit, I have used this term in speaking of the source of the heavy metals. It is true, the term is only a device to avoid questions still unsolved; but the same may be said concerning the phrases "unknown depths," or "unknown sources in depth," which have a similar meaning.

It seems to me that Mr. Emmons and others of my critics have not correctly understood my statements concerning the several branches of the underground circulation; and I therefore beg permission to make my meaning clearer, even at the cost of a little repetition. For this purpose I will take for illustration, not an ideal case, but conditions actually existing, namely, those developed at Przibram, concerning which there exists an abundant literature, shortly to be increased (in the second volume of my *Archiv für praktische Geologie*) by a monograph of my own.

The Przibram district lies, in round numbers, about 500 meters above sea-level, and the mine-workings extend, as is well known, to more than that distance below sea-level. The ground-water level is but a few meters under the surface. The deepest adit drains the mines to about 100 meters; and everything below that level is strictly deep workings, from which the water is lifted to the adit-horizon. A comparison of the water raised from different levels shows that the largest quantities come from the upper ones, and that the amounts diminish with increasing depth, so that at about 300 meters below sea-level no water remains to be raised, the ruling rock- and air-temperature of about 23° C. (74° F.) at that depth sufficing to evaporate the small existing quantity of water. This is certainly a striking proof that the water encountered in mining is of atmospheric origin.

The ore-deposits are steeply-dipping fissure-veins, which are mined by reason of their richness in silver (about 5 per cent., or 50 kilos per metric ton—or say 1458 ounces Troy per ton of 2000 pounds avoirdupois). Even in the neighborhood of the surface the sulphides predominated, but were mixed with a great variety of beautiful minerals, which have made Przibram famous among collectors, and most of which, according to the results of the investigations of F. A. Reuss and others, are of secondary origin. It cannot well be doubted that this alteration is due to the oxidizing properties of the liquids coming from the surface. But this variety of minerals is confined at Przibram to the upper zones. Since mining has penetrated to lower levels, its product has been mainly only rich argentiferous galena, with accompanying zinc-blende, etc. The diminution in secondary minerals, so far as it can be determined, seems to follow closely the progressive diminution, in depth, of the quantity of surface-waters.

Concerning the origin of the secondary alterations, there is (as Mr. Church may be pleased to know) no doubt at Przibram. The only question at issue concerns the explanation of the original vein-filling, consisting of sulphides. This must have come, of course, from some rock as a source; and on this point views are at variance.

1. Professor Sandberger at first conceived that this filling came directly from the country-rock (*Nebengestein*). The technical term *Nebengestein* is more definite, perhaps, than "country-rock." It means literally the rock alongside, or the country-rock or wall-rock immediately in contact with the deposit. In this sense, it is impossible to conceive of any other process than that of lateral secretion, which could make the *Nebengestein* the source of the filling; and I have attempted in my paper to show the improbability of such a lateral secretion of such a filling.

2. Mr. Emmons, in his paper on "The Geological Distribu-

tion of the Useful Metals in the United States," read at the Chicago meeting (*Trans.*, xxii., 53), has connected the derivation of the various metals of different deposits with the observed geological conditions of that country, discussing the metals, iron, manganese, nickel, tin, copper, lead and zinc, mercury and gold and silver separately. In his criticism of my views in this field (pages 200 and 201 of this volume), he has taken occasion to express a general statement for all ore-deposition. According to his opinion, the metallic constituents were derived by lateral secretion from rocks within "reasonable proximity;" and "ore-bearing currents may in such cases have had an upward, downward or lateral motion, according to differing local conditions of rock-structure." This latter expression I would like to amend in accordance with the fact that, while the local conditions of rock-structure indeed influence the movements of liquids, the true causes of the upward, downward and lateral motion, as explained in my discussion of this point, lie outside the particular rock-structure.

I would invite Mr. Emmons to take the standpoint sketched on pages 55 and 56 of this volume, in the depths of the Przibram mines, and see how he would get along with his assumption of lateral movement. And I must repeat that it is not so much the local direction of the currents as the general character and cause of the flow which should be kept in view.

The general phenomenon of descending currents in the Przibram mines is clearly subsequent to the formation of the ore-deposits; and the existence of lateral movements of the vadose circulation which could form these deposits is inconceivable. Let us see, then, whether such movements could occur in depth, in the sense defined by me on page 28 of this volume, and quoted by Mr. Emmons.

We should be forced to assume that the open vein-channels had not extended much deeper than the point (500 to 700 meters below sea-level) at which I have invited Mr. Emmons to stand, and also that there was no special upward tendency of the waters filling these channels. A lateral continuous movement would be only possible if there was something "in reasonable proximity" which would consume the moving current, or force it back to the surface. To expect this phenomenon in a terrane already traversed by channels reaching to the surface is irrational. In the only conceivable sense, it would merely make the lateral movement an incidental part of a general upward circulation. But this favors my view of the ascent of mineral solutions from greater depths than have yet been reached in mining, *i.e.*, from "unknown depth," as Mr. Emmons expresses it, or from the barysphere, as I have expressed it. He also, by the way, assumes the origin of the heavy metals from the barysphere (or "from the depths," as he prefers to say), and goes so far as to intimate that I would make the theory more plausible by allying it with that of Vogt, according to which a process of so-called differentiation, during the cooling of the eruptive rocks, has concentrated their metallic contents in certain regions more or less accessible to our observation. For my part, I must wait until Vogt's ideas have assumed a more solid form; but I cannot help suspecting that Mr. Emmons favors them principally because they bring the concentrated metals in eruptive rocks within the reach of lateral secretion, as a forming process for ore-deposits.

Mr. Emmons doubts my conclusion, based upon Nöggerath's observations, that waters rising under pressure are capable of creating a channel for themselves in soluble rocks. In this connection I must refer to the difficulty encountered in explaining the cavities containing pipes of ore in soluble rocks. In my monograph on Résbánya,* published when Nöggerath's work was unknown to me, I was forced to assume, as the cause of the formation of the cavity, the downward vadose currents, and as the cause of the filling, on the other hand, the ascending currents of the deep circulation; in other words, two processes, representing the extremes of circulation, and successively acting along the same line. Such a dilemma may be presented by any ore-deposit in limestone. Indeed, I became acquainted subsequently with instances indicating that the two processes of cavity-forming and cavity-filling may have been sometimes almost simultaneous.† I was greatly pleased when I learned of Nöggerath's observations and deductions, and I

---

* *Geologisch-montanistische Studie der Erzlagerstätten von Rézbánya, in S. Ungarn.* Published by the Hungarian Geol. Soc., Budapest, 1874.

† See my paper in *Jahrb. der k. k. Bergakad.*, 1893, p. 18, "Ueber die Entstehung der Blei- und Zinklagerstätten in auflöslichen Gesteinen," especially Fig. 14, pl. iii.

took pains at that time to acquaint Mr. Emmons by letter with the consequent change in my own views. The observation, as I convinced myself in 1885, cannot now be verified, for the whole place at Burtscheid is completely built over; but Nöggerath was a highly conscientious observer, and there can be no doubt of the correctness of his statement of the facts. Moreover, the phenomenon is, *a priori*, inevitable. If the highly dilute currents of the vadose circulation, descending by gravity, can eat out their own channels in salt or limestone (as is shown at p. 21 and other places in my paper), all the more might such effects be expected from waters ascending under pressure and more highly charged with reagents. Fig. 9 of my paper, showing the wedge-shaped spaces of corrosion described by Daubrée from Bourbonne-les-Bains, with their summits directed upward, gives actual proof of this.

My reference to the wedge-like form of certain deposits at Laurium was based on an ideal profile. In the spring of the present year (1894) I personally visited the district, and strove to secure more accurate drawings of the position and form of the deposits. I must confess that I was not able to find any such drawings, and I must therefore submit to the rebuke of Mr. Emmons. So far as I know the literature concerning the Larium district, the only accurate drawings are those of the French company in the treatise of A. Cambresy.* (I take this opportunity to correct a typographical error in the pamphlet edition of my paper. Fig. 87 was taken, not from Cordella but from Huot.)

With regard to the essential difference of opinion concerning the Leadville deposits, I may observe that the reason I ventured to discuss that district without having personally studied it is to be found in the magnificent monograph of Mr. Emmons, the interesting conditions which it describes, and its contradiction of current views as to the origin of the Leadville ores. Passing by all corrections and criticisms on points of minor importance, I wish only to keep in view this essential difference of opinion, and to inquire what were the convincing reasons which lead Mr. Emmons to assert in this case a descent of the mineral solutions.

---

* "Le Laurium," par A. Cambresy, *Rev. Univ. des Mines*, 3 ser., t. vi., 1889.

He separates the sources of the metallic substances into "immediate" and "ultimate." The latter, by reason of their purely speculative nature, he does not discuss, but devotes himself to the former. Without being able to doubt that these substances originally came from great depths, and without being willing to assert that they came wholly from the country-rock actually adjoining the deposits, he believes:

1. That they came from above.
2. That they were derived chiefly from neighboring rocks.

With regard to the first of these propositions, I can find in his elaborate monograph no tangible proofs whatever, only conclusions deduced from certain observations. The shape and position of the ore-deposits, whether of those at the contact between porphyry and lime, or those in the limestone, afford no conclusive proof of descending mineral solutions as their source. Indeed, this is disproved by the fact that the deposits were originally sulphides (as they are now shown still to be at greater depths), and such sulphide-deposits cannot be asserted to have been formed by solutions descending from the surface (unless such an application should be made of the case cited on p. 107 of my paper, namely, the reduction to sulphides by means of organic matter). The interior structure of the deposits and of the country-rock, so far as they are described in the publications on the subject, likewise fail to furnish any conclusive proof of this assumption.

In his re-examination of the mines in 1890, Mr. Emmons found, even in the original, unaltered sulphide-ores, no crustification, from which he concludes that in this case there has been no deposition of ore in open spaces, but a metasomatic replacement of the limestone. It is to be hoped that investigations on this point will not be wholly abandoned in future. Mr. Emmons mentions also his recognition of the granular structure, joints and cleavage of the original limestone in the sulphide-ores of the A. Y. and Minnie mines, and speaks of the cracks in the top of the ore-body, "through which the ore-bearing solutions had descended." This is clearly, as stated in this form, an expression of opinion. A detailed and purely objective description, particularly if accompanied with drawings, would be highly valuable, and might constitute the tangible proof, the absence of which I have pointed out. Mr. Emmons gives us ground to hope for further observations in this direction, based upon the latest developments of the mines. For the present, however, it cannot be said that we have any decisive proof from the interior structure of these deposits.

The facts described in the literature concerning Leadville may be equally well used in support of the ascension-theory. As I have remarked (page 107 of this volume), the ores were at first conceived to occur at the contact between porphyry and limestone, or confined to the lime; but afterwards it became clear that not the whole contact-surface as such, but only certain zones of it, could be regarded as the principal centers of the accumulation of ore. These ore-shoots, lying in and near the contact-plane, were the channels of which the mineral solutions availed themselves. A parallel is thus furnished to various other ore-deposits; for instance, the zinc- and lead-deposits of the Alps, the shoots of which are near a contact of soluble with insoluble rock, and pursue the same direction as the stratification.* For the establishment of this analogy, credit is due to the mining engineers who have published their observations at Leadville, and, as Mr. Emmons implies,† have rendered valuable assistance in enlarging our knowledge of the facts as developed by mining.

The text of Mr. Emmons's great monograph on Leadville shows plainly (p. 572) that, under the impression produced by the first publication of Professor Sandberger, the author deemed the ascension-theory to have been already completely overthrown. He assumes that the type of a vein, as described by earlier authorities, is a purely ideal conception, and does not exist in nature. To show that these writers had before them, on the contrary, a real condition, I have cited the developments at Przibram. If we substitute, in that case, for the space of discission the spaces occupied by the Leadville deposits, the situation, as concerns the question of the direction of the ore-bearing circulation, is not altered. The flat dip of the ore-shoots and the solubility of the country-rock at Leadville are scarcely decisive as to this question. Nor does the depth thus

---

* See my treatise (1893), already cited, on the "Origin of Lead- and Zinc-Deposits in Soluble Rocks."

† Page 202 of this volume. See also "The Mining Work of the U. S. Geol. Survey," *Trans.*, x., 412 *et seq.*

far attained in Leadville mining afford conclusive evidence. In my judgment, therefore, notwithstanding the differences between Przibram and Leadville, the same inference must be drawn in both cases as to the direction of the ore-bearing circulation. In other words, Leadville must be declared to be no exception to the general rule that ore-deposits carrying metallic sulphides have been formed by ascending solutions.

Whether the metallic contents were derived wholly or predominantly from the eruptive rocks adjacent to the deposits or occurring within a certain distance, is an independent question.

Mr. G. F. Becker's criticism (page 204 of this volume), having been prepared without opportunity for a thorough combination of authorities, is considered as preliminary only. It deals, as does that of Mr. Emmons, in the main, with metasomatic formations, without reference to formations in open spaces, and, contemplating the former exclusively, seems to disparage the emphasis which I have laid upon crustification as a clear proof of the filling of open spaces. According to his view, the recognizability of successive deposits is dependent upon incidental local circumstances, but the instances he gives do not appear to me adapted to prove his proposition that crustification may be produced by other causes than that which I have assigned.

The banded structure of agates, so far as I have had opportunity to study it, is a genuine crustification. It exhibits incrusted nuclei, stalactites, and other formations characteristic of deposition in an open space, quite independently of the question whether changes in concentration or rapidity of circulation or in the substances contained in the solution were the occasion of precipitation. In like manner the precipitate formed upon a piece of iron immersed in a solution of copper sulphate is a genuine crust, the iron serving as the cause of the precipitation; and the circumstances of such a precipitation in a space filled with solution, though the process take place above ground, present some analogies with underground conditions.

A party of mine-thieves once entered by night an old and extensive mine in Transylvania for the purpose of blasting off and carrying away an exposed mass of gold-ore. The shot opened a hole into an old working (*coranda*, in the Roumanian language), and one of the miners crawled through. The immensity of the space in which he found himself astonished him greatly, but his exclamations of wonder were cut short by the crowing of a cock, which revealed to him that he stood under the night sky, in a great surface-*coranda* or open quarry, which covered the whole area of the mine. Under some circumstances, therefore, it is clear that underground and above-ground are not so very far apart!

A mineral solution standing in a laboratory-beaker, exposed to the air, may practically represent, from our standpoint, a subterranean space, the lower part of which is filled with liquid and the upper part with gas, as I conceived it on p. 24 of my paper.

Mr. Becker doubtless means, by the example he cites, to argue that the banded structure may originate also through replacement of the idiogenites by xenogenites. This may be true, but his instances do not support the hypothesis; for the pseudomorphosis of galena after *calcite* is not a replacement of *limestone* by galena. Moreover, not every "banded structure" is a crustification.

Mr. Becker names two sorts of indications of replacement, namely, crystalline pseudomorphism and the irregular enlargement of fissures in the replaced mass. I beg to say that on pp. 15 and 16 of my paper I have mentioned several other signs, such as the retention of the structure of the original mass; the transformation of fossils into ore; the occurrence of remaining nuclei of the original rock, etc., and that I also suppose a metasomatic process to have taken place when the evidence is merely negative, that is, where indications of cavity-formation, in other words, crustification, are absent. But I have found deposits where the indications of both processes occur side by side, as, for instance, at Rodna, in Transylvania. It was at this place that I had the opportunity, thirty years ago, to demonstrate the metasomatic origin of an ore-deposit. Since that time, however, I have never visited the locality, and have received only superficial data concerning further developments. Outside of calamine-deposits, I have not encountered in my later explorations any cases of metasomatic formation; and I have been led to attach ever-increasing importance to the deposits formed in open spaces, the list of which, as known to me, has been continually growing, while their definite characteristics have become more and more unmistakably clear. Any difference of opinion which has arisen, as a consequence, between my American colleagues and myself, must be left to the judgment of investigators who are equally familiar with both classes of ore-deposits.

My statement, "It is difficult to believe that metasomatic processes could produce such pronounced ore-shoots as those described at Leadville," must be explained from the standpoint I have taken as to the origin of cavities in a soluble rock. On p. 21 of my paper I have shown that, before the origin of the cavity, the rock-pores or interstices are filled with saturated solutions, and that a line of maximum flow must be subsequently set up between the point of entrance and some point of minimum resistance, along which line solutions not yet saturated, finding access to the rock, may ultimately dissolve out open channels or cavities. These will then possess a shape extended in one general direction, such as we encounter almost always in ore-deposits in soluble rocks. The Leadville mining engineers have established such a form for the Leadville deposits; and Mr. Becker has also found it in the quicksilver-deposits studied by him. If I have correctly conceived the formation of these ore-shoots, they should show some indications of free cavity-formation, even when they have been produced in part by the replacement of the original rock.

Finally, as regards the Eureka deposits, I seem to have been misunderstood. I did not assert that the spaces originally occupied by the Eureka ore-deposits had been formed by surface-waters. I merely said (in accordance with Mr. J. S. Curtis) that this was the case with the caves, which accompany the ores altered and redeposited by the action of surface-waters.

Mr. F. M. F. Cazin has called attention to an American example, furnished by the Vermont copper-mine, in which graphite (or organic matter, the remains of which are now represented by graphite), may have reduced the ore-bearing solutions. Mr. Cazin cites the fossil palms converted into copper-glance, in the Trias of Mexico, as proof that the copper was originally dissolved in the Triassic ocean, though perhaps in too small a proportion to injure animal life. With regard to that I must observe that these palms probably occur in a fresh-water basin, from which the character of the ocean of the period cannot be inferred; nor, *vice versa*, can the traces of copper found in corals be adduced as indicating the probable presence of copper in such a basin.

R. W. Raymond, New York City: The labor and pleasure of translating Prof. Posepny's contributions having fallen to me, I have taken special interest in the discussion which they have elicited; and I venture to believe that an attempt on my part to summarize the results thus far attained may be useful as a help to the further discussion which I trust will ensue, and will not be deemed an arrogant assumption of the position of a judge, which is as far from my intention as it is beyond my capacity.

No amount of latitude in such a discussion is reprehensible if it elicits new facts; for the accumulation of accurate data is really more important than the mere iteration of argument, and a new fact, however remotely collateral in its bearing, may turn out to be of inestimable value. In this connection, however, it should be noted that the fact is valuable in proportion as it is not merely the expression of an opinion. When we are told by some authority that he "found unmistakable evidences" of this or that, we are simply asked to accept his conclusion, which might or might not have been our own upon the same phenomena; and the weight we give to the fact of his opinion as indicative of the real facts behind it, which are what we want, depends upon our confidence in him, not only as an observer, but also as a reasoner. In my judgment we should be grateful to Prof. Posepny for the emphasis he has laid, not only in this paper but in many preceding publications, upon the supreme importance of what he has called *rein objective Darstellungen*, a phrase which I have weakened in my translation by rendering it "accurate descriptions," in the fear that the term "objective," used in that sense, would be misleading. In this connection I may remark, that when the admirable paper of Prof. Posepny was sent to me, it bore a title which would have been, literally translated, "Subjective Views on the Genesis of Ore-Deposits," the author meaning thereby to indicate modestly that he offered his paper only as an expression of the opinions to which he had been led by his own studies, and not as a statement of the settled results of science. I took the liberty of objecting to this title, on the ground that "subjective" views might be construed as opinions simply "evolved from the inner consciousness," without any foundation whatever in observed facts; and as a result of this correspondence, Prof. Posepny permitted the use of the simpler title, accompanied with such introductory explanations as would relieve him from the imputation of dogmatism.

Accepting, however, his use of "subjective" and "objective" as connoting statements respectively affected or unaffected by individual opinion, we cannot but appreciate and share his desire for "purely objective" reports of observed facts in the field of his studies. And, since it is extremely difficult to convey an "objective" description in writing, the superiority of a careful drawing (not an "ideal" diagram, though that has its uses, and is often a better vehicle of description than words) is clear. Prof. Posepny has practiced his own doctrine by illustrating his paper with numerous drawings, and, I may add, he has unconsciously enforced that doctrine by betraying his own doubts and difficulties in the interpretation of mere verbal and partly "subjective" descriptions, given by other authors.

The misunderstandings thus occasioned may be left to settle themselves through mutual explanations, such as have been made, more or less fully, in the course of this discussion. It need only be added here that Prof. Posepny's conscientious and frank declarations as to the limits of his personal observation, and his careful references to all authorities cited, constitute a safeguard against error, a full guide to further investigation and a model for our imitation.

But the chief questions of interest to us, I think, are these: What are the characteristic and valuable contributions made by this paper to the theory of the genesis of ore-deposits? and, What are the definite issues on which Prof. Posepny's views differ from those of other observers, as the latter have been represented in this discussion?

Under the first head I think we may regard as pre-eminent the masterly exposition of the subject of underground circulation and the distinction established between the vadose and the deep circulation, the former actuated mainly by gravity and conditioned upon the relative position of the surface-outflow, the latter complicated by the effects of capillarity and pressure due to heat. This distinction supersedes the vague terms "ascending" and "descending," though the author has employed these terms, in accordance with popular usage, and has thereby incurred some unnecessary criticism. For it is really not of the slightest importance to the general theory of this subject whether a given mineral solution was moving horizontally or up and down when it produced a given precipitate. The only significant question is whether it was *on the way* up or down; that is, whether it belonged to the one or to the other branch of the underground circulation. The third view, namely, that such a solution might belong neither to the vadose downward circulation nor to the deep upward circulation, but to a "lateral secretion," Prof. Posepny practically declares to be inconceivable. As I understand his argument (or rather, perhaps, as I would state my own view, which I think to be in substantial accordance with his), it may be expressed as follows:

1. The aqueous solutions underground must be conceived either (*a*) as moving on a general downward course, as parts of the vadose circulation, above ground-water level, or (*b*) as penetrating still deeper into the rocks below drainage-level (the barysphere), or (*c*) as rising from those depths under pressure, overcoming gravity, towards or to the surface; or (*d*) as standing (held by capillarity or otherwise) in rocks, whether above or below the drainage-level, and not participating in the circulation at all.

2. Concerning the condition (*a*), which is most open to our observation, we know a great deal. We know, for instance, from an overwhelming number of observations, that the solutions of the vadose circulation are oxidizing, and that (apart from the, probably rare, re-formation of sulphides by the action of organic matter) they do not precipitate sulphides, but, on the contrary, attack and decompose them.

3. Concerning (*b*), we know nothing by direct observation, but are forced to believe, and justified (by Daubrée's experiments, etc.) in believing, that such a movement actually takes place.

4. Concerning (*c*), we have the evidence derived from hot springs, etc., which has convinced all observers that there is in fact such an ascending circulation, whatever may be their conclusions as to the depth of its origin or the degree of its agency

in forming mineral deposits. The ascension-theory postulates concerning it only that it comes from the depths below drainage-level, and is not moved merely by siphon-action, ultimately due to gravity.

5. Concerning (*d*), it may be said that solutions thus held without participation in the general circulation, while they may affect internal changes in the rocks they occupy, cannot begin, *until they begin to move*, a process of redistributing and concentrating by precipitation elsewhere the substances they hold in solution.

6. Moreover, solutions in the condition (*d*), though not participating in the general circulation, must have reached their *locus* by means of that circulation. They must be conceived as having been a part either of the downward or of the upward branch, or, in other words, as arrested portions of the circulation.

7. Whenever they begin to move, they must join one or the other branch of the circulation; and the deposits they may make must be the result of the laws of that branch, operating upon the nature of the solutions, this in turn being partly dependent upon their original source.

8. There is, therefore, no room for a hypothesis of ore-concentration and deposit in bodies of considerable size by "secretion," independent of circulation, or for a cycle of circulation, complete in itself, yet not participating in the general phenomena described. For continuous currents must come from somewhere and go somewhere; and neither inflow nor outlet is provided, except by the conditions of the general underground circulation, as described.

9. From this standpoint it is clear that the source of the substances carried in solution by a current must lie somewhere in the path which that current has traversed. If the theory of lateral secretion means no more than the assertion that the mineral solutions which have precipitated ore in a given fissure or space have traversed and leached some rock before entering that space and that this rock adjoined or lay in "reasonable proximity" to the space of deposition, it would mean, as to the first proposition, nothing that anybody denies; while as to the second proposition, it would be a somewhat vague assertion, requiring definite proof in each case, and not entitled to the dignity of a general theory.

10. But the theory of lateral secretion, however it may have melted away under the fire of criticism, originally claimed more than this. Prof Sandberger says:*

> "The so-called descension-theory of Werner is purely neptunic, and regards veins as exclusively filled from above downwards by the deposition of ores from liquids, without answering the question, whence these liquids derived their metallic contents. The descension-theory remains good to-day for all cases where, in higher-lying rocks, those substances can be with certainty traced, which have collected as ore-deposits in cavities and fissures in lower-lying rocks, not originally containing them. If the ores are accumulated in fissures, they possess all the characters of fissure-veins. So far as my knowledge of ore-deposits goes, the filling of fissures by ores which can be clearly proved to have filtered in from above is not very frequent; but such filling of irregular cavities are common."

After mentioning as an excellent instance the lead- and zinc-deposits of Raibl (which Prof. Posepny has discussed with very different conclusions), and declaring that he is at present concerned specially, not with such deposits, but with true fissure-veins, Prof. Sandberger proceeds to state as follows the ascension theory, which he says "still counts many adherents," and which he proposes to controvert:

> "The ascension-theory assumes in all cases that the ores occurring in a vein-fissure were derived either not at all, or only in part, from the immediately adjacent country-rock (*aus dem unmittelbaren Nebengestein*), but, on the contrary, from greater depths, and have been introduced into the fissures either by ascending mineral springs or by sublimation. The substances deposited in the veins should therefore be different from those of the adjacent rock, and should only occur in the latter as lateral impregnations from the fissures."

Confining himself to the supposed agency of ascending mineral springs, the author asserts that such springs would not, and in fact do not, deposit minerals in their channels, and discusses at some length the case of Sulphur Bank in California, which he declares to be the only instance apparently contradicting his view. He argues against the conclusions drawn by others from this instance, and concludes as follows (p. 17):

> "If, then, the only region in which it has been deemed possible to assume the filling of vein-pressures by ascending mineral springs as a process now going on, furnishes no trustworthy proofs of this assumption, what remains? In my opinion, only the leaching of the country-rock which bounds the fissures by seepage-waters which have penetrated it, and which deposit the dissolved materials as ores and

---

* *Untersuchungen über Erzgänge*, von Fridolin Sandberger. Wiesbaden, 1882, *Erstes Heft*, pp. 3, 4.

gangue in the fissures of the same (or, in exceptional cases, the nearest neighboring) rock.* This is the so-called lateral-secretion theory in its most prosaic form; and it is this to which I have been so distinctly led by many years of observation and investigation that I am forced to consider it applicable to most ore-veins."

11. It is clear that this theory contemplates the exclusion of the agency of waters rising from below drainage-level. That there are such waters, is an admitted fact; and it must be also admitted that they are under pressure great enough to overcome gravity and friction. All fissures accessible to such waters, they must necessarily occupy; and it seems to follow inevitably that all fissures extending below drainage-level must be filled, up to that level at least, with waters either in actual circulation on their way upward, or temporarily arrested and confined. "Seepage" into such spaces is inconceivable.

12. On the other hand, currents under pressure would necessarily penetrate into the pores and interstices of the rocks bounding their main channels, and the deposit in such rocks of minerals carried from the fissures is more probable *a priori* than the deposit, in the fissures, of minerals dissolved from the adjoining rocks. The opposite would be true if the fissures did not contain water, a condition which can only be assumed when there is a lower outlet, that is to say, only in the zone of vadose circulation.

13. The advocates of lateral secretion must state, at least, their conception of the way in which "seepage" can take place from a porous solid holding water into an adjoining space also filled with water, and under high pressure. That practically no interchange between the two will take place, even if the pressures are equal, is shown by the occurrence of fresh-water springs along our coast, separated by a few feet of sand only from the salt waters of the sea. It is often popularly supposed that the sea-water has been deprived of its salt by "filtration" through the sands; but the real fact is, that the mass of the sea bars the path of a circulation which would carry the spring-water into it, and the spring seeks another way to the surface,

---

* "Nach meiner Ansicht nur Auslaugung des die Spalten begränzenden Nebengesteins durch Sickerwässer, welche dasselbe durchdrungen haben, und die gelösten Stoffe als Erze und Gangarten in den Spalten des gleichen oder ausnahmsweise auch in solchen des nächsten Nachbargesteins."

where it emerges perfectly fresh. The intervening sands are doubtless filled with brackish water, but this takes no part in the circulation, and therefore carries no salt into the channel of the spring. If the Atlantic Ocean cannot "seep" salt into a spring of fresh water, how could a rock, not included in the path of a continuous circulation, impregnate any portion of that path by its "seepage?"

14. Again, it is conceivable that gash-veins, and other spaces wholly within a given rock-mass, may receive concentrations of mineral by "seepage," though even in this case, if the process is to result in considerable accumulations of mineral, it must be a long-continued one, supported by an inflow and outflow; in other words, it must be a part of a general ascending or descending circulation. And since the ascending circulation involves a pressure from the fissure towards the wall-rock, that is, in the wrong direction for "seepage," it follows that, except in the vadose region, and apart from highly exceptional conditions, the products of the leaching of any given rock-mass are not likely to be found predominantly in adjoining fissures.

15. The theory of lateral secretion, therefore, is essentially confined to the region of the vadose circulation; and those who would apply it to the origin of deposits containing sulphides must be prepared to maintain that those sulphides have been deposited from solutions moving downwards or laterally, under the influence of gravity, in other words, surface-waters. Prof. Sandberger does not hesitate to accept this alternative, although he does not perceive, apparently, how it confines the sphere of his theory. According to his view, the metals are disseminated in the country-rocks and silicates, and these rocks contain also sulphate of soda, and other soluble alkaline sulphates, as well as chloride of sodium, all of which, he supposes, are converted by organic matter into alkaline sulphides, which transform the metallic silicates into metallic sulphides.

16. But this explanation encounters two serious difficulties. In the first place, it is opposed to the overwhelming evidence that the downward circulation does not characteristically deposit sulphides, but attacks them; that it does not characteristically contain alkaline sulphides, but alkaline carbonates and free carbonic acid and oxygen. In the second place, the expla-

nation breaks down in the presence of fissures filled with sulphides, extending far below any present or conceivable past drainage-level. The sulphide ore-deposits in such fissures, at the greatest depths attained by mining, show no structural differences or other indications of a different origin, as compared with sulphides in the levels above. There is a change at water-level, but it is notoriously a change from oxidation above, to absence of oxidation below, that level.

17. The lateral-secretion theory, therefore, so far as it is true at all, is no more than a subordinate division of the theory of the formation of deposits in open spaces above drainage-level; and even here it is neither necessary nor plausible, as the explanation of deposits which continue downward, and must be referred, as regards their lower portion, to a deep source. Such deposits may have been altered in character, and even in form, in the vadose region; they probably originated in the deep region.

18. On the other hand, the hypothesis of ascending waters as the vehicle of solution and deposition does not exclude the idea of the leaching of any rock traversed by such waters. It indeed assumes such a leaching as having taken place somewhere. But, as opposed to the theory of lateral secretion (modified to lateral circulation) it assumes the rock immediately adjoining a vein-fissure (when the fissure continues deeper) to be the least likely, not the most likely, source of the metallic ores. And on this point it appeals to the phenomena of crustification. Nothing is plainer than the evidence afforded by the successive crystalline crusts of an amethyst geode, for instance, that the deposition took place first upon the walls of the cavity, afterward upon the crust thus formed, and so on toward the central druse. The very first deposit evidently covered the wall with an impermeable layer; and the material for all succeeding deposits must have come (as the sections of many geodes show visibly that it did come), through a passage from without the mass of the geode. In like manner, the crustified filling of a fissure-vein cannot well have come from the walls of the vein at the place where the first crust deposited would necessarily close those walls. The crusts have been deposited from a solution between them. The central druse was not first formed, and then pushed out by successive deposits behind it, as the

bark of a tree is thickened. The solution depositing the crystals in successive crusts must therefore have been part of a current; and its entrance and exit can scarcely be sought, as a rule, in the walls it has crusted. A side-fissure, entering through either wall, is, of course, not impossible or uncommon. But it cannot be assumed to exist without proof. And when such a thing is actually found, its effect upon the vein is so marked as to raise a strong presumption that the normal source of the vein-solutions was not in that direction.

19. Prof. Posepny has laid much emphasis upon crustification, as he has defined that term. I think he is right in so doing; and I may remark incidentally that his use of new special terms (which has been objected to by some) is justified, in this case, as in other cases, by the greater precision of thought thereby secured. The disadvantage of a preference for ordinary and familiar words, when such words may have many meanings, is illustrated by the manner in which Prof. Posepny, on the one hand, and his critics, on the other, have been misled by the ambiguity of "banded structure." He interprets "banded structure," or equivalent expressions, in some of the authorities he cites, as meaning crustification, and they say that banded structure may arise in several ways, intimating thereby that crustification is not a sure proof of deposition upon cavity-walls. The verbal misconception being corrected, it seems to me that there is no difference between the parties on this head.

20. The assertion that a current is necessary for the deposition of such crustified accumulations is not to be construed as excluding variations in velocity, or occasional stoppages and intermissions. The objection of Prof. Sandberger, that mineral springs do not, as a fact, deposit solid substances in their channels, seems to be based upon the conception of such springs as ascending with unvaried velocity, as if through pipes of uniform diameter. Even pipes, as Professor Posepny reminds us, have been known to receive interior incrustations; but the probability of such deposits is much increased when the effects of variations in the nature and size of the channel are taken into account. *Mutatis mutandis*, the analogy of the deposition of sediments by a running stream is available here. As sands and clays, carried in suspension where the current is most rapid,

are dropped where it is checked through widening of the channel, or from other causes, so the deposits of a mineral circulation will naturally be greatest where the movement is slowest, or is even temporarily arrested altogether; and they will be reduced to a minimum, other things being equal, where the current is most rapid. The phenomenon of distinct crustification, in fact, requires the hypothesis of a relative quiescence of the menstruum. And instances are not wanting underground in which the widening of the vein-fissures, or the change to a flatter dip, has apparently favored the deposition of ore.* The ascension-theory does not exclude these obvious considerations. All it asserts is, that the portion of solution entering a given space, and depositing therein a precipitate, must thereafter escape and give place to another portion of solution, if the process is to be repeated; and that, with regard to deposits of sulphides, formed below drainage-level, the only escape is ultimately upward. But the phenomena of crustification in veins afford, in my judgment, another argument against the theory of lateral secretion. Namely, it is well known that the crustification, even in typical fissure-veins, is not everywhere distinct. If it can be observed, with its characteristic central druse, in one part of a vein, it is held (properly, I think) to be (in the absence of evidence to the contrary) a proof that the similar ores of other parts of the vein have been similarly deposited. The absence of crustification in some places may be explained, on the ascension-theory, by the varying speed of the current, and the varying nature and dip of the walls, as affecting the deposition of adherent crystalline crusts. The chemical or physical causes inducing precipitation may simply produce a suspended precipitate, to be subsequently deposited as a sediment. But if lateral secretion has produced crustification, such as is observed in fissure-veins (as I think, with Professor Po-

---

* On the other hand, increased width of "vein-matter" has often been due to a splitting of the fissure, and the enclosure of fragments of country-rock, which is afterward more or less transformed into gangue, or remains as horses in the vein. Or, such increased width may be (as in the Cornwall tin-mines) the result of a mineralization of the country-rock beyond the limits of the original fissure, producing a mass of altered rock impregnated with ore (the *Zinnzwitter* of the Germans). In such cases, while the aggregate of mineral deposited is doubtless much greater than it would have been had the solution passed through the narrow fissure only, the richness of the material is reduced by the admixture of gangue and rock.

sepny, that it has not), then that structure, it seems to me, should be more uniformly distinct in such veins than it is. For the conception of lateral secretion into a fissure excludes the conception of a current under higher pressure, already occupying that fissure; and the local interference of such a current with the quiet process of crystallization is therefore out of the question.

21. The comparatively small amount of mineral matter contained in the ascending springs of the deep circulation, originating below drainage-level, is to my mind some indication that they have already deposited somewhere the larger part of the substances they have held in solution. They are never saturated solutions. As we find them, they contain what we may suppose to be only remaining traces of the metallic constituents which they may (we may almost say must) have carried at greater depths, temperatures, and pressures. Is not the presence of these minute remainders really an evidence of the larger amounts once present, and therefore of a precipitation *en route?* In connection with this question, the probable conditions of the deep zone must be borne in mind, such as, not only the increased solvent power of the waters of that zone, but also the probable slowness of their downward progress, which is practically (according to Daubrée) a seepage, and which must favor the formation of saturated solutions.

22. In reply to this suggestion, the question may be raised how the deposition of ores, extending almost or quite to the surface, is to be accounted for, if the solutions now encountered below drainage-level are already so nearly exhausted as to be capable of comparatively little further precipitation. Without forgetting that the most dilute solutions may still give precipitates under chemical or physical changes of condition; and that such precipitates, however insignificant, may attain a considerable aggregate amount by long-continued repetition, I think the more comprehensive answer to the above question is found in the conclusion to which we are led by the ascension-theory, that deposits carrying metallic sulphides, though they reach the present surface, were formed mainly below the influence of the vadose circulation, and therefore under conditions such as may now obtain at depths beyond our observation.

23. This suggests another point, to which Prof. Posepny has

called attention, and which was acutely recognized by Cotta, many years ago,* namely, the fact that speculations upon the relation between the contents of mineral veins and their depth are largely vitiated by the vagueness and uncertainty of the element of depth, as estimated by comparison with the present surface. In most mining regions there is unquestionable evidence of great denudation, which has probably removed from the surface a larger mass than has been penetrated anywhere by mining. It seems impossible, therefore, to argue as to the continuance of ores "in depth," meaning thereby beyond 1000 or 2000 feet from the present surface, when that surface itself may have been 10,000 feet underground at the time the ores were deposited. We may imagine that the ascending waters in a vein now rich in metallic deposits "from the grass-roots down," once continued their upward course to the *former* surface, emerging as dilute solutions; or never reached that surface intact, but encountering the vadose circulation, became a part of it; and, in either case, precipitated less and less metallic matter as they ascended. Conversely, we may reasonably imagine that, if we could retrace the course of a mineral spring coming from the deep zone, it might lead us back to the region where it had deposited the treasure of which it now exhibits, at most, only faint remaining traces. And what we might thus fairly imagine concerning an actual spring might be equally true of the channel of a former spring now closed altogether, or occupied only, under changed conditions of altitude and drainage, by the vadose circulation—that is to say, of a fissure-vein, comparatively barren or lean at the present surface. In other words, the present surface is an arbitrary section, cutting off the veins. Those which it happens to intersect in their richer portions are naturally the ones which are developed by mining. Those which it shows to be locally barren are naturally not thus developed, unless local experience supports the hope that they will improve in depth. Such a local experience is doubtless the foundation of the maxim which Cornish miners have carried throughout the world, that "a fissure-vein grows richer in depth," a proposition for which, as a general guide for mining (apart from the effects of surface-waters, which may be

---

* *Die Lehre von den Erzlagerstätten*, Freiberg, 1858. Part I., p. 129.

sometimes impoverishing), is without foundation in experience. For although a comparatively barren fissure may be, and has often been shown to be, the upper part of a vein carrying rich ores below, there is no general law that it must be so; and, moreover, there is no way of determining *a priori* the depth of the barren zone, measured from the present surface.

24. On the other hand, while the varying positions of the present surface prevent generalization as to the relations of ore to "depth," it is unquestionably possible that there may be, in a given fissure, a relation of that kind. The ascension-theory neither asserts nor denies such a supposition. Mr. Rickard's suggestion that the deeper zone must be the region of solution, and a higher zone the region of precipitation, is speculatively reasonable enough; but it amounts to a proposed subdivision of the barysphere into two regions; for the deep zone which Prof. Posepny has called the barysphere includes everything below our observation, and it is in that zone that both solution and precipitation are supposed to have taken place to form the deposits of metallic sulphides. In our ignorance of the conditions of that unknown region, it is scarcely possible or necessary to frame hypotheses concerning them. The practical bearing of Mr. Rickard's suggestion lies in his connection of it with an alleged general phenomenon of the impoverishment of veins in depth, as shown by experience in mining.

25. As to this alleged general phenomenon, I would say first, that even if it were proved, it could hardly be ascribed to the cause suggested by Mr. Rickard, namely, the predominance of solution in lower zones and the confinement of precipitation to higher ones, because the depths reached in mining are not great enough to warrant such a deduction, and also because the instances (such as Przibram) of rich ores continuing for great vertical distances, and down to levels among the deepest ever opened by mining, contradict the hypothesis.

But it must be confessed that there is much evidence which seems to corroborate Mr. Rickard's statement as to the exhaustion of mines in depth. This evidence needs, however, to be carefully collated and critically sifted, before it can be accepted as the indication of a natural law.

a. In such an inquiry all cases must be rejected in which oxidized surface-ores have been mined down to water-level, and the mine has been abandoned by reason of treating the refractory sulphides. In many such cases the oxidized ores are actually richer (*e.g.* in gold) by reason of the alteration they have undergone; but this is not pertinent to the question of original deposition.

b. The abandonment of mines by reason merely of the increased cost of deep mining must be also set aside as affording no evidence on this subject.

c. The fact that in mining a bonanza is traversed, and a relatively barren zone occurs below, does not necessarily indicate a relation between barrenness and depth. The occurrence of a bonanza very frequently involves barrenness of the neighboring portions of the vein. That this is the case on a horizontal line is abundantly proved. An instance in point is furnished by the Bullion mine situated on the Comstock lode, between mines which have produced many millions. The expenditure of millions on the Bullion never produced, so far as I know, a ton of profitable ore. Why should not a similar alternation of rich and barren places occur in the vertical line? The cost of exploration in depth, and particularly in sinking, naturally discourages mine-owners; and the abandonment of an operation under such circumstances really proves nothing.

d. In any case of alleged impoverishment of a vein in depth, not only the actual depth below the present surface, but also (so far as it can be estimated) the probable amount of denudation which the surface has undergone, should be taken into account.

e. The nature of the ore also may have a distinct bearing upon this inquiry. It is my impression that of the loose and vague evidence thus far accumulated, a large part refers to gold-ores, and particularly to free gold in quartz, as "giving out" in depth. I remember that in my last conversation with the late Joshua E. Clayton, a close and conscientious observer, he told me that he had personally examined numerous quartz-veins, occurring all along the flanks of the Sierra Nevada, and had found in every case that the veins, as exposed in the deep cañons cross-cutting them, hundreds of feet below their outcrops on the mountains, were poorer in gold than at the higher level. This testimony is valuable, and it may be that it indicates a general law as to such gold-veins; but it must be borne in mind that some of the California gold-mines have been worked deeper than any cañons have cut the veins. Yet, on the other hand, many of the deep gold-mines of the State have been ultimately abandoned.

26. Mr. Rickard's suggestion has a practical side of great importance. Namely, although, in my judgment, there is no established general law, discouraging the exploration of a vein in depth, so long as the fissure continues well-defined, and especially if it carries any thread of ore, it is undoubtedly the case that mining explorations are too much confined to sinking and drifting, and that there is too little cross-cutting for parallel fissures and ore-bodies. To some extent this is one of the results of our absurd United States mining law, which lays so much stress upon the "apex" and the "lode;" but the mistaken practice of neglecting cross-cuts into the country-rock is not confined to mines operated under that law.

27. Another important point in Prof. Posepny's paper is his proposition (based on Nöggerath's observations in the main, but not lacking other support) that open spaces of dissolution may be formed by ascending as well as descending currents. Since the process of solution depends upon the character of the liquid agent, this is only saying that some ascending waters may be able to dissolve portions of the rocks they traverse; and that if such rocks belong to the class represented by limestone, such currents may produce in them caves and channels, comparable to those notoriously produced by the descending waters. I confess, this seems to me a reasonable proposition, however meager may be the proofs thus far adduced. And I cannot understand, at all events, how opponents of the ascension-theory should object to it; for they do not deny that there are such things as ascending mineral springs, and that these springs hold in solution such substances as carbonates and free carbonic acid. What they deny is that these springs deposit anything in their channels. In that case, they must dissolve without redepositing; and the evidence that they have actually excavated channels underground is afforded by their constitution. They bring the evidence of their guilt with them. To reply that they are part of the vadose circulation only, and hence, no matter what their local direction, belong to the descending branch, is not permissible; for springs en-

countered at great depths in mining have the composition required to make them active solvents. How can it be doubted that the hot waters of the springs encountered in the Bohemian mines (see Nos. 1, 2 and 3 of Prof. Posepny's table, p. 42), which contain "a notable quantity of free carbonic acid," would, if they traversed limestone, excavate cavernous channels in it?

28. Moreover, there is reason why a liquid solvent under pressure, occupying a space in a soluble rock, should eat its way upward rather than downward or laterally—namely, because the insoluble portions of the rock, loosened by the action of the solvent, fall away from the roof of the cavity most easily and completely, leaving fresh surfaces open to further attack. Whoever has visited, as I have done, the salt-mines of the Salzkammergut, in the Austrian Tyrol, where salt is extracted by *Sinkwerke*,* and has observed how the great underground rooms, repeatedly filled with water under pressure, *travel upward* through the mass of the saliferous rock, as their roofs are attacked and dissolved, while their floors are relatively protected by the fallen insoluble débris, can scarcely doubt the possibility of the formation of spaces of dissolution by ascending waters. One variety of this extraction—viz., the so-called "continuous watering," employed in some of the mines—presents a still closer analogy. In that method the water is not introduced periodically into each *Sinkwerk*, to be withdrawn when saturated, and wholly replaced with fresh water for further solution. On the contrary, the flow of water is made continuous, fresh water being admitted at one point while saturated brine is conducted away at another. It is true that the actual flow of the current is downward, the fresh water being admitted above and the brine drawn off below; but this is not an essential feature of the process itself. The actual progress of excavation by solution is upward, and the essential condition is the presence of a pressure sufficient to cause the solvent to penetrate the roof. That being secured, the roof is mainly attacked, the side much less, and the bottom scarcely at all.

29. Prof. Posepny's "Theory of the Sinking of Heavier Con-

---

* Described in Serlo's *Leitfaden zur Bergbaukunde*, 4th ed., Berlin, 1884, vol. i., p. 611 *et seq.*

stituents," as applied to the distribution of gold, etc., in placers, is a valuable addition to our knowledge of such deposits. It is highly desirable that our members engaged in placer or hydraulic mining should give us the results of careful observation upon the conditions presented by the gold-deposits of this country. Few of them have done so thus far, and the field is full of interesting data not yet put into shape for preservation. I am inclined to think, for instance, that "the hypothesis of a natural concentration in running water," which Prof. Posepny disparages, and for which he proposes to substitute the theory just mentioned, would find some support in the phenomena of many American placers, where the gold is concentrated not only on a false or true bed-rock, but in distinct channels along that plane, so that the placer-miners, for many years, have pursued the tortuous channels of "pay-dirt," leaving large areas unworked, which, for some reason or other, did not pay, though they were equally "in the gulch," and had the bed-rock under them, like the rest. I do not mean to deny the possible agency of such a concentration by gravity in loose sands and gravels as Prof. Posepny has postulated, but I fancy it would be hard to explain the distribution of the gold in many of our American placers except by including among its factors the action of running water. If I am correct in this impression, I may venture to consider the case as one in which Prof. Posepny's heaviest artillery can be turned back upon him; since his theory of "settling" may be called a sort of dry "seepage" or secretion by gravity, and my view may be considered as the assertion that, here as elsewhere, there is no deposition without circulation.

Concerning the differences of opinion developed by this discussion, I think it may be said that, upon closer examination, they are not important, except as to the explanations of certain districts and ore-deposits which Prof. Posepny has rather deduced from the writings of others than based upon observations of his own.

With regard to nearly or quite all of these instances, our own experts are not agreed, so that Prof. Posepny has respectable backing for his views, whether they turn out in the end to be correct or not. Certainly he has presented them with a conspicuous absence of dogmatism, and they have been received on the part of our members, I am happy to say, with the respect due to the merits of a veteran authority, and with gratitude for the generosity which has enriched the *Transactions* of the Institute with one of the most important contributions to technical science ever made through that medium.

F. M. F. CAZIN, Hoboken, N. J.: Bergrath Posepny rejects my assumption of the presence of copper in the Triassic sea, claiming that the evidence adduced does not hold good, and observing, in support of his view, " that these palms," the cuprified fossils of which are found in the " coarse yellow sandstones and conglomerates overlying the red beds of the Trias," " on the junction of the Trias with the Cretaceous,"* " probably occur in a fresh-water basin."

The fossil in question is identical with " Podozamites crassifolia," described† as occurring in the State of Sonora.‡ Palms cover at this date a narrow belt along the northern coast of South America, disappearing in the interior. The location of the Nacimiento copper-belt is one, from which the Cretaceous sea retired last of all on this continent. Its waters at this date are shed into the Gulf of Mexico, with no indication anywhere of a pre-existing barrier. I am acquainted with the English and North German Wealden formation, having mined in it; but, as J. S. Newberry did not, so I did not, find a trace of evidence for assuming a sweet-water formation at the Nacimiento copper-deposits.

My assumption, therefore, stands on proper ground, unless more than a probability to the contrary be offered.

---

* J. S. Newberry, *Report on the Expedition of* 1859, pages 117 and 118.

† *Ibid.*, p. 145.

‡ It is one of the various strange things observed in geological reports, that are the compound work of many—that, although J. S. Newberry prominently and repeatedly refers to the palm-fossils of Nacimiento, his plates show naught under that head, but do show a true image of these "palm-leaves," described as collected in "quite a number" by Mr. Redmond from "the Triassic strata at Los Broncos, Sonora," a locality not visited by the expedition of which the report is made. I may mention, as an amusing coincidence, that at Prof. Newberry's and at my time there was at Nacimiento a silver-smith, who hailed from Los Broncos, Sonora, and who, whenever in his trade he needed copper, smelted it in a miniature crucible on a miniature Mexican forge with accordion-shaped bellows, using as his material for copper the fossil palm-leaves of Nacimiento, of which within easy walk from his door he could pick all he was in need of, and of which he kept on hand "quite a number."

If ever J. S. Newberry's and my own observations as to the geological position and normal character of the deposits in question have been objected to on the ground of actual local observations, I am ignorant of the fact.

JOSEPH LE CONTE, Berkeley, Cal.: All geologists, but especially students of the phenomena of metalliferous veins, are under deep obligation to Bergrath Posepny for the very lucid exposition and abundant illustrations of these phenomena contained in his admirable treatise on the "Genesis of Ore-Deposits." Like the previous treatise of Sandberger, though taking an extreme opposite position, it must powerfully revive the interest of students and observers in the purely scientific theory of metalliferous veins. Although read at the International Engineering Congress of the World's Fair at Chicago, in 1893, it has only very recently fallen under my eye. As I have thought much, and published somewhat on this subject, I beg leave to say a few words in the way of criticism on this masterly work.

All, I think, will agree that one of the chief merits of the work consists in the clear distinction which the author draws between what he calls the *vadose*, or superficial, and the *deep* circulation of underground water; the water in the one case containing air, and therefore oxidizing; in the other, destitute of air, and therefore non-oxidizing; the one circulation driven by gravity alone, the direction of the current being determined by the place of outflow, the other driven largely by heat received in the lower parts of its circuit, and the direction of its current being mainly upward.

We are all, I think, especially pleased with the significance he finds in, and the importance he attaches to, the oxidizing and non-oxidizing effects of these two circulations respectively. It follows, from this view, that metallic sulphides are not deposited from the waters of the vadose circulation, unless under the exceptional conditions of the presence of excess of organic matter; and therefore, that the presence of metals in the form of sulphides is usually a sign of deposit from ascending currents of the deeper non-oxidizing circulation.

Most of us, I think, too (and I among the number), will agree with him, as against Sandberger, that since great deep fissures are not empty, air-filled spaces, but are necessarily filled with water, deposits in them cannot take place by seepage or oozing, or lateral secretion from the immediate bounding-walls. Also, that the phenomena of crustification or ribbon-structure of vein-contents seem to negative such a mode of filling as is supposed by Sandberger; that this structure does not indicate a filling by oozing and trickling of waters containing soluble matters, down on a free surface, but rather a deposit in successive layers inward from water contained in the fissure.

For all this, and very much more which I cannot repeat here, we are under many obligations to Bergrath Posepny. Nevertheless, I cannot but think that he carries his ascension-views much too far; that in his zeal against the extreme lateral-secretion views of Sandberger, he has gone to the other extreme of ascensionism; and that a truer view than either may be found in one that shall combine and reconcile these two extremes.

The evidence of the extremeness of his views is found, and indeed is embodied, in his use of the term *barysphere.* As contrasted with *lithosphere*, this term can only mean a region in the interior of the earth, the materials of which are heavier, because more metalliferous, than the superficial lithosphere visible to us. From such a metalliferous barysphere, he thinks, all the metals of ore-deposits (with trifling exceptions) are derived. It is true, that in his reply to objectors, he speaks of his barysphere as only the equivalent of the "unknown depths" of other writers; but, it must be remarked, that this latter term, while open to the objection of indefiniteness, does not, necessarily, carry with it any implication of a region peculiar in its density and in the abundance of its metallic contents, although it is doubtless often used with this implication. The word barysphere, on the other hand, fixes definitely an idea which has long floated vaguely in the minds of many writers on this subject. It will, therefore, form the central point of my criticism.

I.—IS THERE A BARYSPHERE WITHIN REACH OF CIRCULATING WATER?

It is true, that the earth increases in density from the surface toward the center, and probably to the very center itself. This is shown by the fact that the mean density of the earth is more than double that of the superficial parts. It is true, also, that the increasing density, while certainly due, in part, to condensation by increasing pressure, is probably also due, in part, to difference of material, and especially to the presence of metals, as sulphides or native, in greater abundance in the interior parts. It is true, therefore, that the deeper parts of the earth are certainly heavier, and probably more metalliferous, than the superficial parts. In a word, it is true that there is a barysphere, and probably in the sense used by Posepný, as being more metalliferous. But how deep must we go to find this barysphere? Let us see.

Taking the density of the superficial parts of the earth (or what Posepny would call the lithosphere) at 2.5, and the mean density of the earth as a whole at 5.5 (Posepny accepts these figures), and assuming the simplest rate of increase, viz., a uniform rate, then an actual density equal to the mean density of 5.5 would be reached at the depth of 1000 miles, and the central density would be 14.5.* This is an increase of 3 in 1000 miles. At the depth of 100 miles, therefore, the increase would be 0.3 and the density only 2.8. Is it at all probable that we ever have circulating water coming up from any such depth as 100 miles? And yet, 2.8 is only about the density of our more basic eruptives, and therefore wholly undeserving the name of a barysphere. Circulating water may possibly come up from as deep as 10 miles, but at the same rate of increase, the density there is only 2.53—an increase over the superficial density wholly inappreciable. Dr. Raymond, interpreting Posepny, defines the barysphere as all that interior region, the circulating water of which would not come up at all without the aid of heat. Does this mean all but the superficial region traversed by the vadose or oxidizing circulation? If so, it cannot be far from the surface, and the term barysphere, as applied to it, is surely wholly inappropriate and misleading.

But it may be answered that all this reasoning is based on the assumption of a *uniform* rate of increase of interior density; while in fact the great mean density of the earth may be explained by the existence of a highly metalliferous shell at no

---

* By mathematical calculation based on the above conditions, an actual density equal to the mean density of 5.5 is reached at depth of ¼ radius from the surface. Multiplying this gain of 3 by 4 and adding the surface density of 2.5 makes a central density of 14.5 ($3 \times 4 + 2.5 = 14.5$).

great distance beneath the surface and therefore within easy reach of circulating waters. To this view I make the following objections:

1. All our general reasonings concerning the cause of the great mean density of the earth, whether (*a*) condensation by increasing pressure, or (*b*) arrangement of materials of a primal fused earth according to their relative specific gravities, would make the increase progressive to the center. In fact it is hard to conceive the conditions under which a dense metalliferous shell a little way beneath the surface could be formed.*

2. We have abundance of materials coming up in eruptions from depths as great as circulating water is ever likely to reach, and yet these materials show no such density and metalliferousness as is implied in the term barysphere.

But again, it may be objected that I greatly underestimate the depth which may be reached by underground water. This brings up an important but difficult question. Is there any limit to the depth to which meteoric water may penetrate? If so, what determines the limit and where is it? These are questions which science is probably not yet prepared to answer definitely. I once thought, that since the pressure of a water-column increases uniformly with the depth, while the elastic tension of steam in contact with water increases with increasing heat at an increasing rate, so as to develop a logarithmic curve, there must be a depth at which the tension of steam would be equal to the downward pressure, and that at that depth would be found the limit of underground water; and I expressed this conclusion in my *Elements of Geology*, page 99. Further reflection has convinced me that the conclusion is unwarranted. Such a limit would undoubtedly be reached if the increase of tension continued to follow the same law indefinitely. But it is now known that at a certain temperature, called the critical point, steam has the same density as the water from which it is formed. At this point, therefore, it may

---

* Of the two causes mentioned above, the first would probably produce increase at an increasing rate and put the place of density equal to mean density deeper than ½ radius down. The second might give rise to any kind of rate according to the relative amount of the different kinds of metals; but not improbably to a decreasing rate and put the place of mean density higher. The combination of these two would make an indeterminable rate; but something like a uniform rate is as probable as, perhaps more probable than, any other.

be regarded as either steam or water indifferently, and under the slightest change of temperature it takes the one form or the other. Beyond this point it is no longer steam in contact with water, but dry steam, which we know follows an entirely different law. Now the critical point of water is about 700° F. and the tension of steam at this point is about 200 atmospheres. Taking the increase of underground temperature at 1° for 53 feet, or 100° per mile, the temperature of 700° would be found at the depth of seven miles. But the pressure of a water-column there would be about 1100 atmospheres. The tension has not yet even nearly reached the pressure; and, as the law changes here, it would seem that the tension would never overtake the hydrostatic pressure at all. Therefore, if the underground water is limited at all in its downward course, as is probably the case, it must be limited in some other way, probably by increasing compactness of material, under the increasing pressure of superincumbent rock, which, by closing up the pores, would inhibit further penetration, or would make it easier for the water to come up again in ascending currents.

I think we may reasonably conclude, therefore, that whether there be a limit to underground water or not, it is certain that below a certain moderate depth, say 8 or 10 miles, such water cannot be circulating; for beyond this the compactness of rock under superincumbent pressure would be such, that while capillarity and weight of water-column might still urge further movement, passages sufficiently open to allow currents of circulation could not exist.

We may assume, then, that the limit of circulating water cannot be more than 10 miles in depth. Below this, water may indeed penetrate by capillarity and by weight of its own column, but such water does not enter into ordinary circulation, although it may come up in volcanic eruptions and indeed supply the force of such eruptions. Still, below this again, and even to the very center, there may possibly be what Fisher calls *constituent* water, *i.e.*, original water occluded in the primal fused magma of the earth, still present in the interior and coming up in volcanoes, and (according to him) the cause of their eruptions. If there be such, it is not circulating water in the ordinary sense, and therefore may be left out of account in this discussion.

Underground water may be conceived, therefore, as existing in three possible conditions, but more and more doubtfully in the order named:

1. Circulating meteoric water. This of course is certain. It probably extends but a few miles (8 or 10) below the surface.

2. Meteoric water, but not circulating. The existence of this is probable. I have been accustomed to call it "volcanic" water, because it is a probable source of the eruptive force of volcanoes.

3. Constituent water, originally occluded in the primal magma of the incandescent fused earth, and still occluded in the materials of the interior. This, Fisher thinks, is still escaping, and in doing so, fuses its way toward the surface, and finally emerges in volcanic eruptions. This, of course, is very doubtful.

Of these three, if they all exist, we are concerned, I believe, with the first only.

We have assumed 10 miles as the limit of circulating water, and therefore the limit of depth from which metals may be derived. But at that depth, as already shown, there is no "barysphere" in any intelligible sense of that word. For the difference in density and in metalliferousness between the rocks there and those at the surface is quite inappreciable. We have, in fact, much material coming up from this very region, and therefore know its density. Our more basic rocks are indeed far denser and more metalliferous than the average of that region, having acquired greater density by differentiation from an average magma representing that region.

I believe, therefore, that the greater abundance of metallic ores in solution in ascending waters is the result, not of the greater abundance of metals in their lower courses, but of the greater *heat* which they take up in that part of their course and the greater *pressure* to which they have been subjected there. Both heat and pressure greatly increase the solvent power of water upon the feebly soluble metallic sulphides. Thus heavily freighted, the waters lose, in ascending, both heat and pressure, and therefore deposit abundantly in their upward course. In a word, ascending waters are rich in metallic contents, not because they have traversed a barysphere, but *because* *they have traversed a thermosphere.* With equal heat and pressure, I am convinced, they would get as much metal from our more basic rocks here at the surface as they now do from the hypothetical barysphere. These ascending waters are non-oxidizing, not because they have never seen the air, *i.e.*, are not meteoric, but because they have exhausted their oxidizing power by previous oxidation of metals, of organic matters, and other oxidable substances in the upper parts of their downward course.

II.—VADOSE *vs.* DEEP CIRCULATION.

Again, I think, Posepny draws much too sharp a distinction between his two kinds of circulation; not indeed as to their oxidizing and non-oxidizing properties, but as to the force of circulation in the two cases respectively. In his anxiety to distinguish them sharply, he speaks as if the forces of circulation in the two cases were entirely different, being gravity or hydrostatic pressure in the one case and capillarity in the other. Now nothing can be more certain than that hydrostatic pressure is the *fundamental* cause in both cases alike; although heat, by lightening the ascending column and thus disturbing the hydrostatic equilibrium, is the *immediately determining* cause in the latter. As Mr. Rickard, in the discussion, has justly pointed out, the effect of heat in the underground circulation is exactly like its effect in determining circulation in a system of house-warming pipes.

Again, Posepny lays much stress on *capillarity* as an additional force urging forward the circulation. But surely this cannot be so. Capillarity is indeed a powerful force, urging water to where there is none, but an equally powerful force fixing it where it is. So far from assisting, it powerfully impedes circulation, and, where it is strong enough, inhibits it altogether. Dry clay is a powerful absorber of water, but, when once wet, it becomes impermeable to circulation.

In fact, Posepny sometimes speaks of the deep barysphere circulation, as contrasted with the vadose circulation, in such terms that one is left in serious doubt whether he regards the former as meteoric water at all; and yet he speaks of it as circulating. Sometimes it seems as if he regarded his vadose water alone as meteoric and his barysphere water as some other kind of water coming up from the deep interior of the earth, like, for example, the constituent water of Fisher. Such water, if there be any such, might indeed be conceived as coming up from a metalliferous barysphere, such as he supposes. But this would be escaping water, not circulating water. If he means anything like this, it ought to be distinctly stated, for it changes entirely the ground of discussion, and much that I have said above would be wide of the mark. For my own part, unless we adopt Fisher's view, I believe that we never have any water coming up which has not previously gone down. This is what is meant by circulation, but I cannot think Posepny can mean that his deep circulating water is not meteoric; and I therefore say nothing more on this head.

III.—Leaching of Wall-Rock.

Again, although I fully agree with Posepny and his brilliant expositor, Dr. Raymond, that crustification, when it is well developed, indicates deposit from within, by ascending waters already occupying the fissure, and not by laterally incoming water depositing in the act of incoming (in the manner of seepage-water in empty cavities), yet I cannot agree with them in thinking that the pressure of such ascending water would necessarily or even usually prevent the incoming of lateral currents from the wall-rock. It is doubtless true that the ascending water in the fissure is under higher pressure than *precisely similar* water on the outside; for, in addition to the hydrostatic pressure determined by the height of the outlet, it is also under hydraulic pressure in proportion to the velocity of the upward current. But the water saturating the wall-rock is also, of course, under heavy hydrostatic pressure. And when we remember the slowness of the ascending current (which is a necessary condition for deposit), and therefore the slight excess of the pressure over that measured by the height of its outlet; and when we remember further that the ascending water is *hot* while the wall-water is *cooler*, and therefore denser, we may well doubt whether the pressure of the ascending or the lateral waters will be the greater, and therefore whether the current will set outward or inward. The pressure of the ascending water is greater by virtue of its motion, but that of the wall-rock is greater by virtue of its greater density. It seems not unreasonable, therefore, to conclude that sometimes and in some places the current would set outward, and sometimes and in some places it would set inward. In many places, doubtless, the wall-rock is not saturated. In such places, of course, the current would set outward by capillarity, as well as by pressure, until saturation is reached. Of course, also, impediments to upward flow, brought about by filling of the fissure by deposit or otherwise, would increase the interior pressure, and would cause an upward ramification and outflow in many places at the surface.

Although the analogy is by no means perfect, yet, by way of illustration, the ascending fissure-current, with its freight of dissolved matters and its tributary drainage from the country-walls, may be roughly compared to a main river with its freight of suspended materials and its lateral tributaries. In such a stream, the tributaries usually discharge freely into the main river, increasing in volume, though perhaps diminishing its percentage of freight; but sometimes, by the greater pressure of flood-waters, the main stream may back up the tributaries until equilibrium is restored. So in the case before us, the main ascending fissure-stream, with its freight of dissolved matters, usually receives tributaries from the wall-rock, although, by defect of pressure of the latter or increased pressure of the former, the main current may overflow into the wall-rock. Again, in both cases, the percentage of freight is usually greatest in the main stream, and therefore the deposits by diminished velocity and carrying power in the one case and by diminished heat and pressure and solvent power in the other, are heaviest there, although sometimes heavy deposits occur also in the back waters. Again, in both cases, while the tributaries increase the volume of the current, they usually diminish the percentage of freight, although sometimes the reverse may be the fact. Finally, as rivers, when obstructed by their own deposits, may reach their final destination by inverse ramification and through many mouths, so ascending fissure-currents, obstructed by their own deposits, may branch upward and reach the surface by many exits. This, however, can be seen only in ascending currents still depositing, as in the cases of Sulphur Bank and Steamboat Springs. In most cases this part of their course has been carried away by erosion.

In a word, there seems no reasonable doubt that while usually the main deposits have been brought up from below, yet the tributaries from the country-wall do contribute, and sometimes in an important degree, to the metallic contents of the veins. This seems well-nigh proved in those cases given by Sandberger and Becker, in which analyses, especially selective analyses, find notable quantities of the required metals in the more basic minerals of the country wall-rock. To discredit the obvious inferences from the results of a method so much in accord with modern science and substitute a roundabout process of secondary leachings by vadose circulation of primary impregnations derived from a hypothetical barysphere, as Posepny does, must be regarded as a return to the speculative methods of early writers. Again, in cases like the lead-ores of Missouri and Wisconsin, where there is no evidence of disturbance or of igneous agency of any kind, is it not more rational to derive the metals from the wall-rock, though probably from its deeper parts, than from an unknown barysphere?

IV.—A More Comprehensive Theory Needed.

In conclusion, I cannot but think that the views brought forward in 1883 in my paper on the "Genesis of Metalliferous Veins" (*Am. Jour. of Sci.*, vol. xxvi., p. 1, 1883), although I would perhaps now modify them slightly on some points, still represent well the present condition of science on this subject. Those who have read that paper will remember that it is an attempt based partly on my own investigations of the phenomena of metalliferous vein-formation now going on at Sulphur Bank and at Steamboat Springs, and partly on a general survey of the whole field, to embody a comprehensive and rational theory, avoiding extremes on both hands. In it I devoted considerable space to combating the extreme lateral-secretion views of Sandberger. I did so because, on account of the recent appearance and signal ability of his treatise, it seemed likely to do harm by carrying scientific opinion too far in one direction. If it had been Posepny's treatise instead of Sandberger's, I should have felt equally compelled to combat it, and on the same ground. Posepny quotes freely from my papers on "Sulphur Bank" and on "Steamboat Springs," but not from that on "Genesis of Metalliferous Veins." Whether he has seen it, I do not know.

There has always been, and still is, a strong tendency to extreme views on this subject. On the one hand, ascensionists would derive all metals from a mysterious metalliferous region —a "barysphere," and so strong is their advocacy that even when analysis finds the required metals in notable quantities in the wall-rock, they discredit the obvious inference by suggesting a secondary leaching of materials deposited there by primary baryspheric currents. On the other hand, the lateral-secretionists would derive metals not from ascending currents at all, but wholly from direct secretion from the immediate bounding-walls; and so strong is their advocacy that even when the deposit of metals from hot ascending currents is proved by direct observation, as at Sulphur Bank and at Steamboat Springs, they seek to throw discredit on the obvious inference in regard to all metalliferous veins, by giving many cases in which hot springs do not deposit any metals. My paper was an earnest attempt to combine what is true in each, and thus to reconcile these extremes by a more comprehensive view, which explains their differences.

According to my view, the source of metals is, indeed, on the one hand, by leaching, but not by lateral secretion; on the other hand, not from a hypothetical barysphere, but from the wall-rock; though, again, not from all points alike, but mainly from the deepest parts, and even from below the deepest parts, of sensible fissures. As in the case of many other disputes, I believe both sides are right and both are wrong. Ascensionists are right in deriving metals mainly by ascending currents from great depths, but wrong in imagining these depths to be an exceptionally metalliferous barysphere. They are wrong also in not allowing subordinate contributions by lateral currents from the wall-rock higher up. The lateral-secretionists, on the other hand, are right in deriving metals by leaching, from the wall-rock, but wrong in not making the main source the thermosphere.

In the uncolored light of a more comprehensive view, many of the difficulties and obscurities of the subject disappear.

1. Ore-deposits, using the term in its widest sense, may take place from many kinds of waters, but especially from alkaline solutions; for these are the natural solvents of metallic sulphides, and metallic sulphides are usually the original form of such deposits.

2. They may take place from waters at any temperature and pressure, but mainly from those at high temperature and under heavy pressure, because, on account of their great solvent power, such waters are heavily freighted with metals.

3. The depositing waters may be moving in any direction—up-coming, horizontally moving or even sometimes down-going, but mainly up-coming, because by losing heat and pressure at every step, such waters are sure to deposit abundantly.

4. Deposits may take place in any kind of water-ways—in open fissures, in incipient fissures, joints, cracks, and even in porous sandstone, but especially in great open fissures, because these are the main highways of ascending waters from the greatest depths.

5. Deposits may be found in many regions and in many kinds of rocks, but mainly in mountain-regions and in metamorphic and igneous rocks, because the thermosphere is nearer the surface, and ready access thereto through great fissures is found mostly in these regions and in these rocks.

Some Principles Controlling the Deposition of Ores.*

BY C. R. VAN HISE, MADISON, WIS.

(Washington Meeting, February, 1900.)

PART I.—GENERAL PRINCIPLES.

---

* Published by permission of the Director of the United States Geological Survey.

PART II.—APPLICATION OF PRINCIPLES TO ORE-DEPOSITS.

PART I.—GENERAL PRINCIPLES.

INTRODUCTION.

THE following paper upon the principles controlling the deposition of ores is adapted from a treatise on Metamorphism, to be published hereafter as a Monograph of the United States Geological Survey. In the present paper the argument can be made only in outline. The argument is especially fragmentary in the treatment of the general principles controlling the circulation of underground water.

It will be held in this paper that the deposition of most ores is but a special case of the general work of groundwaters, of exceptional interest to man. In order to understand the special problem, it is necessary to have a profound knowledge of the general principles controlling the circulation and work of groundwaters. In the treatise from which this work is adapted I have attempted to treat this subject more fully and broadly than has heretofore been done. From this treatise so much is abstracted as seems absolutely necessary in order to understand the special application of the work of groundwaters to the genesis of ore-deposits. Where points are not covered with sufficient fullness, I beg the reader to suspend judgment until he sees the full treatise.

In the treatise, as well as in the following paper, I have of course drawn upon the knowledge contained in the writings of all previous workers. No general treatise upon a broad subject is the work of a single man. It is the conjoint product of all previous workers and its writer. In the following discussion of ore-deposits I am indebted to all who have contributed ideas to this subject, from the great Bischof to Sandberger and Posepny. I have tried to give full credit to all by numerous references; but I cannot be sure that I have done full justice in every case. A comparison with the writings of others will show that I am in accord with Prof. Joseph Le Conte upon more points than with any one else.*

Ore-deposits may be divided into three groups, viz.: (A)

---

* See discussion in this volume, page 270. "On the Genesis of Metalliferous Veins," by Jos. Le Conte: *Am. Journ. Sci.*, 3d Series, vol. xxvi., 1883, p. 1 *et seq.*

ores of direct igneous origin, (B) ores which are the direct result of the processes of sedimentation, and (C) ores which are deposited by underground water.

Ore-deposits of direct igneous origin are probably of limited extent. Certain very basic igneous rocks have been worked as iron-ores. In Norway are sulphide ores of various metals which Vogt* holds to be a direct segregation from a magma. Emmons† has also favored the idea of at least a first concentration of the metallic contents of ore by processes of differentiation from igneous rocks, more particularly basic ones. In many cases where ore-deposits, and especially sulphides are supposed to be igneous, the question may pertinently be asked as to how far aqueous agencies have worked in connection with the igneous agencies. I suspect, in most cases, that even if a first concentration has been accomplished by magmatic differentiation, that a second and more important concentration has been performed by underground waters, and this position I understand Emmons also to hold. Upon the question as to how far some ore-deposits are the direct processes of igneous agencies I do not propose here to enter.

To a limited extent ores are also the direct result of processes of sedimentation. As an instance of such ores may be mentioned some placer deposits. Possibly some ores are due to sublimation.

However, in so far as ores are of igneous origin, or are the direct result of the processes of sedimentation, or are the results of sublimation, they are excluded from the scope of the present paper. I intend here to consider only the third group of ores, —those produced through the agency of underground waters.

My first and fundamental premise is that the greater number of ore-deposits are the result of the work of underground water.

THE THREE ZONES OF THE LITHOSPHERE.

In another place‡ I have shown that the outer part of the crust of the earth may be divided into three zones, depending

---

* J. H. L. Vogt: *Zeitschr. für prakt. Geol.*, Jan. and Apr., 1893; Oct., 1894; Apr., Sept., Nov., Dec., 1895.

† *Trans. Am. Inst. Min. Eng.*, vol. xxii., pp. 53–95. "The Mines of Custer County, Colorado," by S. F. Emmons: *17th Ann. Rept. U. S. Geol. Surv.*, part ii., 1895–96, pp. 470–472.

‡ "Principles of North American Pre-Cambrian Geology," by C. R. Van Hise, *16th Ann. Rep. U. S. Geol. Surv.* for 1894–5, pt. i., p. 589 *et seq.*, 1896.

upon the character of its deformation: an upper zone of fracture, a lower zone of rock flowage, and a middle zone of combined fracture and flowage.

Zone of Fracture.

The zone of fracture is that near the surface. In this zone the rocks are not deformed mainly by flowage, but by fracture. They are adjusted to their new positions mainly by rupture and differential movements between the separated parts. When rocks are deformed in the zone of fracture the ruptures which occur are those of faulting, jointing, differential movements between the layers (or accommodation), fissility, and brecciation. The so-called folds in the zone of fracture are chiefly the result of numerous parallel joint-fractures across the strata with slight displacements at the joints, giving each block a slightly different position from the previous one, and thus as a whole making a fold. For instance, the folds of the rigid rocks in the Alleghenies are not in the main true flexures, but a series of slightly displaced blocks.

Zone of Flowage.

In the zone of rock-flowage the deformation is by granulation or recrystallization, no openings being produced, or at least none except those of microscopic size.* This conclusion rests upon arguments which cannot here be fully repeated. However, it may be said in passing that the conclusion that a zone of rock-flowage exists at moderate depth is based, first, upon deduction from known physical principles as to the behavior of solid bodies under pressure, and second, upon observation. It is well known that when a rigid body, such as rock, is subjected to stress greater than its ultimate strength, it must rupture or flow. If a rock be subjected to a stress in a single direction greater than its ultimate strength in that direction, and the rock is not under pressure in other directions, rupture occurs. However, if we suppose that the rock be subjected to stresses greater than the ultimate strength of the rock in all directions, and that the difference in the stresses in different directions is greater than the ultimate strength of the rock

---

* "Principles," *cit.*, p. 594, *et seq.*

under the conditions in which it exists, then if openings could be produced by a rupture, they would almost immediately be closed by pressure. In other words, at a certain depth below the surface of the earth, if we could suppose that cracks and crevices are formed by the deformation to which the rocks are subjected, the pressures in all directions being greater than the ultimate strength of the rock, these cracks and crevices would be almost immediately closed.

Since this conclusion was reached, Adams has actually deformed marble under the conditions supposed to exist at moderate depth below the earth, with the result that the rock changed its form without rupture and with no perceptible openings or cracks.*

Before the above inductive reasoning or Adams' experiment was made, I had become convinced from observation that at moderate depth rocks are deformed with fracture and differential movements between the solid particles (*granulation*), and by continuous solution and redeposition by underground water (*recrystallization*).† It was calculated that for all but the very strongest rocks, flowage must begin at a depth not greater than 12,000 meters,‡ for at this level the weight of the superincumbent mass is greater than the ultimate strength of the rocks.

Factors Influencing Depth at Which Flowage Occurs.—In the case of anticlinal arches a portion of the load may be removed by the supporting limbs, and thus the depth of the level at which the zone of flowage occurs beneath the arch be theoretically somewhat increased. However, it is highly probable that lateral stresses and increased temperature which always accompany rapid deformation, more than compensate for any removal of load. Time is another important factor. It is well known that a stress which in a short time is insufficient to rupture material may, if long continued, result in its deformation by flowage. The geologist has this factor, time, to a larger extent than scientists in any other subject, and it is a factor which he has con-

---

* Experiments in the flow of rocks are still being made at McGill University by Frank D. Adams. A preliminary account was presented to the Geol. Soc. Am., Montreal meeting, 1897. This is summarized in "Science," vol. vii., 1898, pp. 82-83.

† "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise. *Bull. G. S. A.*, vol. ix., 1898, pp. 295-313, 318-326.

‡ "Principles," *cit.*, p. 592.

stantly to keep in mind. How important this factor is may be illustrated by the deformations of rocks as result of very moderate long-continued pressures. In some cases, in cemeteries, marble slabs have been placed horizontally and suspended at the ends. In the course of a score or more of years such slabs are found to have sagged in the middle a very considerable amount. If the slabs had at the outset been bent to this extent they would have undoubtedly been ruptured. The change in form is only possible by rock flowage, either through a differential movement of the solid particles with reference to one another or by solution and redeposition, *i.e.*, recrystallization, or the two combined. The consideration of time leads me to believe that the limit of 10,000 to 12,000 meters placed as the level at which flowage of the strong rocks must occur is probably too great, and observations upon deformation in the cores of mountain masses which have been deeply denuded confirm this conclusion. Rocks, even of the strongest kind, have in many instances been deformed by flowage rather than by fracture, when at depths much less than 10,000 meters.

Other factors, such as igneous intrusions or orogenic movements, increase the heat and pressure acting on the rock, and thus tend to diminish the depth at which flowage occurs.

If this reasoning is correct, it follows that all fissures must disappear at some depth, and that the maximum depth is limited by the depth of the zone of fracture for the strongest rocks.

Zone of Combined Fracture and Flowage.

There is a zone of combined fracture and flowage below the zone of fracture, because rocks have varying strengths, because there is great variation in the rapidity of deformation, in the temperature at which the deformation occurs, in the moisture present, and in various other factors. A weak rock, for instance a shale, may be deformed by flowage at a much less depth than a strong rock, such as a granite. Thus the belt of combined fracture and flowage is of considerable thickness, possibly as thick as 5000 meters. In this zone we have all combinations of the phenomena of fracture in the various ways above mentioned, and of flowage by granulation and recrystallization.

It is highly probable that the openings of the zone of fracture gradually decrease in size as depth increases, until in the zone of flowage the openings are, as already explained, microscopic or non-existent. If a gradation such as indicated exists, it is a necessary corollary that the deformations of the zone of fracture must have their equivalents in the deeper seated zone of flowage and flexure. This point I have fully developed in other places.* It is explained that in depth faults are replaced by flexures, and that any deformation of a large mass of a given rock from one form to another by fracturing may be paralleled by similar changes of form in the zone of flowage, the result being there accomplished by granulation of the mineral particles or by recrystallization, or by both.

It might be thought that the above general statement is a deduction which cannot be confirmed by observation, but such is not the case. Many rocks which have been deformed in the zone of flowage or in the zone of combined fracture and flowage, as a consequence of denudation have reached the surface, and one is able to observe all the transition phenomena of deformation between the zones of fracture and flowage. These I have somewhat fully described in another place.† An excellent illustration of the deformation of a rock mainly by flowage, but in a subordinate way by fracture, is the Berlin rhyolite-gneiss, described by Samuel Weidman.‡ The formation of this rock was mainly that of recrystallization, but many of the mineral particles were granulated. Also many minute joint crevices were formed which were subsequently filled by cementation.

It follows from the above reasoning that fissures may disappear at different depths below. Where there are fractures with large displacements, fissures are likely to extend to very considerable depths. In proportion as the displacements are small, the fissures are likely to disappear below at less depths. Furthermore, as has already been explained, certain rocks are deformed by flowage at a much less depth than are other rocks. Therefore, in a region in which there is a great shale

---

* "Principles," *cit.*, p. 676; "Metamorphism," *cit.*, pp. 313–318.

† "Principles," *cit.*, pp. 601–603; "Metamorphism," *cit.*, pp. 312–313.

‡ "A Contribution to the Geology of the Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin," by S. Weidman. *Bull. Wis. Geol. and Nat. Hist. Surv.*, No. III., pt. 2, 1898.

or slate formation at a moderate depth, a strong fissure in more brittle rocks at the surface may disappear as it encounters the shale formation, being replaced there by a flexure. I have little doubt that considerable fissures thus disappear at a depth less than 1000 meters.

Illustrations of the disappearance of fissures with depth are found at various places. In the gold belt of the Sierra Nevadas, Lindgren* says it is "an incontestable fact that many small veins close up in depth."

Not only may fissures die out below, but fissures may disappear above, the fault along the fissures being replaced by a flexure in the overlying stratum, which yields by flowage. This is beautifully illustrated by the Enterprise mine, of Rico, Col., described by Rickard,† where faulted fissures in sandstone and limestone disappear above, at the place where shale is encountered, the shale accommodating itself to the fractures below by monoclinal flexures. (See Fig. 9, p. 409.)

The marked effect which the character of the country rock may have upon the nature of a fissure is well illustrated in the Cripple Creek district, where, according to Penrose,‡ the fissures in the hard rocks are sharp, clean-cut breaks, while in the soft rocks they are ordinarily a series of very small cracks, constituting a displacement of a kind which I call a distributive fault. Well illustrating this are mines which are partly in hard and partly in soft rock. "The vein on which the Buena Vista, Lee, Smuggler, and Victor mines are located occupies a sharp, clean-cut fissure, partly in the massive rock and partly in the hard breccia; but when it passes into the soft, tufaceous breccia on the east slope of Bull Hill the fissure is represented only by faint cracks occupied by no vein of importance. In this case the force which caused the fissure overcame the cohesion of the harder rock sufficiently to make a clean break, but in the more plastic rock it overcame cohesion only to the

---

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, p. 162.

† "The Enterprise Mine, Rico, Col.," by T. A. Rickard, *Trans. Am. Inst. Min. Engineers*, vol. xxvi., 1897, pp. 906–980.

‡ "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr. 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, p. 144.

extent of causing a series of faint fractures without any one well-defined break."*

This point of transition between the zone of fracture and the zone of flowage and the dying out of fissures below is dwelt upon in order to exclude the hypothesis of filling of fissures from the bottom. If fissures gradually decrease in size and finally die out, the streams which make their way into the fissure must enter from the side or from above. For further development of this point, see pp. 335–337.

In closing the subject it may be said that in all cases where rocks have been deformed in the zone of rock flowage, or in the zone of combined fracture and flowage, and are now at the surface, there will be superimposed, upon the effects of the deep-seated deformation, the deformation by fracture, resulting from earth movements during the time the rock is slowly migrating through the zone of fracture to the surface.

THE WATER-CONTENT AND OPENINGS IN ROCKS.

Since the ore-deposits considered in this paper are the work of underground water, and since the flowage of underground water is mainly through the openings in rocks, it is necessary to consider the condition of the water in the openings and the character of the openings which may occur in rocks.

As to the content of water the zone of fracture may be divided into two belts, an upper belt above the level of groundwater called the belt of weathering and a lower belt below the level of groundwater called the belt of saturation. Above the level of groundwater the openings in the rocks are ordinarily only partly filled with liquid. Under different conditions, which need not here be discussed, the water in the openings varies from an exceedingly small fraction of that required to fill the openings, to saturation.

Condition of Water in the Zone of Fracture.

In the belt of saturation, from the level of groundwater to its base, if it be limited to a depth of 10,000 meters, the H_2O is in liquid form, as water. The water is, however, for much of the belt superheated. If the increment of increase of tempera-

---

* *Loc. cit.*, p. 144.

ture be taken as 1° C. for every 30 meters, the critical temperature of water, 364° C., would be found at a depth of 10,920 meters. At any given place the water is subject to the pressure of the superincumbent column. The question, whether hydrostatic pressure increases at a rate sufficient to prevent the vaporization of the water, must be answered.

If the temperature of the water were 100° C., or just at the boiling-point at the surface of the earth, the most unfavorable assumption to holding the water as a liquid in the zone of fracture, it would still be true that the water would be in the form of liquid in this zone, as is shown by the following table based upon this supposition, column (1) being temperatures, column (2) being pressures necessary to hold H_2O as a liquid at these temperatures, column (3) being depth in meters at which the pressures would be produced, column (4) being the depth which would be required to produce the temperatures on the supposition that the increment of the increase of temperature is 1° C. for every 30 meters, and column (5) being the actual temperatures which exist upon this supposition at the depths represented by column (3):

(1.) Temperatures (100° C. at Surface).	(2.) Pressures Corresponding to Temperature of Col. 1.	(3.) Depth Necessary to Produce Pressure of Col. 2.	(4.) Depth Necessary to Produce Temperature of Col. 1.	(5.) Temperatures Actually Existing at Pressures and Depths of Cols. 2 and 3.
Deg. C.	Atm.	Meters.	Meters.	Deg. C.
120	2	20	600	100.66
180	10	100	2,400	103.33
225	25	250	3,750	108.33
265	51	510	4,950	117.00
310	99	990	6,300	133.00
340	148	1,480	7,200	149.33
365	205.5	2,055	7,950	168.33

From this table it will be seen that the hydrostatic pressure at various depths is far in excess of that required to hold the water in the form of a liquid; or, looked at in another way, for any given depth the temperature is not sufficiently high to allow the water at that depth and pressure to exist in the form of a gas.

Therefore, where the increase of temperature is normal, the pressure at any point down to the level at which the critical temperature of water is met is clearly much more than adequate to prevent the water from changing to steam. Where magma is intruded in the lithosphere, the temperature may become so high that this statement will not hold. This, however, is the exceptional, not the usual, case. Furthermore, it is conceivable that as result of deformation itself the temperature of the rocks might rise so high as to convert the water present into the form of steam. This possibility will not be discussed. However, it is believed to be probable from investigations upon metamorphism that this condition of affairs rarely if ever obtains, since, as I have elsewhere explained, long before the critical temperature of water is reached, solution and deposition of rock material, or recrystallization, readily takes place, and in this change the work converted into heat is far less than in mechanical granulation.*

The Openings in Rocks.

The openings in rocks include (1) those which are of great length and depth, as compared with their width, and thus are essentially flat parallelopipeds; (2) those in which the dimensions of the cross-sections of the openings are approximately the same, and therefore resemble tubes of various kinds, and (3) irregular openings.

(1) The openings of the first kind are those of faults, of joints, of fissility, and of bedding partings. The openings of this class are likely to be continuous for considerable distances. This is true to the largest extent of fault openings, is true to a less extent of joint openings and bedding partings, and to a still less extent of the openings of fissility. It is recognized that many of the fissures are exceedingly complex. They are, indeed, in many instances, a series of parallel or intersecting fractures, forming a zone of brecciation. However, for such a zone, as a whole, the statement still holds that the openings have great length and depth as compared with their width. In position, the joint-, fault-, and fissility-openings ordinarily have an important vertical element, or at least traverse the beds. Frequently they are nearly vertical, or traverse layers of formations at right angles. In consequence of this, they are very important factors

---

* "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise, *Bull. G. S. A.*, vol. ix., 1898, pp. 310–311, 313–318.

in the flowage of underground water. Relatively pervious formations separated by impervious formations may be thus connected. Pervious formations overlain by impervious formations may be connected with the surface. Bedding-partings are parallel to the layers. Since underground waters very frequently follow formations, the bedding-partings, which extend long distances, become very important factors in the promotion of flowage parallel to the formations. This is especially true of the contact of formations of different character. These contacts are places of maximum differential movements, of consequent complex fracturing, and therefore of important openings and large circulation.

(2) The spaces of the second class are those of the mechanical sediments, including conglomerates, sandstones, soils, tuffs, etc. The openings of mechanical sediments have a strong tendency to a definite form, and are continuous. The forms of these openings have been fully discussed by Slichter.* The openings alternately narrow and widen. At their wider parts their sections are roughly polygonal, the polygons having more than three sides, and these are curved. At their narrowest places, the cross-sections of the openings approximate to triangles, and where the grains are of equal size, the triangles are equilateral. The form of the tubes at their minimum cross-section is due to the contact of three grains in a plane, the space between which is nearly triangular.

(3) Irregular openings are those of the vesicular lavas and the irregular fractures of the rocks. They are in part continuous and in part discontinuous. In rocks where the openings are exceedingly irregular in form, the flowage of water is limited to the continuous openings, however small they may be.

Openings of any of the above classes, whether a result of deformation or produced by original sedimentation or formed in connection with volcanic action, may be enlarged by solution. Indeed, this will be the case wherever the processes of solution more than counterbalance the processes of precipitation. It is later explained that this is the more likely to occur with downward moving water than with upward moving water. Since

---

* "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, 19*th Ann. Rept. U. S. Geol. Surv.*, for 1897–98, pt. ii., pp. 305–323.

downward moving waters are dominant above the level of groundwater and prominent in the upper part of the belt of saturation, it is in this area that openings are most frequently enlarged by solution. (See pp. 327–329, 413.) It has been argued by Posepny* that openings serving as channels for underground water may be wholly produced by solution. That openings may be somewhat prolonged and different openings connected by solution, thus helping underground circulation, is more than probable, but that important passages are produced wholly by solution is an assumption which I think has not been verified by the facts of observation.

Size and Number of Openings.—Large openings are favorable to rapid flowage. Small openings are unfavorable to rapid flowage. This results from the fact that the friction between the walls and the moving column steadily becomes greater for a given volume of water as the openings become smaller. Large openings are favorable to a somewhat direct course. Small openings are favorable to a circuitous route. The direct course of water in large openings is illustrated by limestone regions, where there are numerous large joints and caves within which the water is quickly concentrated. This being the case, the flowage of water is very largely in the upper part of the zone of fracture. Where the openings are small, a circuitous route must be taken, for to pass a given volume of water from one point to another it is necessary that a wide range of openings must be used. This is more fully explained, pp. 309–317.

Fault, joint, bedding, and fissility openings may be so numerous that the pore-space is very large. Upon the average fault openings are farther apart, but larger than the joint openings, and joint openings are wider spaced and larger than the openings of fissility. It cannot be said which kind of openings upon the average gives the larger pore-space. Since, however, large openings are favorable to rapid flowage, for a given pore-space the fault openings are likely to give a greater flowage than joint openings, and joint openings a greater flowage than those of fissility. This follows from the greater size of the fewer openings. To this is to be added the element of greater

---

* "The Genesis of Ore-Deposits," by F. Posepny, this volume, pp. 12–17.

continuity of the larger openings. Therefore, with a given pore-space, the flowage may be vastly greater in the case of faults than in the case of joints, and much greater in the case of joints than in the case of fissility. It will later be explained that the larger openings are occupied by the trunk streams, and that in these openings ores are most likely to be concentrated; hence, ore-deposits most frequently form in fault-fissures, less frequently in joints, and still less frequently in the smaller and more discontinuous openings.

If the principle that large openings are favorable to rapid flowage be applied to mechanical sediments, it follows that with a given pore-space the coarse conglomerates furnish a much larger flow than fine conglomerates, the fine conglomerates a larger flow than the sandstones, and these a vastly larger flow than the fine-grained shales.

Upon the basis of size, openings in rocks may be divided into (a) openings which are larger than those of capillary size, or supercapillary openings, (b) capillary openings, and (c) subcapillary openings.

For water, openings larger than capillary openings, according to Daniell,* may be circular tubes which exceed .508 mm. in diameter, or may be sheet-openings, such as those furnished by faults, joints, etc., whose widths are one-half of this or exceed .254 mm. To movement of water in such openings the ordinary laws of hydrostatics apply. Capillary openings for water solutions include those which, if circular tubes, are smaller than .508 mm. in diameter, or, if sheet spaces, are narrower than .254 mm., and which in either case are larger than the openings in which the molecular attractions of the solid material extend across the space. Such openings in the case of circular tubes are those smaller than .0002 mm. in diameter, or, if sheet passages, are below .0001 mm. in width. Capillary openings therefore include circular tubes from .508 mm. in diameter to .0002 mm. in diameter, and sheet passages from .254 mm. in width to those .0001 mm. in width. Capillary openings of other forms have a range limited between .508 mm. and .0001 mm., but no one form has so wide a range as this. To movement of water in openings such as these the laws of cap-

---

* *Text-Book of Physics*, by Alfred Daniell, 3d ed., 1894, pp. 277, 316.

illary flow apply. By subcapillary openings are meant those in which the attraction of the solid molecules extends from wall to wall. These include all tubes smaller than .0002 mm. in diameter, and sheet openings smaller than .0001 mm. in width. For intermediate forms the subcapillary openings have as their maximum limit a range from .0002 mm. to .0001 mm.

Within this paper I cannot fully discuss the laws of flowage for each of these classes of openings and their application. This is fully done in a treatise on "Metamorphism," from which this paper is abstracted. It is, however, necessary to summarize the laws of flowage of water in each of the three classes of openings.

The flowage of water through supercapillary tubes nearly follows the ordinary laws of hydrostatics, *i.e.*, the flowage of water is as the square root of the pressure due to head. If $V =$ velocity, $H =$ pressure due to head, and $G =$ force of gravity, then $V = \sqrt{2GH}$. For instance, the velocity resulting from a head of 10 cm. would be the square root of 2 x 981 x 10 cm.

This formula is only approximately correct, for the internal friction in supercapillary tubes is dependent upon the viscosity of the solutions (a factor considered on p. 311), upon the regularity of the tubes, and upon the velocity of flowage. If the tubes are not straight, eddies will form which will increase the internal friction and decrease the speed of movement. In the long, rough, irregular underground passages not of determinable size, eddies may so increase the internal friction as to render the formula of hydrostatic flow inapplicable. Further, as a result of the viscosity, the resistance increases with increase of velocity, so that where the velocity of movement is considerable, even if the tubes are open and continuous, the formula gives too high results.

The flowage of water with a given head in supercapillary openings is very rapid indeed, as compared with the smaller openings. The supercapillary openings include the greater number of the fault openings, joint openings, bedding partings, many openings of fissility, and the openings in the coarser mechanical sediments, such as very coarse sandstones, and conglomerates.

According to Poiseuille's law, the flowage of water in capillary openings is proportional not to the square, as in supercapillary openings, but to the fourth power of the radius; is proportional not to the square root of the pressure, as in supercapillary openings, but to the pressure; is inversely proportional to the length of the tube; and is indirectly proportional to the viscosity of the liquid.*

From the foregoing it follows that the flow in a tube with a radius of .2 mm. in diameter would be sixteen times as great as in a tube .1 mm. in diameter. Furthermore, in a tube of a definite length, if the pressure be doubled the flow would be doubled, if trebled the flow be trebled. With a given pressure, if the length be doubled the flow would be diminished to one-half, if trebled to one-third. The viscosity of underground waters decreases rapidly with the temperature, being only one-fifth as much at 90° C. as at 0° C. Therefore, with capillary tubes of a given size the flowage would be five times as fast at 90° C. as at 0° C.

How important the laws of capillary flow are in the movement of underground water and the production of ore-deposits will be understood when it is known that the openings of all ordinary sandstones and mechanical sediments are capillary openings. Furthermore, it is to be remembered that at a depth of 2700 meters, supposing the increment to be 1° C. for 30 meters, the temperature is 90° C. Therefore this fact, because of decreased viscosity, is very favorable to the flowage through the openings at considerable depth.

Notwithstanding the increased mobility of water, the circulation in small capillary tubes is very slow indeed; so slow that layers of rocks in which the openings are of small capillary size, such as those of dense clays and shales, are spoken of as impervious. Although this is not exactly true, the movements of water through such materials is slow as compared with the movement in larger capillary openings.

Openings of the third class are subcapillary. In these the

---

* According to Poiseuille, the general formula for the flow through a tube of circular section is $f = \frac{a^4 p}{8 \mu l}$, in which f is the discharge in cubic centimeters per second, a is the radius of the tube, l its length, p is the difference in pressure at its ends in dynes per square centimeter, and μ is the coefficient of viscosity of the liquid. (See "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, 19*th Ann. Rep. U. S. Geol. Surv.*, pt. ii., p. 317.)

attraction of the solid molecules extends from wall to wall. The water is held as a film glued to the walls by the adhesion between the water and rock. There is no free water. In such openings as these the flowage must be exceedingly slow or nil. Subcapillary openings as here used include also intermolecular spaces.

It is evident, from the reasoning given on the preceding pages, that the openings in the zone of rock-flowage are those of subcapillary size. Furthermore, it is evident that the subcapillary openings are discontinuous. It has been seen that at a depth greater than about 11,000 meters the water probably has a temperature greater than the critical temperature of water; but in the opinion of some physicists the liquid state may persist even after the critical temperature be passed.* Whether the H_2O below this depth is a liquid or is water-gas cannot certainly be determined; but it may be supposed that the viscosity is comparatively small. Furthermore, the water is under enormous pressures. Under circumstances of temperature exceeding the critical temperature of water and very great pressure, one would be rash to assert that water does not pass through the exceedingly small subcapillary spaces of rocks in the zone of flowage, or possibly also through the intermolecular spaces. Some movement of water might also occur in connection with the processes of solution and deposition, or recrystallization, which, as I have explained, is characteristic of this zone. That is to say, the mobility within the solid material implies at least an equal mobility in the liquid material which is also present.

In reaching a probable conclusion it is, however, to be remembered that it must be assumed that the rocks of the lower part of the lithosphere are also probably saturated with water, and that the pressure above is resisted by equal pressure from below. Doubtless, under the changing conditions caused by rock deformation, metamorphism and denudation, and by other vicissitudes to which the lower part of the lithosphere is subjected, the water-pressures become unequal at various times and places, and at such times and places there would be an undoubted tendency for water to move from places of great pressure to places of less pressure.

---

* Preston, "Theory of Heat," p. 378.

Whatever conclusion may be reached as to the possibility of the circulation of water in the zone of rock-flowage, it will probably be agreed by all that the circulation, if it occurs at all, must be exceedingly slow. Indeed, upon this point we are not confined to deduction. We have an almost certain inference from the character of the alterations which occur in the zone of rock-flowage. In my treatise on Metamorphism I show that within the zone of fracture, immigration and emigration of rock-material is very great, and that the composition of a rock may within this zone be materially modified as a consequence. However, while a rock in the zone of flowage may be transformed from a massive form to a schist or a gneiss, the composition of the resultant schist or gneiss is almost identical with that of the original rock. Had there been rapid and extensive circulation of water within this belt, it would have been inevitable that the composition of the resultant metamorphosed rocks would have been different.

Ore-Deposits Derived from Zone of Fracture.

We conclude from the foregoing that while underground circulation of water upward, downward, and lateral, is a possibility within the zone of rock-flowage, it is very slow, and that it cannot be appealed to to explain metalliferous deposits. If any one asserts that the metalliferous materials of mineral veins are derived by water circulation from the centrosphere,* or are derived from the lithosphere* below the zone of rock-fracture, I hold this to be a pure unverified assumption for which there has not as yet been adduced one particle of evidence, and opposed to which stand well-known principles of physics concerning the movement of water in minute openings, and all observations which have been made as to the actual changes which have taken place in the rocks once within the zone of rock-flowage.

The original source of much of the material for the metalliferous deposits may, indeed, be largely the centrosphere or the lower part of the lithosphere; for from these sources vast masses

---

* The term lithosphere is here applied to the outer shell of earth, which is known to be solid. The term centrosphere, following Powell, is applied to the central mass within the lithosphere comprising the greater part of the world, as to the character of which we have no definite knowledge.

of volcanic rock are injected into the zone of fracture or brought to the surface. This is especially true during great periods of vulcanism. Furthermore, it is well known that in regions of volcanic rocks many ore-deposits are found. Also it is believed that all the rocks of the lithosphere were originally igneous, and that from these igneous rocks the sedimentary rocks have been derived by the epigene forces, *i.e.*, the forces working through the agencies of atmosphere and hydrosphere. It follows, therefore, that the metals of ore-deposits, either directly or indirectly, are derived from igneous rocks. However, the ores are directly derived from rocks in the zone of fracture by circulating underground waters. The rocks which furnish the metallic compounds may be intruded igneous rocks; they may be extruded igneous rocks; they may be the original rocks of the earth's crust; they may be sedimentary rocks derived by any of the processes of erosion from primary rocks; they may be the altered equivalents of any of these classes.

That there is a sufficient amount of metalliferous material within the rocks of the zone of fracture to account for all metallic deposits will be admitted by all. It is well known that the amount of material which it is necessary to suppose to be originally present in the country-rock within the reach of the underground water circulation in the zone of fracture, in order to fully account for the ore-deposits, is an exceedingly small fraction of 1 per cent.; such small fractions in the case of the rarer metals that the numbers have little significance to us. Even in the case of the common metals, such as iron, lead, zinc and copper, the fraction of a per cent. which it is necessary to suppose to be present is exceedingly small. This is well illustrated by the lead- and zinc-district of southwestern Wisconsin. Here, according to Prof. Chamberlin, Mr. Buell has calculated that if the source of the metal in the Potosi district, the richest in the region, be restricted to a layer 100 feet deep and limited on the outside of the area of paying crevices by half the average distance between the crevices, to account for all the lead which had been taken out, it would only be necessary to suppose that the rock contained "one-fourteen-hundredth of one per cent., or a little more than seven millionths part of the rock."*

---

* "Ore-Deposits in Southwestern Wisconsin," by T. C. Chamberlin, *Geol. of Wis.*, vol. iv., 1882, pt. iv., p. 538.

The second fundamental premise of this paper is, that the material for ore-deposits is derived from rocks within the zone of fracture.

The Source of Underground Water.

Since it has been shown it cannot be assumed that there is any considerable circulation of underground water in the zone of rock-flowage, it follows that we cannot suppose that the water of the zone of fracture passes into or is derived from the zone of rock-flowage on any large scale. Doubtless this transfer does take place to some small extent. Also, through the agency of vulcanism water occluded in magma is transferred from the zone of rock-flowage, or even possibly from the centrosphere, to the zone of rock-fracture. Furthermore, hydration and dehydration of the rocks are constantly taking place, and these processes may not balance. However, the amount of underground water coming from the deep-seated zone of rock-flowage in these ways at any one time is relatively small, and therefore the meteoric water entering the crust substantially balances that issuing from it. Hence, so far as the main work of ore-deposition is concerned, the water is that of the zone of rock-fracture, and this water is water of meteoric origin, which makes its way from the surface into the ground, and there performs its work and issues to the surface again.

The third premise of this paper is that by far the major part of the water depositing ores is meteoric.

The Cause of the Flowage of Underground Water.

The fourth premise of this paper is, that the flowage of underground water is caused chiefly by gravitative stress.

Gravity is effective in the movement of underground water in proportion to the head. Head is due to the fact that the water entering the ground at a certain level, after a short or long underground journey, issues at a lower level.

The efficiency of gravity is also dependent upon temperature. In so far as water is warmer at its point of issuance than it was when it joined the sea of underground water, this is favorable to circulation, and gives an effect in the same direction as head. This is due to the fact that the density of water varies inversely with the temperature.

Taking the volume of water at 4° C. as 1, its volume at 50°

C. would be 1.0120; at 75° C. would be 1.0258, and at 100° C. would be 1.0432.* Therefore the increase in the temperature of underground water may lessen its density as much as 4 per cent. without exceeding its boiling-point at normal pressure, and a diminution of density of 1 per cent. or more is probably not uncommon. It is therefore evident that in columns of water of equal length the stress of gravity is considerably greater upon the column having the lower temperature. That the difference in gravitative stress, due to difference in temperature, may be sufficient to produce rapid circulation in pipes which are supercapillary, is shown by the use of the principle in the hot-water system of heating buildings. Underground, as in the hot-water system of heating, heat is the energy which causes the water to expand, and gives a difference in density. When heat has produced a difference in density of the two columns, gravity is the force which inaugurates and maintains the circulation.

It is believed that underground circulation may be promoted in an important degree by difference in temperature of the descending and ascending columns of water, resulting from heat abstracted from the rocks, due wholly to their normal increment of temperature with depth. Later it will be shown that the downward moving water is ordinarily dispersed in many small openings and moves relatively slowly. Therefore it may be supposed at any given place to have approximately the temperature of the rocks. The upward movement of water, upon the contrary, is shown to be usually in the larger openings and relatively rapid. Therefore at any given place its temperature is probably higher than is normal for the rocks at that depth. The result is to give the descending and ascending columns a difference in temperature, the ascending column being hotter. As already noted, the expansion of water with increase of temperature is considerable, amounting to over 4 per cent. between 0° C. and 100° C., that is, a given mass of water would occupy a volume 4 per cent. greater. In other words, if there is an average difference of 100° C. in the ascending and descending columns, 100 feet of the downward moving

---

* "Exercises in Physical Measurements," by L. W. Austin and C. B. Thwing 1896, p. 151.

water would balance 104 feet of the upward moving water. If we suppose the descending and ascending columns to be connected, of equal height, and having an average difference of 100° C. in temperature, this would be equivalent to a head of 4 feet per 100 feet all along the length of the column. Probably the difference in temperature between the columns is not often so great as 100° C., but the illustration shows that the difference in temperature between ascending and descending columns of the same length may give a sufficient stress to overcome friction and viscosity, and give a somewhat rapid movement to underground water.

As an illustration of the principle may be mentioned the water-power of the sea-mills of Cephalonia, which, according to the Crosbys, is wholly due to the difference in the temperature of the descending and ascending waters.* In regions where vulcanism or dynamic action has recently occurred, the difference in density resulting from difference in temperature in the descending and ascending columns may be an even more important influence in the circulation of the underground waters than in regions where the high temperature is due to the normal heat of the rocks. Such a region is the Yellowstone Park.

In some cases the issuing water throughout a great region is very clearly at a higher temperature than the entering water, and in such regions this difference in temperature must be a very important factor in its underground circulation. In such cases the difference in temperature of the descending and ascending waters generally results from the normal increase of temperature due to depth, from regional vulcanism, and from the rocks having a higher temperature than normal because of recent orogenic movements.

An excellent illustration of such a region is the Cordilleran region of the western United States, in which there are many valuable ore-deposits. Gilbert† and others have shown that scattered throughout this vast region, occupying nearly one-

---

* "The Sea-Mills of Cephalonia," by W. F. Crosby and W. O. Crosby, *Tech. Quar.*, vol. ix., 1896, pp. 6–23.

† "The Geology of Portions of Nevada, Utah, California and Arizona, Examined in the years 1871 and 1872," by G. K. Gilbert, *Rept. Geog. and Geol. Surveys* west of 100th Meridian, vol. iii., 1873, pt. 1, pp. 148–149.

third of the United States, are many hot springs, the temperatures of which vary from 37° C. to 100° C. More numerous than these are the warm springs, the temperatures of which are below blood heat. The warm springs may be considered as including those between 18° C. and 37° C. According to Gilbert, the water of all the foregoing springs exceeds the mean annual temperature of the region by 8.3° C.

Although we have no data by which to verify the statement, I have no doubt whatever that the springs, the temperature of which is above the mean annual temperature, but less than 8.3° C. above, exceed by many times the total of all springs the temperatures of which are 8.3° C. or more above the normal temperature of the region. And it is to be remembered that a slightly increased temperature of issuing water over that of the falling water through the vast number of springs and through seepage is of far greater quantitative importance than the marked increase of temperature in the comparatively few warm and hot springs. This illustrates the old principle that the widespread, moderate forces are incomparably more important than the more conspicuous, but more circumscribed forces.

While gravity is the only important force to which appeal can be made to account for the circulation of waters producing ore-deposits, circulation in some small degree does result from other immediate causes. For instance, earth movements may deform the rocks, and in this process squeeze out the water, as in the production of the crystalline schists from the sedimentary rocks. If the deformation of the rocks be referred to their ultimate cause, gravity, even the circulation of the water resulting from deformation is indirectly due to the stress of gravity. However, the important immediate causes of movements of underground water below water level are two—gravity and deformation.

But whatever the cause of the flow of underground water, the direction of movement is from places of greater pressure to places of less pressure. A current going in any direction is evidence of an excess of pressure in the rear of the current. Thus, water which enters by seepage or through capillary tubes into a larger opening, such as a fissure, must be under greater pressure than the column of water into which it makes its way. Whether the motive force in the movement of the water is difference in gravitative stress or deformation, or any other cause, the excess of pressure resulting in movement is behind the current.

In the foregoing statement as to the cause of the movement of underground water, only the vertical component of the columns has been considered. The horizontal component of the column has no effect. So far as there is horizontal movement, the energy required for this movement to overcome friction and internal viscosity is derived from the forces already mentioned,—that is, gravitative stress or deformation.

Belts of Underground Circulation.

The circulation of underground water is divided into two parts: that of an upper belt above the level of groundwater, and a lower belt below the level of groundwater.

Upper Belt of Underground Circulation.—The upper belt of underground water circulation extends from the surface to the level of groundwater. The thickness of this outer belt of water circulation varies greatly. At or near streams, lakes, or ocean, and in areas where the surface is not much higher than the adjacent bodies of water, the level of groundwater may reach near or to the surface, and thus there may be, for these areas, either a very thin upper belt of circulation, or none. In regions of moderate elevation and moderate irregularities of topography the level of groundwater is usually from 10 feet to 100 feet below the surface. It is especially likely to be near the surface in regions where there is a thick layer of drift or a thick layer of disintegrated rocks. In elevated and irregular regions, and especially those in which the precipitation is rather small, the level of groundwater may be from 100 to 300 feet below the surface. In high, desert regions, and especially limestone regions, the level of groundwater may be from a thousand to several thousand feet below the surface.

The position of the level of groundwater is more fully considered further on, in connection with the belt below that level.

A large amount of the water which enters the upper belt is, without entering the lower belt, again brought to the surface through capillarity, or through the influence of vegetation. The circulation of this water in the upper belt alone has little influence upon the ore-deposits, and is here ignored. Another portion of the groundwater moves downward through the upper belt and joins the sea of underground water. This water is associated with oxygen, carbon-dioxide, and other gases. These substances perform various classes of work, which are considered on pp. 329–334.

Lower Belt of Underground Circulation.—The lower belt of circulation has as its upper limit the level of groundwater. This level is not horizontal, but is undulating, the undulations following the topography. A topographic map of a region is to a certain extent a topographic map of the level of groundwater; but the latter is less accentuated. The elevation of the contour of the groundwater at a given place is less than the elevation of the surface contour by the depth of the level of groundwater.

That the level of groundwater roughly follows the topography is shown by the fact that upon many hills and mountains, wells reach water at the very moderate depths of a few score, or at most 100 or 200 feet. The relation is further illustrated by the fact that where a shore begins to rise from a body of water, as from a lake, the level of groundwater also rises, but not so rapidly. As an example of this may be mentioned the case of a well at Madison, Wisconsin, about 1200 feet from Lake Mendota and 88 feet above its surface, in which the water is on an average about 52 feet above the surface of the lake.*

In general, the more accentuated the topographic features, the greater is the difference between the surface topography and that of the level of groundwater. However, this difference also depends upon the character of the rocks. Where the openings in the rocks are numerous and large, there is a greater difference in the topography of the surface and of the level of the groundwater than where the rocks are less open. In fractured limestone regions containing caves, the level of the groundwater may follow approximately that of the drainage of the district, and thus there be a great difference between the topography of the surface and that of the groundwater. Where a region is covered with a thick mantle of fine material, as drift,

---

* "Principles and Conditions of Movements of Groundwater," by F. H. King, 19*th Annual Rept. U. S. Geol. Surv.*, for 1897–98, pt. ii., p. 99, 1899.

the topography of the groundwater may very closely follow that of the surface. Finally, the less the precipitation the greater the difference between the contours of the surface and the level of groundwater. In the Grand Cañon region of Colorado we have a district in which the topography is much accentuated with sudden and great changes in elevation, in which the rocks are largely limestone and the precipitation small. Therefore in this region there is a very great difference between the topography of the surface and that of the level of groundwater.

Capacity of Water for Work in the Lower Belt of Underground Circulation.—The temperature of water in the lower belt of underground circulation increases with depth. The average increment is about 1° C. for 30 meters. Supposing the water at the surface to be 0° C., it would be 100° C. at a depth of 3000 meters. At a depth of 10,000 meters it would be 333° C. It has been shown, pp. 291–293, that the pressure increases with depth with sufficient rapidity to hold the water in the form of a liquid. Therefore the work of the water in the zone of fracture below 3000 meters is that of superheated water. It is well known that pure water at ordinary temperatures is capable of dissolving all compounds to some extent, but the amount of the more refractory compounds dissolved is exceedingly small. But pure water at a high temperature is a potent solvent. Barus has shown that water at temperatures above 185° C. attacks the silicates composing soft glass with astonishing rapidity.*

At 180° C. various zeolites can be dissolved in pure water, the material crystallizing out on cooling. Lemberg shows that water at 210° C. slowly dissolved anhydrous powdered silicates. It is therefore apparent that water in the lower part of the zone of fracture is a most potent chemical agent.

Furthermore, it is well known that one salt in solution may assist water in dissolving another salt. For instance, the presence of alkaline sulphides is very favorable to solution of sulphides of the heavy metals, such as copper, silver and gold. On the other hand, the presence of one compound in solution

---

* "Hot Water and Soft Glass in their Thermo-dynamic Relations, by C. Barus, *Am. Jour. Sci.*, IV., vol. ix., 1900, pp. 161–175.

may be unfavorable to the solution of another compound. Thus in the underground waters the material in solution continually affects the capacity of the water to dissolve and precipitate other materials. This subject will be further discussed, pp. 324–326.

Movements of Water in the Lower Belt of Underground Circulation.—The complex movements of underground water may be resolved into two components, horizontal or lateral movements and vertical movements.

The vertical component of the journey of underground waters in the zone below the level of groundwater may be considered as confined to the zone of fracture, and is probably measured at a maximum by 10,000 meters, or at most by 12,000 meters. The lateral component, on the other hand, may vary from a few meters to hundreds or even a thousand or more kilometers. Upon the average, the horizontal component is probably far greater than the vertical component.

In order to understand the work done by underground water in its journey, it is first necessary to know the path which it follows. Upon this point the recent analytical work of Prof. C. S. Slichter* gives the desired information. He has ascertained that the spaces in soils and in mechanical sediments, so far as the flowage of underground water is concerned, may be considered as a series of triangular tubes. By Prof. Slichter's analysis the flowage of water from one place to another, say from A to B (see Fig. 1), is not by a direct path, but by a large number of diverging paths from A during the first part of the journey, and by a large number of converging paths to B during the latter part of the journey. This may be illustrated by supposing the water to be poured into a well, A, and to flow to a well, B. The horizontal course of the water is represented by Fig. 1, and the vertical course by Fig. 2. These conclusions apply equally well to any porous rock other than a soil or sandstone in which the spaces are distributed in a somewhat uniform manner.

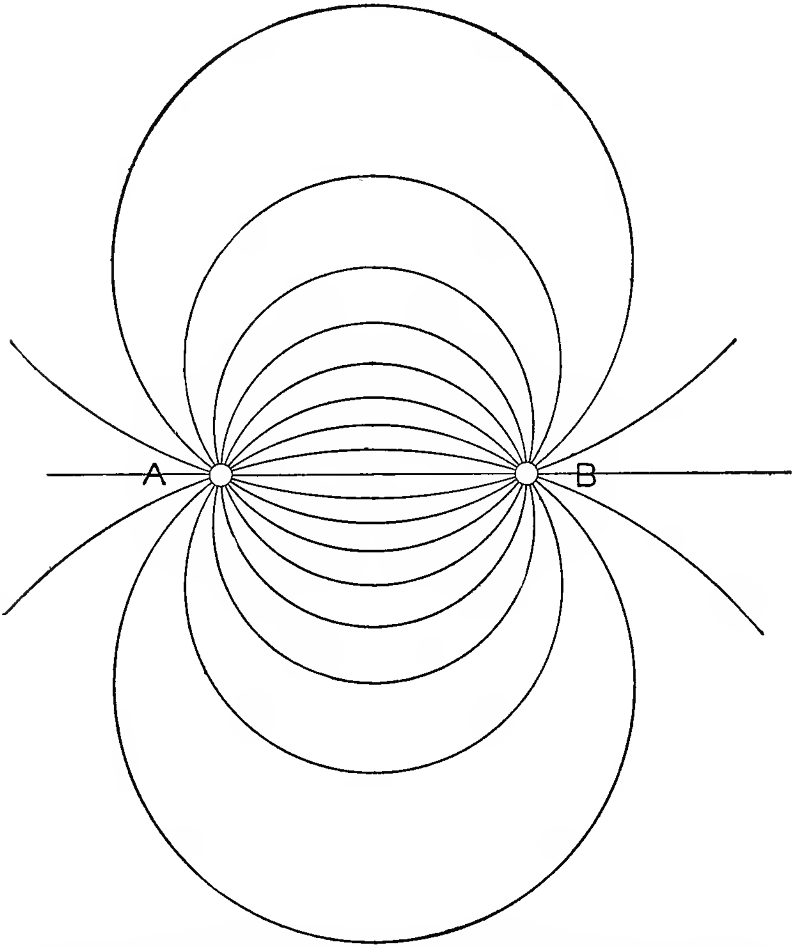
It is apparent that these conclusions have far-reaching consequences as to the flowage of underground water. In the

---

* "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, 19*th Ann. Rept. U. S. Geol. Surv.*, for 1897–98, p. 312.

passage of the water from the top or slope of a hill to a point of issue at the foot of the hill, supposing these to be the only points of entrance or issuance of the water, and supposing the spaces to be uniform, the vertical course would be represented by the lines of Fig. 3, and the horizonal course would be represented by the lines of Fig. 1. We see at once that for the larger topographic features the vertical component of flow may pass quite to the lower limit of the zone of frac-

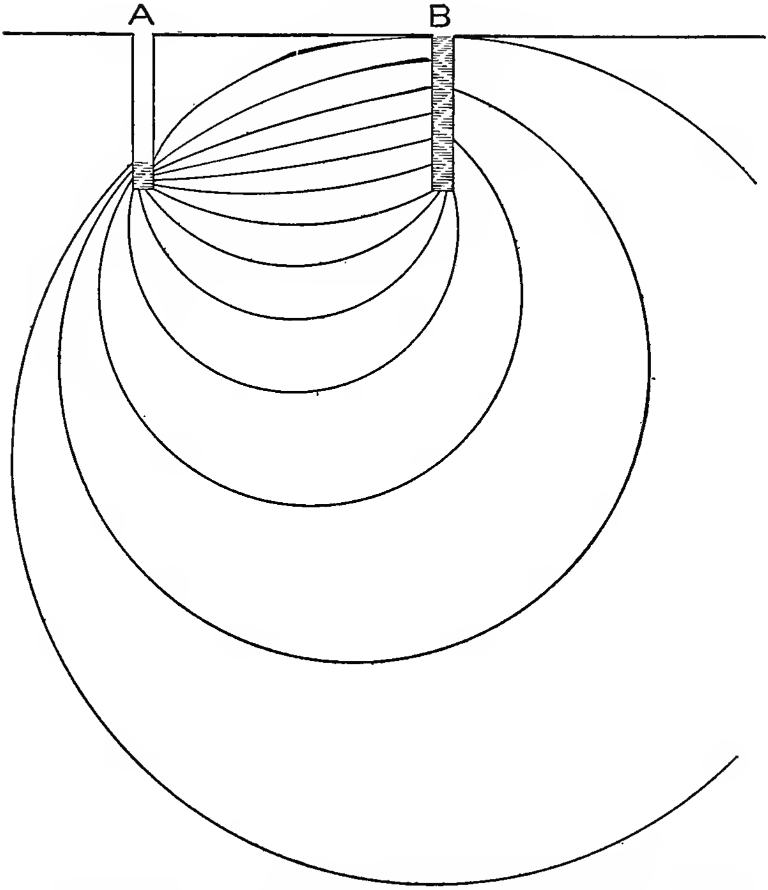
Fig. 1.



Ideal Horizontal Section of the Flow of Underground Water through a Homogeneous Medium, from One Well to Another.

ture. This would probably be true even if water throughout its underground journey remained at a constant temperature. But it is to be remembered that the deeper water penetrates, the higher its temperature; also that the movement of water in the lower part of the zone of fracture is largely through capillary openings; further, that the flowage in capillary openings is inversely as the viscosity; and, finally, that the viscosity decreases rapidly with increase of temperature. Therefore, the increase of temperature with depth is a potent factor favorable to a deep course for underground water. It therefore seems probable

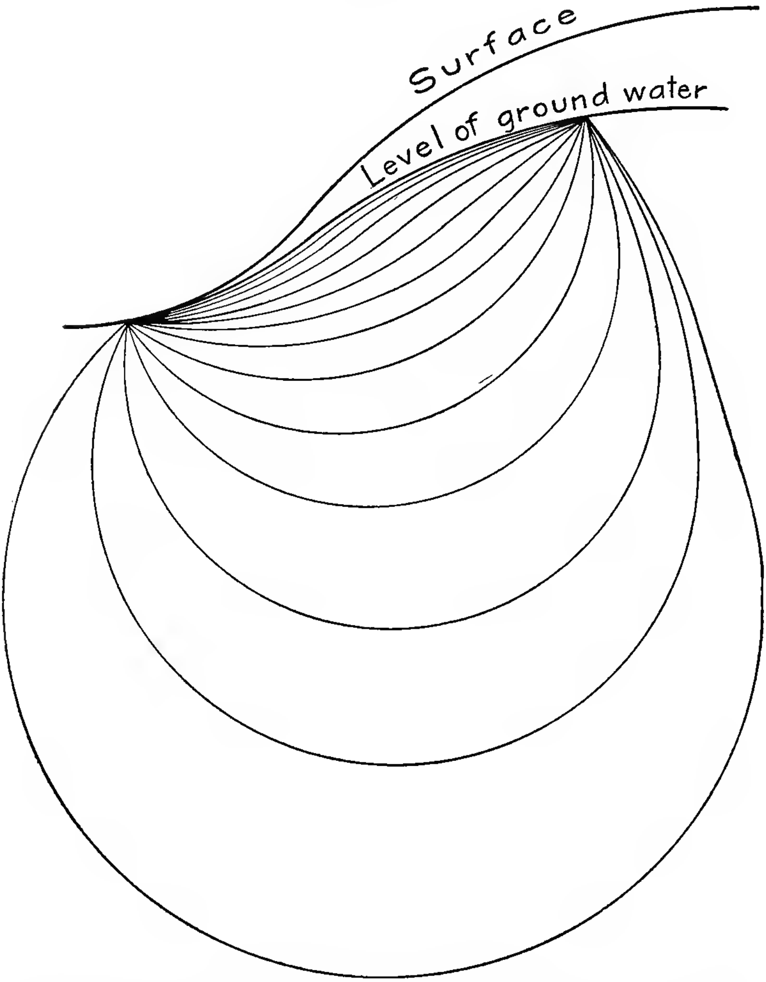
Fig. 2.



Ideal Vertical Section of the Flow of Underground Water through a Homogeneous Medium, from One Well to Another.

that as a result of head due to topographic irregularities and temperature differences, the entire zone of fracture is being regularly traversed by underground waters. Of course, the

Fig. 3.



Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at One Point on a Slope and Issuing at a Lower Point.

amount of flowage is far greater in the upper part of the zone than in the lower part, but even in the lower half or third of the zone of fracture the amount of flowage cannot be considered small.

The principle of the distribution of the flowage of water over the entire available area is well illustrated by the case of water flowing horizontally into a beaker from one side and overflowing the beaker on the other side. The movement of the water will not be confined to the liquid near the surface of the beaker, but all portions of the water in the beaker from the top to the very bottom will take part in the flowage, although, of course, the rate of movement will be much more rapid at the top than at the bottom.* The well-known hydrodynamical principle thus illustrated, that the entire available cross-section will always be utilized by flowing currents, is directly applicable to lateral moving waters in the zone of fracture. It is conclusive evidence that this zone will be searched to its base by moving waters, although the waters joining and departing from the underground sea appear and disappear at the surface.

In an actual case of underground flowage the water does not enter the ground at a single point, but enters at every point of a slope. As a sample case, we may suppose that the water entering on a slope reaches the surface again at the level of a stream in an adjacent valley. To get an idea of the complexity of the flow in this ideal case, we may arbitrarily select a number of points where the water enters, and trace out its course. We may plat by different kinds of lines, continuous and broken, the vertical components of the flowage of the water which enters at each place independently of the water that enters at other places. (Fig. 4.) We have a series of intersecting lines in the figure representing the vertical components of movement.

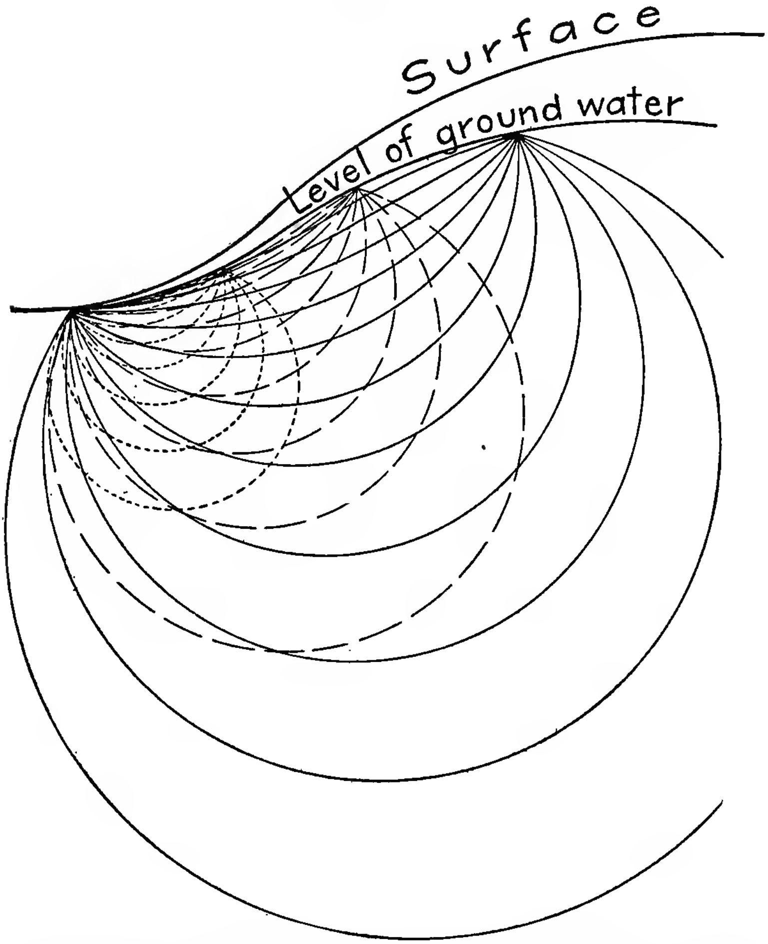
It is not supposed that water actually follows paths similar to those represented by the figure, for there is mutual interference of the water entering at the various points. As a result of this, the water entering the opening nearest the exit would take a more direct course than the average of that platted; but, as a consequence of this, the water from the next openings up the slope would take a more indirect course, on the average, than that platted, and so on. The total result would be to give

---

* Slichter, *cit.*, p. 331, sect. 5. Compare Posepny, *cit.*, this volume, p. 26.

an average course for the water which can be represented by combining the independent curves. (Fig. 5.) The effect, so far as the geological action of the underground water is concerned, would be approximately the same, whether the course of the water were that represented by Fig. 4 or that represented by Fig. 5. This statement, applicable to a few points of entrance and one of exit, is equally applicable to a great number of points of entrance. The statement can be further ex-

FIG. 4.

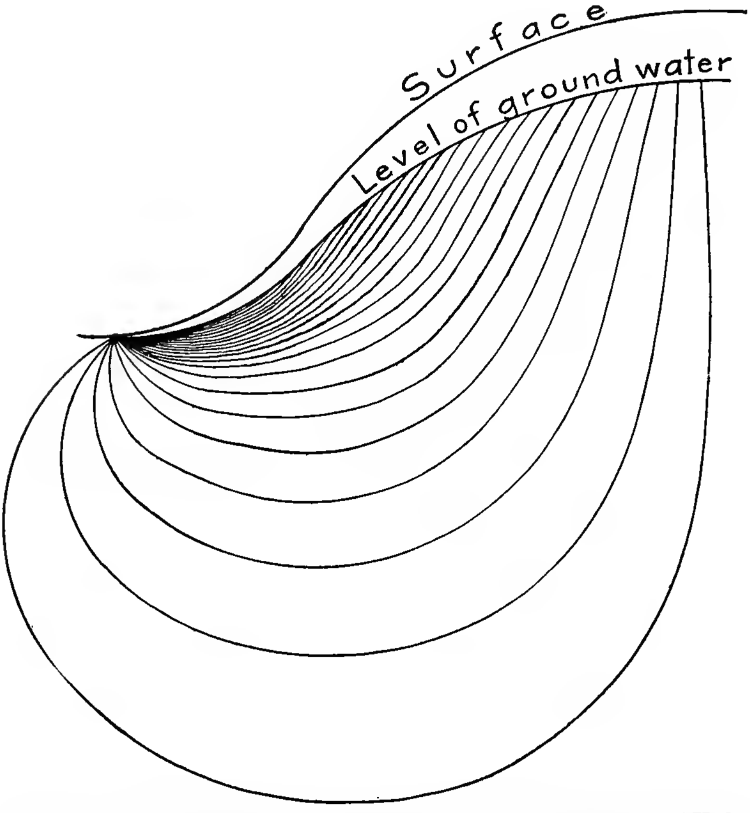


Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at Three Points and Issuing at a Single Point, Each System of Flow Being Independent of the Others.

tended to an indefinite number of points of entrance distributed along the contours of the slope as well as up the slope, and to many points of exit at or near the level of the valley.

The Preferential Use by Water of Large Channels.—In nature the points of entrance for groundwater are indefinitely numerous, and the places of exit comparatively few. The water falls upon the ground everywhere and enters the innumerable pores between the grains. After a longer or shorter underground course, perhaps passing under many subordinate hills and valleys, it escapes to the surface as a spring or by seepage, nearer the drainage-level than where it entered the ground. The

FIG. 5.



Ideal Vertical Section of the Flow, through a Homogeneous Medium, of Underground Water Entering at Many Points along a Slope and Issuing at a Single Point of Lower Elevation.

water began its journey through an almost infinite number of openings. It issues at many openings, but these are few compared with the vast number of those at which it entered.

This conclusion is based on the following facts: Openings in rocks are never of uniform size. It has been seen that the resistance to flowage in capillary openings is far greater than in supercapillary openings. In supercapillary openings of moderate size the resistance is greater per unit of flowage than in larger ones. Thus there is a strong tendency for the water starting through innumerable small openings to converge into larger and larger openings, which are the lines of least resistance. Of course, it may go long distances underground, as in some sandstones, without finding larger openings than those near the surface; but if large openings exist, they will be fully utilized. Finally, when a single opening or a group of openings larger than the average reach the surface at a lower altitude than the average level of entrance of the water, there is a spring.

It has been seen that during the first part of the underground journey of water the vertical component is downward, and during the latter part of its journey the vertical component of much of it is upward. It follows that, on the average, the downward movements of water are through the smaller, and the upward movements through the larger, openings in the rocks. Of course, where large openings are available for the downward-moving water they will be utilized; and doubtless the larger openings are utilized to a great extent by the downward moving waters. However, even if this be the case, the statement would still be true that *upon the average* the larger openings are more extensively used by the upward moving water than by the downward moving water. From the foregoing it appears that the system of circulation of underground water has a very close analogy to that of a tree of a peculiar character.

The points of entrance are the ends of the indefinite number of twigs; these twigs unite into a branch; the branches unite to produce a larger branch; the larger branches unite into a trunk; and at the end of a trunk is a spring. The analogy of an underground drainage system to a tree is even closer than that of a surface system, for in a system of underground water circulation three dimensions are concerned to an important extent, while in a surface system of drainage the movement of the water is approximately confined to a plane. However, from what has gone before, it is clear that the tree of underground water has a peculiar shape. The twigs and branches have an important downward component; the larger branches of the tree may be considered as approximately horizontal; and the trunk usually has an important upward component. Thus twigs, branches and trunks together ordinarily make a great U. The sides of the U may be rather close together in the case of marked topography, where the water issues near the places of entrance. The sides of the U may be very far apart in the case of gentle topography, where there is great lateral movement of the water. Such a system of underground movement is somewhat similar to that of a surface system of drainage.

The analogy of a tree has been utilized in order to get definitely in mind the general character of the circulation of underground water. However, the analogy must not be pushed too far. A tree commonly has but a single, continuous, solid trunk, although willows and other trees have many trunks. Very frequently, indeed commonly, the trunk-channels of underground water circulation are very complex. While a main water course may exceptionally occupy a single open passage, ordinarily it is composed of a number of interlocking passages. These may be the parallel openings of a complex fault, they may be the smaller numerous openings of a zone of fissility, or they may be the more open spaces of sandstones or conglomerates. In short, a trunk-channel of underground water differs only from other channels in that they are places where there is more circulation.

Physico-Chemical Principles Controlling the Work of Underground Waters.

Before considering the actual geological work of underground water in the alteration of the rocks and in the production of ore-deposits, it is necessary to consider briefly the physico-chemical principles which control that work.*

---

* In my treatise on "Metamorphism" (*Monograph U. S. Geol. Survey*) I consider this subject in detail. In the present paper, only that portion of this part of the Monograph is summarized which is absolutely necessary in order to understand the deposition of ore-deposits.

Chemical Action.

The fundamental principle of chemical dynamics is that chemical action is proportional to the active mass. This is the law of mass action.*

Chemical action may take place between gases and gases, between gases and liquids, between gases and solids, between different liquids, between liquids and solids, between different solids. So far as the depositions of ores are concerned, the reactions in connection with underground liquid solutions are by far the more important.

The water of rocks, whether at ordinary temperatures and pressures or at higher temperatures and pressures, may take any of the substances with which it comes in contact into solution; may deposit substances from solution; may combine with substances forming hydrates, as in the case of many of the zeolites or of limonite from hematite; may part with its hydrogen in exchange for bases, and especially the alkalies and alkaline earths, thus at the same time changing the composition of the rock and taking the bases replaced into solution, as in the change of enstatite to talc. There may be reactions as a result of different substances being taken into solution at different times; there may be reactions as a result of different solutions coming together, and thus mingling; there may be reactions between substances in solution and the solid material with which the water is in contact; there may be reactions as a result of changing temperature and pressure. All of these changes are of the nature of chemical action. Therefore, by chemical action of underground water is meant the taking of material into solution, the deposition of material from solution, the interchange between materials in solutions, the interchange between materials in solutions and adjacent solids, and, finally, the interchange of the adjacent solid particles. But this last reaction is probably accomplished through the medium of a separating film of water, in which case the apparently simple reaction is really accomplished by transfers between the solutions and solids.

In all these interchanges the materials therefore pass through a state of aqueous solution, and, according to modern ideas of physical chemistry, the salts in aqueous solution are at least

---

* "Outlines of General Chemistry," by W. Ostwald: Translation by Walker, 1895, p. 292.

partly separated into their ions. Their properties in this condition are therefore the sum of the properties of their separated ions. Indeed, the potency of water as an agent through which metamorphism may take place is due, according to these ideas, to its capacity to separate substances which it holds in solution into their free ions. In this power of ionization water exceeds all other solvents. And it is by the migration of these free ions that the interchanges are accomplished. As the greater portion of underground liquid solutions are rather dilute, at least where somewhat free circulation is the rule, we may suppose that the salts held in solution are largely separated into their ions, and therefore these free ions are ever ready for chemical reactions.

Also water reacts upon the salts it holds in solution by hydrolitic dissociation, producing free acids and hydrates of the bases. This process is especially important with the salts of the weak acids.* The dominant acids of nature are the very weak acids silicic and carbonic; and, therefore, hydrolitic dissociation is very important. The silicates of the alkalies in dilute solutions are practically completely decomposed, the result being the liberation of free silicic acid and hydrates of the alkalies, as shown by Kahlenberg and Lincoln.† The carbonates of the alkalies are also, to a considerable extent, similarly dissociated.

Underground Aqueous Solutions.—The quantity of a solid which can be dissolved in liquid depends upon the number and nature of the compounds present, upon the pressure, and upon the temperature.

When a solid salt is placed in liquid, it forms a homogeneous mixture of salt and liquid. This statement applies to all natural compounds,—that is, the minerals of nature are salts which are soluble in water. No substance is wholly insoluble in the underground waters, even at ordinary temperatures and pressures. This statement applies alike to quartz and the most refractory silicates. Under surface conditions, the etching of quartz grains is evidence of the first statement,‡ and the uni-

---

* "Theoretical Chemistry," by W. Nernst, 1895, p. 660.

† "Solutions of Silicates of the Alkalies," by Louis Kahlenberg and A. T. Lincoln, *Journ. Phys. Chem.*, vol. ii., 1898, p. 89.

‡ "Solution of Silica Under Atmospheric Conditions," by C. W. Hayes, *Bull. Geol. Soc. Am.*, vol. viii, 1897, pp. 213–220.

versal decomposition and partial solution of the silicates is evidence of the second; and in the lower zone of water circulation the solution of quartz and the refractory silicates may be completely accomplished, as in the case of the Calumet and Hecla conglomerates, many of the bowlders of which have been completely dissolved and their spaces taken by copper.

The quantity of material which may be dissolved in any case under definite conditions has a limit. When this limit is reached the solution is saturated. This limit depends upon pressure and upon temperature.

The Relations of Solution and Temperature.—The relations of temperature and solution have two phases; (1) the speed of the reaction, and (2) the quantity of material which may be held in solution.

(1) The speed of solution is greatly increased by rise of temperature.* A slight increase in temperature may increase the rate of solution out of all proportion to the absolute change in temperature. At temperatures above 100° C., and especially above 185° C., the activity of water may increase to an amazing degree. The rapid solution of glass by Barus† at temperatures above 185° C. illustrates this. At any temperature solution will continue until the point of saturation is reached. However, it is clear that this state will be attained at high temperatures in but a small fraction of the time required at low temperatures. For instance, to saturate an underground solution with the refractory silicates or sulphides at ordinary temperatures might require months or even years, while to saturate them at temperatures above 185° C. might require only an equal number of minutes, or at most hours. The capacity of water for action at high temperatures combined with pressure, considered below, is adequate to explain the complete recrystallization of great volumes of natural glass and crystallized rocks.

(2) The effect of temperature upon quantity of material which may be held in solution does not admit of a simple gen-

---

* "Theoretical Chemistry," by W. Nernst. Translated by C. S. Palmer, London, 1895, p. 568.

† "Hot Water and Soft Glass in their Thermo-dynamic Relations," by C. Barus. *Am. Journ. Sci.*, 4th series, vol. ix., 1900, pp. 167–168.

eral statement.* For most substances moderate increase of temperature gives greater capacity for solutions; but for many substances there exists a temperature at which there is the maximum capacity for solution, and the amount of material which may be held in solution at higher and lower temperatures is less than this maximum. For various substances this maximum capacity for solution lies between 60° C. and 140° C., and for many substances it is probably below 200° C. It therefore follows in underground solutions that a general statement cannot be made as to how change of temperature may affect solubility. However, it is highly probable that up to temperatures of 100° C., and, therefore, to depths of 3000 meters, increase of temperature increases the average capacity of underground water to hold material in solution. It may be probable that the average capacity of underground water may increase to temperatures considerably above 100° C., and, therefore, to depths greater than 3000 meters. But when water passes downward to the deeper parts of the zone of fracture the increase in temperature may lessen the average capacity for holding material in solution, provided the joint effect of pressure be barred.

The Relations of Solution and Pressure.—In general, the volume of the solvent plus that of the salt is greater than that of the solution. For a given quantity of the solution the contraction is greater the more of the solvent is used.† In some cases, however, the volume of the salt and solvent is less than that of the solution, or expansion results from dissolving the solid. Sal ammoniac in water is an illustration of this case. From the foregoing relations we obtain a rule as to the relations of pressure to solubility.‡ In the common case in which the volume of the solution is less than that of solvent and salt, pressure increases solubility; for in that case solution tends to bring the molecules nearer together and works in conjunction with the pressure. In the reverse case, that in which the volume of the solution is greater than that of solvent and salt, pressure decreases the solubility, the reason being the reverse of that of the previous case.

---

* "Solutions," by W. Ostwald. Translated by M. M. P. Muir, London, 1891, pp. 55–77.

† "Solutions," *cit.*, p. 82.

‡ "Theoretical Chemistry," by W. Nernst, 1895, p. 567.

It is well known that the solubility of calcium carbonate and some other carbonates is increased by pressure.* It is a fair inference from Barus' work that the solubility of the silicates is also increased by pressure. Barus† found that when soft glass is dissolved in water at temperatures above 210° C., the volume is 20 to 30 per cent. less than the two separately. This glass was one which contains alkalies, alkaline earth and lead, and, therefore, is somewhat similar in composition to many natural silicates. The solubility of many other salts, besides the carbonates and silicates, occurring underground is increased by pressure. While, therefore, pressure may lessen the solubility of some natural salts, in the majority of the complex underground solutions the volume of the solution is less than that of the salts and solvent separately; and, therefore, the total of the salts in solution is generally increased by pressure.

It has been pointed out that in the lower part of the zone of fracture increase in temperature with depth may exceptionally lessen the average amount which may be held in solution, but increasing pressure with increasing depth promotes solubility. The quantitative values of these two elements are, however, unknown, and no positive statement can be made as to whether the increasing temperature and pressure combined in passing to the lower part of the zone of fracture increases or decreases the capacity of underground water for solution. However, it is clear that to very considerable depths, that is, to 3000 meters or more, the joint effect of the temperature and pressure factors is to increase the average capacity for solution.

Precipitation—After a number of chemical substances are brought together, and especially when they are united by a solvent, interactions between them may occur which, after a time, appear to cease. When the conditions have become such that there is no increase or decrease in the amount of any one of the chemical compounds, the system is in a condition of chemical equilibrium.‡ The interaction may result in the precipitation of compounds.

---

* "Gold-quartz Veins of Nevada City and Grass Valley, California," by W. Lindgren. *17th Ann. Report U. S. Geol. Survey*, 1895–96, pt. ii.; 1896, pp. 176–178.

† "Hot Water and Soft Glass in their Thermo-dynamic Relations," by C. Barus. *Am. Journ. Sci.*, 4th series, vol. ix., 1900, p. 173.

‡ Nernst, *cit.*, pp. 355–356.

Since the separation of material from solution in underground waters is of the utmost importance, it is necessary to consider the conditions under which precipitation takes place. It is clear that the necessary condition for precipitation is supersaturation; for if a solution be sufficiently supersaturated some of the material must be thrown down, or be precipitated.

Supersaturation and consequently precipitation may result in various ways, of which the following are the more important: (1) By change in temperature, (2) by change in pressure, (3) by reactions between aqueous solutions, (4) by reactions between liquid solutions and solids, and (5) by reactions between gases and solutions or solids, or both.

1. Precipitation by Change in Temperature.—Change in temperature is the rule for underground circulating waters. The waters which are passing to lower levels are upon the average becoming warmer. Waters which are rising to higher levels are upon the average becoming colder. Also, there are changes of temperature both positive and negative due to varying local conditions.

If the temperature of a saturated solution changes in a direction adverse to solution, it tends to become supersaturated. If crystals of the solid in solution are present, and this is usually the case with underground solutions, considerable supersaturation does not occur; for the excess of salt separates, so that at any given temperature equilibrium is nearly retained by continuous adjustment.

It has already been seen that increase of temperature to 100° C. or more promotes solution, and decrease of temperature from 100° C. or more causes supersaturation, and therefore precipitation. One would, therefore, expect that descending waters which are increasing in temperature are, upon the whole, constantly taking additional material into solution, at least to a depth of 3000 meters, and that waters ascending above this level which are becoming cooler are upon the whole precipitating material. However, this statement needs various qualifications. As a consequence of the action of igneous rocks and dynamic action temperatures higher than the normal for a given depth may be obtained. While these temperatures may be so high as to be unfavorable to the quantity of material held in solution, they are very favorable to rapid solution. Since the temperature is variable which causes the maximum solution of a given salt, it follows that as water passes down through the middle part or lower parts of the zone of fracture, or as it becomes somewhat highly heated because of the presence of igneous rocks or of heat produced by orogenic movement, that the increase of temperature may induce the precipitation of some compounds, and favor the solution of additional quantities of other compounds. Therefore, because of changing temperature in the middle and lower parts of the zone of fracture, and where igneous rocks are present or earth movements have occurred, there is selective solution and precipitation. However, in the normal case within the belt of which we have most exact information, that is, the upper 3000 meters of the crust of the earth, the upward course of water is likely to be favorable to precipitation. (See pp. 339–346.)

2. Precipitation by Change in Pressure.—It has been seen that where waters are descending the pressure is constantly becoming greater, and they are capable of taking additional material in solution. Where waters are ascending the pressure is constantly becoming less, and they are, therefore, not capable of holding so much material in solution. Hence, the pressure effect in ascending waters is to promote precipitation. All of these statements apply to the average complex underground solutions. Exceptional cases may exist where the reverse effect occurs.

3. Precipitation by Reactions between Aqueous Solutions.—Physical chemistry holds that when solutions containing various salts are mixed, the resultant solution will contain all the salts and ions which can be made by the various combinations of their positive and negative factors. In any given case there is a constant relation between the amount of a salt which can be held in solution and the number of free ions of that salt which balance each other, and upon this fact are based the laws of precipitation from solutions.

The laws of chemical precipitation from aqueous solutions are somewhat complex, and cannot be here fully summarized. So far as present purposes are concerned, the old statement of chemistry will suffice. When solutions of two or more kinds are mingled, if a compound or compounds can form which are insoluble in the liquids present, this will take place and precipitation will follow.*

The most important case of precipitation in nature is that resulting from the mingling of aqueous solutions of solids.

Another case of precipitation occurring in nature results from mixing solutions, one of which contains a gas. Perhaps the most important case of this kind is the mixing of a solution containing oxygen with one containing salts of iron protoxide. As a result of this, the salts will be changed from ferrous to ferric, and the iron in latter precipitated either as a sesquioxide or hydrosesquioxide. In the latter case hydration occurs simultaneously with the oxidation.

4. Precipitation by Reactions between Liquid Solutions and Solids.—A very important underground reaction is that between the solutions and the adjacent solid materials. Ordinarily in this case a portion of the solid material is taken into solution and a portion of the material before held in solution is deposited. This principle may be illustrated by the laboratory experiment in which metallic iron is placed in a solution of a copper salt, for instance copper sulphate. The iron goes into solution as sulphate and metallic copper is precipitated. An excellent case illustrating precipitation from solution in nature, one of the most fundamental importance, is the almost immediate partial substitution of magnesium for the calcium of shells and corals by the sea-waters.

In order that crystals in a solvent shall grow, it is necessary that the solutions shall be saturated or supersaturated at the immediate place of crystal growth. Since, underground, there is always a superabundance of solid material present as compared with the amount of water, we may suppose that at a moderate depth below the surface, and especially in the smaller spaces where movement is slow, the solutions are often saturated. It is a well-known fact that under conditions of saturation, with a superabundance of solid material, the larger crystals grow at the expense of the smaller ones, and that this process goes on more rapidly in proportion as the temperature is high and the pressure is great. This principle is taken advantage of in the

---

* For a more exact statement of the principles of precipitation see the various treatises on physical chemistry. A simple statement of the laws of precipitation is given by C. F. Tolman, *Journ. of Geol.*, vol. vii., 1899, pp. 587–591.

chemical laboratory in the production of a coarse precipitate before filtration by boiling or other means, the finer particles of the precipitate being dissolved and the coarser ones being enlarged at their cost.

5. Precipitation by Reactions between Gases and Solutions, and Solids.—The reactions between gases and liquid solutions and solids involve matter in all its three forms. The laws of their mutual interactions are very complex, and they cannot here be taken up. But for the present purpose it may be said that the result of the mixture of gases, liquid solutions and solids, may result in the precipitation of a substance from solution. The most common active gases present underground are carbon dioxide, hydric sulphide, and oxygen. The action of hydric sulphide upon a solution may throw down a sulphide of a metal; the oxidizing action of oxygen may result in precipitation, as in the case of peroxidation of iron. Furthermore, the action of the gases and liquid solutions may together result in the abstraction of substances from the solid compounds and the precipitation of them, or parts of them, elsewhere. The combined action of gases, liquids and solids is more common in the belt of weathering than elsewhere (See pp. 327–329.)

THE GENERAL GEOLOGICAL WORK OF UNDERGROUND WATERS.

It has been seen that the geological work of underground waters is dependent on many factors. Some of these are the limitation in depth by the zone of fracture, the nature of the openings in the rocks, the rapidity of the flowage, the character of the materials through which the waters flow, the character of the substances it may carry in solution, the pressure, and the temperature. Of these many factors, two are ever working together according to very definite laws. These are pressure and temperature. Both increase with depth, and therefore greatly promote the activity of deep underground waters. However, of all of these varying factors, varying temperature is the one which is of incomparably the greatest importance. High temperature ordinarily results from depth of penetration; but it has been pointed out that it may result from various other causes, of which chemical action, mechanical action and the presence of intrusive igneous rocks are the more important. The capacity which water has for taking and holding various relatively insoluble compounds in solution increases as the temperature increases, to 100° C. or more. The velocity of chemical reactions increases enormously with increase of temperature. Not only is high temperature favorable to geological work because of the chemical activity of the water, but high temperature greatly decreases its viscosity, and this, as already explained, is favorable to depth of penetration and flowage through minute openings. Since the temperature changes of underground water are commonly dependent upon depth, the vertical component of the movement of underground water is ordinarily far more important in geological work than the longer horizontal component.

Division of the Zone of Fracture into a Belt of Weathering and a Belt of Cementation.

So far as the work of underground water in the production of ore-deposits is concerned, the zone of fracture may be divided into two belts: (1) an upper belt of weathering, and (2) a lower belt of cementation. The belt of weathering extends from the surface to the level of groundwater, and for a variable distance into the sea of underground water. The belt of cementation extends from the bottom of the belt of weathering to the bottom of the zone of fracture.

In the belt of weathering various gases are present, of which carbon dioxide and oxygen are the more important. With these are a great variety of solutions and the greatest possible variety of solids. The reactions in the belt of weathering, therefore, involve gases, liquids and solids. Furthermore, in this belt we have the complicated action of organic bodies upon inorganic bodies. These organic compounds vary in magnitude from the smallest bacteria to large trees, which act both while alive and dead. It is, therefore, clear that the chemical reactions in the belt of weathering are of an extraordinarily complex character. Only the more important of them will be considered. The dominant ones are carbonation, hydration, oxidation and solution.

The process of carbonation takes place upon a most extensive scale in the belt of weathering, producing abundantly carbonates of the alkalies, alkaline earths and iron, and less abundantly carbonates of other metals. Where vegetation is absent the air in the soil contains only a small amount of carbon dioxide, but where vegetation is abundant and is decaying upon a large scale, the carbon dioxide in the soil is from 15 to 100 times more abundant than in air; hence, in the process of carbonation the presence of vegetation is of fundamental importance. The dominant compounds upon which the process of carbonation acts are the silicates. In the carbonation of the silicates the silica separates as silicic acid.* Since the quantity of silicates decomposed by carbonation is very great, the amount of silicic acid liberated is enormous. This passes into solution, and, as explained below, is transferred to the belt of cementation.

Next in importance to carbonation is hydration. While hydration is usual in the belt of weathering, under some conditions, and especially those of great aridity and high temperature, dehydration may occur.

Oxidation is also very general in the belt of weathering, but deoxidation may occur in regions of very luxuriant vegetation, where there is an unusually large amount of reducing material.

If the compounds formed in the belt of weathering all remained *in situ*, the volume of the rocks would be greatly increased by the above changes; but simultaneously with these reactions, solution, the fourth important reaction of the belt of weathering, is taking place upon a great scale. The quantity of material dissolved is more than sufficient to counterbalance the increase in volume due to the chemical changes, and consequently the volume of the rocks continually decreases. In consequence of this preponderance of solution the openings of the belt of weathering tend to increase in size. However, this is not apparent with the unconsolidated materials at the surface, for gravity brings the particles together as fast as material is dissolved; but in the rocks below the soils, which have sufficient strength to support themselves, the openings are widened. The best illustrations of rocks with enlarged openings are the limestones.

In connection with the chemical changes above summarized, mechanical action is continually subdividing the material.

---

* "Solutions of Silicates of the Alkalies," by L. Kahlenberg and A. T. Lincoln. *Journ. Phys. Chem.*, vol. ii., 1898, pp. 88–90.

In general, then, in the belt of weathering, disintegration, decomposition and solution are the rules. The minerals which remain are usually few and simple; the volume of the rocks is diminished; they soften and degenerate; and they are finally destroyed as coherent solids.

In the belt of cementation, hydration, carbonation, oxidation, and deposition occur. Hydration and deposition are the characteristic reactions. Carbonation and oxidation are subordinate. The reactions take place by metasomatic change within many of the original minerals and by deposition of material within the openings. Many of the minerals produced are strongly hydrated. Because of hydration and deposition the volume of the rocks is increased. Cracks and crevices produced by mechanical action, such as those of faults, joints, bedding partings and fissility; and the openings originally present in the rocks, such as pore-spaces in the mechanical sediments and the vacuoles in volcanic rocks, are slowly but certainly filled by the action of the groundwater, and the rocks are thus cemented and indurated. This process may be called construction.

The belts of weathering and cementation, therefore, contrast strongly. In the former solution continually takes place; in the latter, deposition; in the former we have disintegration, decomposition and softening; in the latter we have cementation and induration; in the former the volume of material is lessened; in the latter it is increased; in the former the characteristic chemical reaction is carbonation; in the latter it is hydration. Therefore, the belt of weathering is characterized by disintegration and decomposition, carbonation, hydration and oxidation, by solution and decrease of volume. The belt of cementation is characterized by cementation and induration, by hydration, by deposition, and by increase of volume.

Migration of Material from the Belt of Weathering to the Belt of Cementation.

It is believed that the material dissolved in the belt of weathering is largely deposited in the belt of cementation. Thus may be explained the steady diminution of a given mass of material in the belt of weathering, and the increase in mass of the material in the belt of cementation. Since this migration of material is one of great importance, it will be necessary to consider it in some detail.

As a result of the horizontal component of the movement of underground water, there is a tendency for material to be taken into solution and to be abstracted by the water. The longer the horizontal underground course, the nearer will the water approach to saturation with the compounds with which it is in contact, because of the time factor. If the journey be long, the state of saturation may be attained at an early stage, after which the additions and subtractions of material upon the average neutralize each other. Throughout the journey there are various chemical interactions. There may be solution of material at a certain place and later deposition of it elsewhere; there may be interactions between the solutions and solids; there may be interactions between the mingled solutions from different sources. However, these reactions do not change the end-result—that is, the longer the horizontal journey the richer the solutions become, and material is abstracted until the point of saturation is reached.

Since it is clear that, so far as the horizontal movement of underground water is concerned, the effect is to abstract material, and since deposition, with consequent cementation and consolidation rather than solution is a general fact in the belt of saturation, we conclude that this result must be due to the vertical movement of the water. In the downward journey of the water from the surface to the level of groundwater, it is continuously taking material into solution, and therefore steadily contributes an increment of material to the sea of underground water.

After the water reaches the level of groundwater, movement does not cease. Disregarding the lateral movement, the sea of underground water at a given place might be considered as a column moving downward as rapidly as the increment of groundwater is added from above. However, superimposed upon this vertical movement is lateral movement which carries it to some point where upward movement is taking place. Therefore the amount which continues downward is an ever-decreasing fraction of the entire amount of precipitation which joins the sea of groundwater. But for this part the pressure and temperature steadily increase, and the capacity of the water to take material into solution steadily changes. One might conclude that during at least the first part of the downward course of the water solution was occurring. During the upward course of the water, pressure and temperature steadily become less, and one might conclude that for at least the latter part of the upward course deposition was occurring. However, these simple statements do not fully cover the facts; for, as already pointed out, the relations of temperature and pressure are exceedingly complex, and also deposition, cementation and consolidation seem to be general facts for the belt of cementation.

It has already been pointed out that the conditions for solution are very favorable in the downward passage of water through the belt of weathering, and that each unit of water which joins the belt of cementation carries with it in solution a certain increment of material. During the long-continued erosion of a region the belt of weathering at any given time represents the residual disintegrated and partly decomposed material then above the level of groundwater. Thus the belt of weathering is steadily progressing downward. The forces of weathering are continually finding new material at the bottom of the belt upon which to work. Therefore, as denudation goes on there is ever a belt of a certain thickness which contributes material to the belt of cementation below. Hence we have an adequate source for an increment continuously added to the belt of cementation. If this increment thus added to the sea of underground water could be deposited throughout its course in the belt of cementation, there would be a sufficient cause for the induration of this belt.

However, according to one of our fundamental premises, the quantity of water which emerges by seepage or through springs to the surface and joins the run-off must be equal to the amount added to the sea of groundwater by percolation. The question must therefore be asked as to the relative amounts of materials carried to the sea of groundwater by percolation and that abstracted from it by the ascending waters. To this question no answer based upon comparative analyses can be given. However, the general deposition and consolidation in the zone of cementation already emphasized seems to be conclusive evidence that the amount of material contained in issuing water is not so great as that which joins it through percolation.

Of the substances deposited in the belt of cementation, quartz is undoubtedly the one which dominates over all others. The one great process in the belt of cementation is silication. Next in abundance to the quartz, the various silicates are deposited, and especially the zeolites and chlorites. Of less importance are the carbonates of the alkaline earths. Still less abundant are the various metalliferous ores and associated gangue minerals not of the classes already mentioned. While these subordinate products are of great economic importance, their quantity is insignificant as compared with the non-metalliferous deposits.

If it is certain that the one great process of the belt of cementation is silication; it is equally certain that the one great process in the belt of weathering is the carbonation of the silicates, thus forming carbonates and liberating soluble silicic acid. Hence it is highly probable that silicic acid is the dominant constituent contained in solution in downward percolating waters. Therefore we have a source both for the deposited quartz and for the process of silication which forms the silicates. In another place* I have shown that one of the deep-seated dominating reactions is the process of silication of the carbonates or the substitution of silica for carbon-dioxide with the simultaneous liberation of carbon-dioxide. This process takes place at moderate depth, especially under dynamic conditions, although it is especially important in the zone of rock-flowage. The carbon-dioxide liberated in part joins the underground waters. Such carbonated waters are very capable of taking into solution the salts of the metals, and particularly the salts of the alkalies, alkaline earths and iron. The solutions which reach the surface bear as their more abundant compounds the carbonates of the alkalies, alkaline earths and iron. With these are also other salts, including the salts of the valuable metals. Also issuing waters contain other acids besides carbonic acid, such as chlorhydric, sulphydric, sulphuric and others.

From the foregoing it appears that during the circulation of

---

* "Metamorphism of Rocks and Rock Flowage," by C. R. Van Hise, *Bull. G. S. A.*, vol. ix., 1898, p. 282.

water in the belt of cementation the processes of precipitation and solution are selective. Quartz and silicates are the dominant precipitates. Carbonates of the alkalies and alkaline earths are the dominant salts which join the run-off. The above precipitations and solutions are precisely what should be anticipated from the laws of chemical action already given. The compounds which upon the average are thrown down to the greatest extent, are those which are least soluble and most abundant. The compounds which are retained in solution to the greatest extent are those which are most soluble and least abundant. However, of the more soluble and less abundant compounds a portion is precipitated. The conditions under which we would expect partial precipitation of these compounds, at least for the upper 3000 meters, are those of lessening temperature and pressure. These are the conditions of the ascending columns of water. It has already been seen that the ascending columns are likely to be the main water-channels. Hence is explained the frequent precipitation of soluble carbonates of the alkaline earths and rare metalliferous ores in these trunk channels.

It is not supposed that the above furnishes a full explanation of the cementation of the entire zone of fracture. It has been pointed out, p. 329, that hydration is perhaps the most characteristic reaction of this belt and that hydration results in expansion of volume. So far as this reaction takes place, and it undoubtedly occurs on a most extensive scale, this would tend to fill the openings and thus cement and consolidate the rocks without reference to material from the belt of weathering. Thus, for instance, metasomatic change including hydration in a vesicular basic igneous rock may so increase the volume of the material as to completely fill the vesicles by zeolites, quartz, and other minerals without the addition of any material from an extraneous source. Which of the two factors, material from the belt of weathering, or expansion by the processes of metasomatism including hydration, is the more important in filling openings in the belt of cementation, I am wholly unable to state.

Other factors also, doubtless, enter into the cementation of openings. Some of these have already been mentioned. These are selective solution and precipitation, depending upon varying temperature and pressure, and the reaction of the different solutions upon one another. Another factor which is probably important is diffusion, but its action is too complex to be taken up in this general paper.

By the various processes of cementation the larger openings are filled with deposits. However, where one of these contains metalliferous ores in sufficient quantity to be of service to man, many thousands are filled with quartz, calcite, dolomite, and other gangue minerals. I repeat again that the deposition of the ores is but a special phase of a general geological process of great consequence.

PART II.—APPLICATION OF PRINCIPLES TO ORE-DEPOSITS.

The general discussion in Part I. is believed to contain in large measure the philosophy of the formation of ore-deposits by underground waters. It is now clearer than when first stated that the deposition of the greatest group of metalliferous ores is a special case of the work of underground water.

There have been endless discussions as to whether ore-deposits are produced by descending, lateral-secreting, or ascending waters. It is a corollary from Part I. that the first concentration of many ore-deposits is the result of descending, lateral-moving, and ascending waters. I say first concentration; for it will subsequently appear that many, if not the majority, of the workable ore-deposits have undergone a second concentration.

The larger, more nearly complete idea of the genesis of ore-deposits comprises all of the old ideas, shows that instead of being contradictory, as supposed by many, they are mutually supporting; combined, they furnish a much more satisfactory theory than any one of them alone. How true these statements are will later more clearly appear.

In the first stage of the concentration of many deposits the waters are descending. During the descent they are widely dispersed in small passages, have an exceedingly large surface of contact with the rocks, come under conditions of increasing temperature and increasing pressure, and are moving slowly downward. All of these conditions favor solution to the point of saturation. The various metalliferous elements present in exceedingly small quantities in the rocks, as well as many other compounds, are picked up. (See pp. 319–322.) This follows from the law of physical chemistry, that a solution will hold some part of all of the elements with which it is in contact. While deposition as a whole may be occurring in the belt of cementation, solution of the ores certainly takes place.

The waters which perform the first work in the genesis of ore-deposits are descending waters.

Superimposed upon the downward component of the moving waters is a lateral component. This lateral component, combined with the vertical component, carries water sooner or later to the trunk channels. The amount of water taking part in the lateral movement is greatest near the surface of groundwater, and from that surface steadily decreases to the bottom of the zone of fracture. It has been explained that all fissures and other openings gradually die out below as the zone of rock-flowage is neared. (See pp. 288–291.) Therefore, for a given fissure, the waters which enter it do so from the side or top, not from the bottom. Furthermore, the water does not enter the fissure at a single place, but may enter at numberless points all the way along its course, from the deepest parts of the fissure to the surface. Somewhere, however, the water which enters a fissure must flow from it. This place may be at the surface of the ground or at a considerable depth below the level of groundwater (see Fig. 6). The streams entering the fissure at high levels may have a downward component, and contribute water abundantly. Below the level at which water escapes laterally from a channel of given size, the water contributed to it decreases on the average with increase of depth, until in the deeper part of the zone of fracture the contributions are very small. Posepny* calls attention to the generally observed fact of the decreasing amount of laterally contributed waters as depth increases. As a specific instance of this, he mentioned the Przibram district, in which the water which enters the fissures below a depth of 300 meters is so small as to be insignificant.

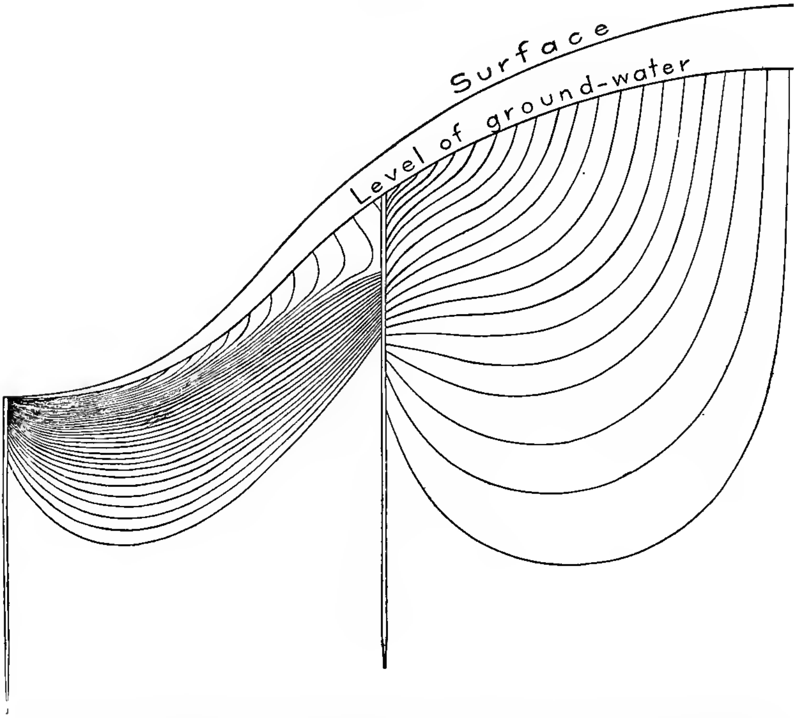
While the amount of water laterally entering a fissure steadily decreases from near its top to the bottom, the amount

---

* This volume, p. 242.

of mineral material per unit volume in all probability steadily increases; for the waters entering at a low level take a longer journey through smaller openings and at higher temperatures and pressures than the waters entering at a high level. Therefore it is clear, if the rocks with which the deeper water comes in contact can furnish metalliferous materials, that such water will be heavily loaded. It follows from this, even if the amount of water which is furnished in a given brief time to a fissure be small, that such water may furnish from the country-rock much more mineral material in solution than sufficient to entirely fill a fissure during its long life. This is evident from the following: Water issuing at the surface from mineral springs generally contains more than 1 part of silica in

FIG. 6.



Ideal Vertical Section of the Flow of Water Entering at a Number of Points on a Slope, and Passing to a Valley Below, through a Homogeneous Medium, Interrupted by Two Open Vertical Channels, on the Slope and in the Valley Respectively.

100,000.* If it be premised that only as much silica be deposited as issues at the surface, in order completely to fill a fissure it would be necessary only to suppose that the amount of water which enters a unit length of a fissure is 100,000 times as great as the volume of a unit length of the opening.

We now understand that the amount of water entering a fissure decreases from the level of groundwater to its bottom, but that the amount of mineral matter brought into the fissure by the water (but not necessarily deposited) increases per unit volume from top to bottom. It is, therefore, impossible to make a general statement as to whether more mineral material is contributed to a trunk channel in its upper portion or in its lower portion. Doubtless this varies in different cases. Other conditions than amount of water or depth may be controlling factors in this respect. For instance, if igneous rocks be intruded at high or low levels only, the presence of the igneous rocks may furnish conditions which determine the amount of metalliferous material contributed by the waters.

While the foregoing paragraphs imply that the lateral moving waters are also downward moving, this is meant only as a general rule. The lateral movement may be accompanied by no downward movement. Not only this, but lateral movement may be accompanied by an upward component. Indeed, this is believed to be very frequently the case, especially so far as the main branch streams in the deeper parts of the zone of fracture are concerned. In so far as there is an upward component in these branch streams, the reactions which obtain are the same as those of the trunk channels to be considered below.

From the foregoing, *it appears that ores are carried to trunk channels by laterally moving waters. Lateral secretion is therefore an essential step in the first concentration of ore-deposits*, although I use the term lateral secretion in a broader sense than did Sandberger.

We have now reached the place where the ore-deposits themselves are found. As already noted, these mainly occur in the more continuous larger openings. These openings are

---

* "Lists and Analyses of the Mineral Springs of the United States," by A. C. Peale, *Bull. U. S. Geol. Surv.*, No. 32, 1886.

occupied by the trunk streams of circulating waters, and therefore the journey of the water is in the latter part of its course. Hence these trunk streams, as has already been shown (p. 316), have in general an upward rather than a downward vertical component. The waters reaching the trunk channel at any point immediately begin their ascent. At any given cross-section of a channel there must pass all of the water contributed below. This amount at great depth has already been seen to be small. From a small amount, the waters steadily increase in volume to the point where they begin to escape laterally from a trunk channel (see Fig. 6). Hence from a trunk channel of a definite size the circulation is slow below and increases in speed above. Near the bases of the channels from which the Mammoth Hot Springs and geysers of the Yellowstone Park issue the amount of water contributed may be small, and the movement of the water may be exceedingly slow. Even if true, as held by some, that rapid movement of water is unfavorable to deposition of ores, it is wholly possible at moderate depths and especially in the deeper parts of a channel from which the flow at the surface is rapid, that the conditions are those of slow movement and rapid precipitation of ore-deposits.

As the water passes upward, the variety of solutions as well as the amount increases; for each stream differs in its salts from any other, since no two streams can possibly have had exactly similar histories. Moreover, the character of the wall-rock may vary from place to place. The pressure and the temperature are also lessening. These conditions are favorable to precipitation. *Therefore, many ores in their first concentration are precipitated by ascending waters.*

It is now clear that a satisfactory account of the genesis of ores includes ascending waters. By the ascending waters many ores in their first concentration are actually precipitated, and thus the emphasis which has been placed upon this part of the work of circulating waters.

The broader statement of the genesis of a great class of ore-deposits is that the water after penetrating the earth is widely scattered in contact with rocks in innumerable minor openings. These waters travel downward with steadily increasing pressure and temperature. They take up the constituents of the ore-deposits. The downward movement of the waters has superimposed upon it a lateral component, as a result of which the waters are carried to the larger openings. During this process, also, the waters continue to take material into solution. In the larger openings where the waters are congregated they are upon the average at first ascending with decreasing temperature and pressure, and there the ores are precipitated.

Of course, from this statement it is not meant to imply that materials are not deposited by descending and lateral moving waters, nor that materials are not dissolved by ascending waters. Indeed, it is certain that solution and precipitation are taking place at all times throughout the entire course of all the branches of the underground circulation. This is a necessary consequence of the laws of physical chemistry. It is only meant to imply that in the first concentration of one class of ore-deposits, solution so far as the ores are concerned is the rule for the descent and deposition for the ascent, although there is no doubt that there are many local exceptions to this.

It is of course understood that the underground circulation in any actual instance will be much more complex than that given in the simple ideal case which has been considered. This part of the subject will be developed. For instance, it is certain that, in the same mineral-bearing area, immediately adjacent trunk-channels may have had very different histories. This is especially well shown by the deposits of Butte, Montana, where there are two parallel main zones of mineralization, only a short distance apart, the mineral wealth of one of which is mainly copper, while that of the other is mainly silver.* Many of the other special factors which modify the simple general statement above given are discussed on pp. 393–421.

The Precipitation of Ores by Ascending Waters.

The precipitation of ores in the trunk-channels by ascending waters is of so much importance in the concentration of ores that this process needs further consideration. The precipitation results from the various principles given pp. 322–326.

---

* "Notes on the Geology of Butte, Montana," by S. F. Emmons. *Trans.*, xvi., 54, 1888.

Precipitation by Decrease of Temperature and Pressure.

The general relations of solution and precipitation as a consequence of varying temperature and pressure have been considered pp. 323–325. Where the increment of temperature is normal, it has been seen that decreasing temperature and pressure resulting from the ascension of waters from at least a depth of 3000 meters are favorable to precipitation. Furthermore, the same statement holds even if the increment of temperature is greater than normal, provided the temperature does not greatly exceed 100° C., and cases in which water issues at the surface at such temperatures are very rare. Moreover, probably decreasing pressure and temperature with rising solutions at depths greater than 3000 meters are favorable to precipitation. Since it has just been shown that ascending waters are likely to be in trunk-channels, these are the places where lessening temperature and pressure are most likely to produce precipitates. Therefore the openings of faults, joints and bedding partings and the more open places in porous sandstones, conglomerates and amygdaloids, are likely to have material precipitated in them as a consequence of lessening temperature and pressure.

When one attempts to apply these general statements to specific salts, we find experimental data lacking. It is undoubtedly the case that decreasing temperature and pressure are much more influential in the precipitation of some salts than of others; and that with a few salts decreasing temperature and pressure are favorable to solution. Until experimental work has determined how the various salts commonly found underground respond to changing temperature and pressure, it is impracticable to specify the ores the precipitation of which are strongly favored by decrease of temperature and pressure. One would expect that precipitation as a consequence of changing temperature and pressure would tend to give a somewhat orderly vertical distribution of the various metalliferous ores.

Precipitation by Mingling of Solutions.

Precipitation in the trunk-channels is produced by reactions caused by the mingling of various solutions. The solutions may be those of solids in the water, or of gases in the water, or of both. According to the modern theory of solutions, a solid dissolved in water is in the form of a gas; and therefore, so far as the precipitation is concerned, it makes no difference whether the substance in the water, if separated, would be a solid or a gas.

It is evident that solutions from different sources are entering a given trunk-channel at many places. Each of the incoming streams will have a solution different from that entering by any other stream, although in many cases the differences may be slight. As a case of certain considerable differences may be mentioned the ascending and descending streams. (See pp. 377–378.) Thus a multitude of streams of different composition enter and mingle in a trunk-channel. If in a chemical laboratory a multitude of solutions taken at random are thrown together, it is certain that various precipitates will be formed. It is just as certain when the various solutions in an underground channel come together that precipitates will frequently form. This mingling of solutions is one of the most important of all the factors which results in the deposition of the ores. I have little question that in this fact of the wide variety of solutions which enters a given channel we have in a large measure the explanation of the variable richness in ore-deposits in a given fissure. It is well known that an ore-deposit varies in richness in an exceedingly irregular manner. At a place in a fissure where a metal is abundantly found, the explanation in many cases is certainly that at or near that place there entered a stream which either carried the precipitated metal or carried an agent capable of precipitating the metal which was already in the trunk-channel. For instance, it is believed that where the great bonanza of the Comstock lode was found, there or near there entered either solutions rich in gold and silver which met other solutions capable of precipitating this gold and silver, or else at that place there entered a solution having a compound which was capable of precipitating the gold and silver already traveling upward within the lode. Perhaps the former hypothesis is the more probable.

Ore-chutes, or chimneys of ore of exceptional richness, are very frequent phenomena in veins. These are sometimes parallel with the dip, at other times pitch to the right or left of it. The explanation of these ore-chutes in many instances I believe to be a cross-fracture or joint through which waters entered, either carrying metalliferous material itself or solutions capable of precipitating the metalliferous mineral in the trunk-channel at the place where the lateral streams of water entered.

The lead and zinc deposits of the Mississippi valley, according to Jenney, are larger at the crossings of two sets of fissures than elsewhere. This may be partly explained by the greater abundance of the solutions furnished by two sets of fissures, but are probably at least partly explained, as suggested by Jenney,* by the mingling of two different kinds of waters, thus giving conditions favorable for precipitation.

In the Enterprise mine, at Rico, Col., described by Rickard,† the ore-bodies are in vertical veins and in flats under shales. While a set of cross-veins is barren, "the rich ore-bodies overlie them in the contact zone." Below the shale it is common to find ores of more than average grade in the pay veins where they are broken by the cross-veins. It is believed the explanation of these relations is the reactions resulting from the mingling of the solutions of the "verticals" with the inclined cross-veins.

The silver-lead deposits of the Aspen district of Colorado, described by Spurr,‡ furnish an instance of very probable precipitation of rich ore-chutes by the mingling of solutions. Spurr states that generally an ore-body is "found at the intersection of two faults, one of these faults usually dipping steeply, while the other is much flatter." For this "the explanation is offered that by the mingling of solutions which had previously flowed along different channels the precipitation of metallic sulphides was brought about."

Probably the rich ore-chutes of gold ore in the Sierra Nevada, which, according to Lindgren, pitch to the left as one looks down the veins, further illustrate the principle of precipitation by mingled solutions. For the most part, Lindgren makes no statement as to the relations of ore-chutes and lateral seams. However, on the Canada Hill vein there are "occasional rich bunches at the intersections" of the two systems of veins.§

---

* "The Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 1894, pp. 189-190, 224.

† "The Enterprise Mine, Rico, Col.," by T. A. Rickard, *Trans.*, vol. xxvi., 1897, pp. 977-978.

‡ "Geology of the Aspen Mining District, Colorado," by J. E. Spurr, *Mon. U. S. Geol. Survey*, No. 31, 1898, pp. 230, 234-235.

§ "The Gold-quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann. Rept. U. S. Geol. Surv*, pt. ii., 1896, p. 195.

It is believed that the Cripple Creek deposits likewise illustrate this principle. Penrose* notes that many of the rich ore-chutes occur at cross-fissures. The formation of these ore-chutes at such places is doubtless partly explained by the greater amount of solutions furnished at an intersection of two trunk-lines of underground circulation; but it is thought probable that the main cause for the formation of ore-chutes at such places is the reaction of solutions furnished by one set of fissures upon those furnished by the other set. However, it is but fair to say that Penrose makes the explanation the "mechanical one, in deflecting the course of the ore-bearing solutions."

While apparent irregularities in the kinds and percentages of metals are doubtless in many cases explained as above, the distribution of the metals in a definite order from the surface downward, and the general law that many valuable metalliferous ores grow poorer in depth if the measure be 1000 meters or more are to be explained by other principles. Of these, varying temperature and pressure are important; but more important in many instances, as will be shown subsequently, is a second concentration produced by descending waters.

Reactions Due to Wall-Rocks.

Precipitation of metalliferous ores from the solutions in the trunk-channels due to the influence of the wall-rocks are frequently produced in the following ways: (1) It has already been explained that a solid when placed in contact with a liquid may precipitate some compound previously held in solution, some part of the solid going into solution at the same time. Thus, the wall-rock may precipitate ores. (2) The wall-rock produces an effect upon the trunk-solutions by furnishing precipitating solutions to it, and this may result in precipitation of metals already in solution within the trunk-channels. (3) The wall-rock itself may furnish metalliferous material for the ore-deposit which may be precipitated when it reaches the trunk-channel by the solutions there contained. This has been greatly emphasized, probably over-emphasized, by Sandberger. Where the wall-rock is easily soluble, ready enlargements of the openings occur,

---

* "Mining Geology of Cripple Creek, Colorado," by R. A. F. Penrose, Jr., *16th Ann. Rept. U. S. Geol. Surv.*, 1894–95, pt. ii., pp. 164–165, 1895.

furnishing places for the deposition of the metalliferous material. (See pp. 413–416.)

It is believed that the effect of the wall-rock in these various ways in the production of many ore-deposits is of great importance. As an illustration, may be cited the very general association of lead-ores with limestone. Probably by far the larger portion of the lead-ores mined in the past have come from within limestone. I believe it to be highly probable that the position of the ores in limestone is due to the character of this rock. Any one of the factors above mentioned might be more important in a given case, but doubtless in many instances two or more work together. Thus, the position of the lead in a limestone may be partly explained by reactions between the solutions of the trunk-channel entering the limestone and the limestone itself. Or, the precipitation of the lead may be partly the result of the reactions between the solutions furnished by the trunk-channel and the solutions furnished by the limestone. In a given case the waters of a trunk-channel entering the limestone may be acid. The solutions from the limestone would immediately react upon this solution, tending to neutralize it, and the precipitation of lead sulphide might be a consequence. Or, the wall-rock might furnish the lead, as in the Mississippi valley. The ready solubility of the limestone would furnish the openings and caves, giving a receptacle for the lead, as in southwestern Wisconsin.

A still clearer case of precipitation resulting from the influence of the wall-rock is the well-known occurrence of metallic copper about grains of magnetite, and in the openings of sandstones, conglomerates and amygdaloid of Keweenaw Point.* Where the copper is about the magnetite it seems perfectly clear that the protoxide of iron in the magnetite was the reducing agent which precipitated the metallic copper.† The metallic copper between the particles was doubtless precipitated by ferrous solutions furnished by the wall-rocks, which in many cases are basic volcanics.

The reactions due to the country-rock are more likely to be effective in proportion as it is porous, and therefore allows solu-

---

* "The Copper-Bearing Rocks of Lake Superior," by R. D. Irving, *Mon. U. S. Geol. Surv.*, No. 5, 1883, p. 420.

† Irving, *cit.*, Pl. xvi., Fig. 1.

tions to permeate it. The country-rock is especially effective in its reactions where the trunk-channel is a complex one, and gives a large surface of action. This is illustrated by the Calumet and Hecla conglomerate, by the Cripple Creek ore-deposits,* and by many other districts (see p. 395).

A particularly clear illustration of the effect of the wall-rock is furnished by ores in which the sulphides are confined to strata containing organic matter, as in some copper-deposits† and some of the gold-reefs of Australia. In the case of the copper-deposits, the organic matter has in all probability reduced sulphites or sulphates to sulphides. The function of the organic material in the case of the gold may have been to reduce it to metallic gold, or to reduce it through the production of *ous* salts, for instance, ferrous sulphate (see pp. 373–375).

General.

In conclusion, it may be said that the precipitation of metallic ores by the mingling of various solutions is probably the most important single factor which results in the first concentration of ores. Probably next in importance to this are the reactions upon the trunk-streams due to the wall-rocks. Inasmuch as the waters of lateral streams from beyond the wall-rocks must pass through the latter, many of the streams contributing through the wall-rocks to the trunk-channels produce an effect partly due to materials more remote than the wall-rocks and partly to the wall-rocks. Thus in many cases the effect of solutions beyond the wall-rocks and that of solutions furnished by the wall-rocks cannot be discriminated. However, since the effect of the wall-rocks has been so much discussed, it seemed to me best to treat the two separately as far as practicable.

Diminishing temperature and diminishing pressure, while probably subordinate in their effect to the mingling of streams and reactions due to the wall-rocks, are in many instances undoubtedly important, and in some instances may be the dominant factors. In general, the tendency of writers has been to

---

* "Mining Geology of Cripple Creek, Colorado," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, 1894–95, pt. ii., p. 163, 1895.

† "The Genesis of Ore-Deposits," by F. Posepny, and Discussion of same, by F. M. F. Cazin, this volume, pp. 131, 209–210.

emphasize the effect of diminishing temperature and pressure, and to minimize or even disregard altogether the effects of mingling solutions or the wall-rocks, or both.

The Compounds Deposited by Ascending Waters.

Of the metalliferous ores, those of iron, copper, lead, zinc, silver and gold are the more important. Where these are deposited by ascending waters they occur mainly as sulphides. In many cases the sulphides are simple binary salts. However, sulpharsenites and sulpharsenates, sulphantimonites and sulphantimonates are common; but these also are sulphides, and all will be thus referred to without qualification. Besides sulphides, metallic products sometimes occur, as in the case of copper and silver; also tellurides, carbonates and silicates are formed.

Why average compounds deposited by ascending waters are, for the most part, not oxidized compounds, but sulphides, tellurides, or metallic compounds, is easily explained. The widely disseminated, downward-moving water, bearing oxygen, is robbed of this constituent early in its course. Ferrous compounds are abundantly present in the rocks in the forms of magnetite and silicates. Iron is a strong base; and where ferrous compounds are present they continue to abstract the oxygen of the downward moving waters until it has practically disappeared. Moreover, buried organic matter takes oxygen from underground waters. In believing that the sulphides are commonly precipitated by ascending waters in the openings below the level at which oxidizing solutions are active, I follow Le Conte and Posepny.*

Source of the Metals.—The nature of the rocks which contribute the metallic salts has been much discussed. With Sandberger,† I have little doubt that the metallic constituents of ores are in large part derived from the igneous rocks which have been intruded or extruded into the lithosphere; and especially is this true of the basic rocks. Le Conte‡ points out that the undoubted frequent occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the

---

* "On the Genesis of Metalliferous Veins," by Joseph Le Conte. *Am. Journ. Sci.*, third series, vol. xxvi., 1883, p. 4. "The Genesis of Ore-Deposits," by F. Posepny, this volume p. 44.

† "Untersuchungen über Erzgänge," by F. Sandberger, 1882.

‡ *Op. cit.*, p. 10.

igneous rocks, this promoting the work of underground solutions. That the heat furnished by the igneous rocks is a very important factor in the production of the ore-deposits, I have no doubt. Since it is very difficult to prove that the metallic content of an igneous rock is original, it is impossible to make any general statement as to whether the metallic content or the heat furnished by the igneous rocks is the more important in the production of ore-deposits. It seems to me clear that both are important; and equally clear, in many cases, that both work together. That is to say, an igneous rock may furnish all or a part of the metal which appears in an ore-deposit, and the heat of the same igneous rock may greatly assist its concentration by the underground waters.

While the massive igneous rocks are the undoubted source of a large portion of metallic deposits, it is also equally certain that another large part is derived from the sedimentary rocks and the metamorphosed, or partly metamorphosed, igneous and sedimentary rocks. Lastly, it is also certain that many ore-deposits derive their metalliferous content in part from igneous rocks and in part from sedimentary rocks. Probably this is the most frequent of all cases. To give any estimate of the relative amounts of metalliferous materials derived from the original igneous rocks and from the secondary rocks is quite impossible.

This statement will, of course, be very unsatisfactory when applied to an individual district. However, it is not the purpose of this general paper to consider individual districts, except as they illustrate principles. It is properly the part of the geologist or mining engineer who studies an individual district to find the source of the metal. In many cases, careful investigations can undoubtedly determine this point, as, for instance, that of the iron-ores of the Lake Superior region. In other districts, however, the most exhaustive study may not enable the investigator to determine the source of the metalliferous material. This is especially likely to be true of ore-deposits produced by ascending waters from a somewhat deep circulation. The underground waters may have their sources of supply in rocks which do not reach the surface, and have not been penetrated by the mine workings.

In concluding this part of the subject, it may be suggested that in many instances mistakes have been made in assuming that some one formation, sedimentary or igneous, is the sole source of the valuable metals. Such an assumption is particularly prevalent in papers descriptive of gold deposits and silver deposits. In many districts where there are various sedimentary and igneous rocks, I have no doubt that the silver and gold are partly derived from two or several formations.

Source of the Sulphur of Sulphides.—According to modern research, the metallic sulphides are original constituents of igneous rocks. This is a direct observation; but even if the observation had not been made, the large amount of sulphur compounds issuing from the interior of the earth in connection with vulcanism would lead to the conclusion that sulphides must exist in the igneous rocks. It is therefore probable that sulphur, as sulphide, is or was present in sufficient quantity in the original rocks to fully account for all of the sulphur compounds in the ore-deposits.

It is, of course, well known that sulphides in the belt of weathering are largely oxidized to sulphites and to sulphates, and taken into solution by descending waters. These compounds join the sea of underground water. There the sulphites and sulphates, either just below the level of groundwater or at a greater depth, may come in contact with buried organic material. Under these conditions it is well known that the sulphites and sulphates are reduced to *ous* salts, or to sulphides.

Occasionally the metals may be carried to the trunk-channels as sulphites and sulphates, and there be reduced to sulphides. This would be especially likely to happen where the ores are disseminated through beds bearing carbonaceous material. Cazin mentions the Vermont copper-mine as a case where the ores are mingled with organic material.* Rickard mentions a number of cases where the deposition of the ores is confined to material containing organic matter, the more important being those gold-bearing sulphide reefs of Australasia, California and Colorado, where the ore is associated with strata bearing organic matter.†

---

* "Discussion of the Genesis of Ore-Deposits," by M. F. Cazin, this volume, pp. 209–210.

† "The Origin of the Gold-Bearing Quartz of Bendigo Reefs," T. A. Rickard, *Trans.*, xxii., 1893, 314–315. "The Enterprise Mine, Rico, Colo.," T. A. Rickard, *Trans.*, xxvi., 1897, 977–979.

In one case of the gold-quartz veins of California, in carbonaceous argillite, pyrite occurs in the argillite but not in the quartz. This is very strongly suggestive that the carbonaceous matter of the argillite has reduced the sulphates to sulphides. This occurrence in the California gold-belt is especially suggestive, since the analyses of two springs of ascending waters at the 400-foot levels in two separate mines show the presence of considerable quantities of sulphates.*

Probably also sulphites and sulphates may be reduced to sulphide by ferrous iron in the rocks. If this reaction takes place, it should be especially characteristic of the more basic rocks. The frequent occurrence of sulphides in the altered basic rocks, and especially the scoriaceous basic rocks, is very strongly suggestive that this reduction has taken place. So far as I know, this reaction has not been before suggested. It is probably an important one in the reduction of the sulphites and sulphates to sulphides in the lower part of the zone of fracture, and may explain the deposition of sulphides in rocks where organic material is not available for the reduction.

The sulphides, whether as original constituents of the igneous rocks or produced by the above reactions, are taken into solution and deposited in the main channels of water-circulation. Of the fact of the solution and deposition of the sulphides there can be no doubt. However, the solvents in different cases are doubtless different, and moreover, in a single case, the solvents are probably complex. It is well known that the sulphides of the valuable metals are somewhat freely soluble in alkaline solutions, and especially solutions of the alkaline sulphides.† Furthermore, from observation in the field it is known that certain of the sulphides have been thus transported, as for instance at Steamboat Springs and Sulphur Bank,‡ and doubtless this manner of transportation is very common. However, as shown in another place, the bicarbonates with an excess of carbon-dioxide are the most abundant compounds in underground solutions. These bicarbonates are largely those

---

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, p. 81; also Plate VIII., p. 140, and pp. 121–123, 172–173.

† Lindgren, *op. cit.*, pp. 177–178.

‡ Le Conte, *cit.*, *Am. Jour. Sci.*, Third Series, vol. xxvi., p. 3.

of the alkalies and alkaline earths. Such carbonated waters also favor the solution of sulphides. Furthermore, sulphides are doubtless rendered more soluble by the presence of various other compounds in the underground solutions. However, the transportation of sulphides is not limited to solutions which bear other compounds; for the sulphides themselves are soluble in pure water to some extent, as has been shown by Doelter.*

But in whatever form the sulphides are transported, they are largely precipitated in due time in the trunk-channels. By denudation these sulphides may again reach the belt of weathering when the cycle is complete. The sulphide may be again oxidized to sulphate, and so on. It is therefore clear that sulphur, as sulphide and sulphate, may again and again take part in the deposition of ores;† but the first source of the sulphur must be the sulphides of the original rocks.

In this connection Chamberlin has noted that in Wisconsin waters comparatively near the surface bear oxygen and oxidized compounds, while deep artesian waters are "marked by slightly sulphuretted waters."‡ Thus analyses of waters in a region of comparatively undisturbed sedimentary rocks confirm the statements of the previous paragraphs. That is to say, waters which are deep-seated, and therefore must take an upward journey to reach the surface, are likely to bear sulphides.

While it is believed that sulphides are generally deposited by upward-moving waters, this is not supposed to be the universal case. Nature's processes are always too complex to be covered by a single general statement. As a result of mingling solutions at various places, and of reactions between solutions and walls, many lateral moving and downward moving streams doubtless do deposit rather than dissolve sulphides. Indeed, in the frequent case already noted, where in downward-moving waters, sulphites or sulphates are reduced by organic matter to sulphides, precipitation of a portion of the sulphide is usual. But still the statement would hold true that upon the average more sulphides are dissolved by descending waters than deposited, and more sulphides are deposited by ascending waters than dissolved.

---

* Lindgren, *op. cit.*, pp. 179–180.

† Le Conte, *op. cit.*, p. 13. Compare Posepny, this volume, p. 72.

‡ "The Ore-Deposits of Southwestern Wisconsin," by T. C. Chamberlin, *Geol. Wis.*, vol. iv., 1882, p. 547.

We conclude, therefore, that, *whatever the source of the sulphides as first concentrates, these ores are generally deposited by ascending waters in the trunk-channels.*

Source of the Carbonic Acid of Carbonates.—Aside from sulphhydric acid, the other acid of great importance in the deposition of ore-deposits is carbonic acid. This as is well known is, indeed, the dominant acid contained in issuing underground waters. This point both Le Conte and Posepny strongly emphasize.* I have already pointed out two sources for the excess of carbon-dioxide held in the underground waters. Where vegetation is abundant, carbon-dioxide is concentrated in the soil. A large part of this is retained in the belt of weathering by the process of carbonation of the silicates, but another part joins the sea of underground waters. Another source for the carbon-dioxide is that liberated from cavities within rocks. It is well known that in many rocks a large amount of carbon-dioxide is included in innumerable microscopic cavities. When such rocks are complexly deformed in the zone of fracture, the fractures must intersect many of these cavities, and thus liberate the carbon-dioxide. Where there are zones of crushing, that is, where there are trunk-channels for percolating waters, the amount of carbon-dioxide which may thus be liberated may be considerable. Another source for the carbon-dioxide is a process of silication, explained p. 332, as a result of which the carbonates are decomposed by the silicic acid at depth, liberating the carbon-dioxide. Therefore, deep-seated waters are ever receiving contributions of carbon-dioxide, and thus are continually more capable of taking metals in solution, until the waters reach conditions where silication does not occur.

In this process of silication alone is believed to be an adequate source of carbon-dioxide; so that metals may be carried as bicarbonates and the water also hold a further excess of carbon-dioxide.

A very interesting confirmation of the liberation of silica by the process of carbonation near the surface and the liberation of carbon-dioxide, probably by the process of silication at depth, as above explained, is furnished by the Geyser mine of Custer county, Colorado, described by Emmons.† Here waters were

---

* Le Conte, *op. cit.*, p. 11. Posepny, this volume, p. 44.

† "The Mines of Custer County, Colorado," by S. F. Emmons, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, pp. 460–464.

analyzed from the 154 meter and the 615 meter levels. The superficial waters contained ten times as much silica as the deep-seated waters. In the deep waters the carbonic acid is greatly in excess of that contained in the vadose circulation.

General.

The foregoing statement explains to some extent the source of the compounds deposited by ascending waters. But it is not the intention here to discuss its application to each individual metal. This I do not attempt, because I lack the necessary accurate observations upon which such a discussion should be based. To tell in what manner each of the individual metals is carried will require very detailed investigation. For instance, the questions as to the condition in which gold occurs in the original rocks, the manner in which it is carried in solution, and the form in which it is deposited have been much discussed. However, the difficulties in this and other cases, since the modern theories of physical chemistry have been developed, do not seem to be so great as when it was supposed that we must regard each metal in solution as combined with some one acid. It has already been stated that all substances are soluble in water, and somewhat readily soluble in various underground solutions. It is believed that in the very dilute underground solutions, metallic salts are largely in the form of free ions. Therefore, in one sense, gold and other metals in solution are not combined with acid ions, although they are balanced by them. Where precipitated, a metal might be thrown down in the metallic state, as, for instance, copper, silver or gold, by the ions which once balanced it being balanced by other metals.

While it is not the purpose here to take up the solution and deposition of the compounds which occur in ore-deposits in detail, it is necessary to refer to the law of mass-action in this connection. Other things being equal, those compounds which are abundant will be dissolved in larger degree during the downward course of the waters, and the same compounds will be most abundantly precipitated in the trunk-channels. It is well known that iron is the most abundant of all the metallic compounds in the crust of the earth. In this fact, combined with the law of mass-action, we have the dominating abundance of iron sulphide as compared with all sulphides of other metals. It is well known in many cases that the deeper a mine goes below the level of groundwater, the greater the proportion of iron sulphide and the less the proportion of the other metals, as a result of which, combined with increased cost of working, it frequently does not pay to work a deposit beyond a certain depth. The law of mass-action explains the abundance of the iron sulphide; it does not explain the frequent relative increase in the iron sulphide and the decrease of more valuable sulphides as one passes from the level of groundwater into deep workings. To explain this we must take into account the effect of the downward-moving waters, discussed under the succeeding heading.

We have now seen that the zone of fracture is searched by the percolating waters; that metalliferous materials taken into solution by the downward and lateral moving waters are carried to the trunk channels of underground circulation; that in these trunk channels the metalliferous materials are precipitated in various ways. Thus a first concentration, by ascending waters giving sulphurets and metals of some of the elements, is fully accounted for.

In some cases the deposits thus produced are sufficiently rich, so that they are of economic importance. In these cases, which undoubtedly exist, but which perhaps are less numerous than one might at first think, a concentration by ascending waters has been sufficient.

A conspicuous illustration of ore-deposits of this class which may be mentioned are the metallic copper deposits of the Lake Superior region. The copper was in all probability reduced and precipitated directly as metallic copper from upward moving cupriferous solutions. The reducing agents were the ferrous compounds in the solid form, in part as magnetite and as solutions derived from the iron-bearing silicates. When the copper was precipitated, the iron was changed into the ferric condition.* It is well known that metallic copper once formed is but slowly affected by the oxidizing action. Oxidation has, in fact, occurred in the Lake Superior region, but from the

---

* "Paragenesis and Derivation of Copper and its Associates on Lake Superior," by R. Pumpelly, *Am. Jour. Sci.*, Third Series, vol. ii., 1871, p. 353.

facts now to be observed not to an important extent. An oxidized belt may have formed in pre-glacial times, but if so it was swept away by glacial erosion, and sufficient time has not since elapsed to form another. The ore-deposits now worked have apparently remained practically unchanged since the time of their first concentration. In this fact we have the explanation of the great richness of these deposits to extraordinary depths.

As a case of sulphide deposits which continue to great depth without diminution in richness, may be mentioned the gold-quartz veins of Nevada City and Grass Valley, California. According to Lindgren, "it can be confidently stated that there is no gradual diminution of the tenor of the ore in the pay-chutes below the zone of surface decomposition,"* although within the same chute there are many and great variations in richness. This statement is applicable to deposits which reach a vertical depth of 500 or 600 meters. If Lindgren is correct in thinking the gold-quartz veins of the Sierra Nevada do not diminish in depth below an extremely superficial upper zone, this would be a case in which sulphuret ores were sufficiently concentrated by ascending waters alone to afford workable ore-deposits.

THE PRECIPITATION OF ORES BY ASCENDING AND DESCENDING WATERS COMBINED.

Thus far we have considered ores precipitated by ascending waters alone. However, many of the ores thus produced have been profoundly modified by the action of descending waters.

Where the point of exit of the ascending waters of the trunk channels is in a valley or near the level of surface drainage, the waters may continue to ascend quite to the surface. However, where the openings are below slopes the waters ordinarily do not continue to ascend to the surface, but make their way laterally from the trunk-channel at and below the level of groundwater (see Fig. 6). Above the level of groundwater, and frequently for a certain distance below the level of groundwater, the movement is downward in the openings. The water

---

* "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, *17th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, p. 163.

thus moving downward includes not only that which directly passes into the trunk openings at the surface, but a much larger quantity which converges into these openings from the smaller openings on all sides.

In regions in which mining is going on, denudation has ordinarily truncated the veins for considerable depths, in many cases to hundreds or even thousands of meters. It is therefore clear, in a majority of cases, that portions of the fissures in which the waters are now descending were, in the past, in all probability much deeper below the surface, and therefore the waters at that time in the larger fissures were probably ascending. During the time the water was ascending, the first concentration of sulphurets and other products took place. But as a result of the downward migration of the belt of weathering and the downward movement of water in that belt, alteration and secondary concentration of ore-deposits have taken place. This second concentration of ore-deposits is of the very greatest importance, and I believe largely explains the frequent greater richness of the upper 50 or 100 or 500 meters, and in some cases 1000 meters, as compared with lower levels.

It has already been pointed out that the descending waters bear oxygen and carbon dioxide; and furthermore, that solution is taking place. Moreover, the belt of weathering is migrating downward because of erosion. The result of all these changes is to produce an upper belt of second concentrates from the first concentrates formed by ascending waters. This material may be divided into three parts: (1) above the level of groundwater is a belt largely composed of oxides, carbonates, chlorides and associated products, which, however, may contain enriched sulphides. (2) Above and below the level of groundwater is a transition belt composed of sulphides rich in the valuable metals, such as gold, silver, copper, lead and zinc, which, however, contain subordinate amounts of oxidized products. (3) Deeper down is a belt of lean sulphides bearing small amounts of the more valuable sulphurets, and which commonly passes into iron sulphide. Between the three classes of material there are gradations. The oxidized belt gradually passes into the rich sulphide belt; the rich sulphide belt gradually passes into the poor sulphide belt.

The above results are due to a complicated set of reactions which cannot here be given in full. It is, however, clear that if the sulphides are equally abundant the sulphide which is the most easily oxidized will be the first to disappear. The order of disappearance will therefore be iron, copper, zinc, lead, silver. It is, however, understood that the oxidation of an easily destroyed sulphide is not complete before the oxidation of a refractory sulphide has begun. All of the sulphides are oxidized all the time, but the more readily a sulphide is oxidized, the more rapidly it is destroyed. During oxidation the sulphides are largely altered to soluble sulphates, which are taken into solution and carried downward.

The evidence of the extensive formation of sulphates in veins by descending water is found in the presence of sulphates in mine waters and in the frequent formation and precipitation of basic ferric sulphate in the veins, as, for instance, at Cripple Creek,* and in the Mercur district, Utah.† The formation of gypsum and magnesium sulphate in veins is scarcely less positive evidence of the oxidation of the sulphides to sulphates. Further evidence of the formation of sulphates by oxidation of the sulphides is furnished by the hydrous sulphate of aluminum which occurs in the gold-veins of California.‡

The sulphides, however, are not all oxidized to sulphates; a portion of them, by oxidation, break up into sulphurous oxide and oxides of the metals. A part of the oxides unite with the carbonic acid to produce carbonates. Finally the oxides and oxidized salts, both formed in place and transported, react upon the unaltered sulphides, producing richer sulphurets. The reactions may be between an oxide or a salt of a metal and its sulphide, as, for instance, the oxide or sulphate of copper upon the sulphide of copper, as given by the following equations:

$$6CuS + 2Cu_2O = 5Cu_2S + SO_2,$$

and

$$6CuS + 2Cu_2SO_4 + 3H_2O = 5Cu_2S + 2H_2SO_4 + H_2SO_3.$$

---

* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, p. 130.

† "Economic Geology of the Mercur Mining District, Utah," by J. Edw. Spurr, 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, p. 433.

‡ "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, p. 120.

Or the reaction may be between the oxide or salt of one metal and the sulphide of another metal, as, for instance, copper oxide or copper sulphate upon iron sulphide, thus precipitating copper sulphide. The particular reactions in an individual case will depend upon the relative solubilities of the compounds present, and the law of mass-action. This will more clearly appear upon subsequent pages.

The concentrations by ascending and descending waters have been considered as if they were successive. In some instances this may be the case; but frequently it is much more probable that ascending and descending waters are at work upon the same fissure at the same time, and that their products are, to a certain extent, simultaneously deposited. For instance, under the conditions represented by Fig. 6, a first concentration by ascending waters is taking place in the lower part of the fissure, and a second concentration by descending waters is taking place in the upper part of the fissure. Between the two there is a belt in which both ascending and descending waters are at work. The rich upper part of an ore-deposit which is worked in an individual case may now be in the place where ascending waters alone were first acting, where later, as a consequence of denudation, both ascending and descending waters were at work, and still later, where descending waters alone are at work. The more accurate statement for this class of ore-deposits, therefore, is that ascending waters are likely to be the potent factor in an early stage of the process, that both may work together at an intermediate stage, and that descending waters are likely to be the potent factor in the closing stage of the process.

The above general statement may perhaps be better understood if supplemented by a consideration of specific associations of the metals. The associations which are chosen for illustrative purposes are as follows: (1) associations of lead, zinc and iron, (2) associations of copper and iron, (3) associations of silver and gold with the base metals.

THE ASSOCIATION OF LEAD, ZINC AND IRON COMPOUNDS.

In order to understand the relations of the lead, zinc and iron compounds where they occur together in ore-deposits, it seems advisable to take an individual district rather than to make a general statement. An excellent illustration of the association of these metals is furnished by the Upper Mississippi Valley, and this district will therefore be considered.

Facts of Occurrence.

Here, as is well known, in openings in limestones, lead and zinc minerals are associated with marcasite, and some pyrite and chalcopyrite.* Calcite is an abundant gangue mineral, as would be expected, but it and the other gangue minerals will here not be taken into account. Since the pyrite and chalcopyrite are very subordinate, they will not again be alluded to. All of the sulphide of iron will be referred to as marcasite.

The order of occurrence in the district is commonly as follows: Above the level of groundwater in the belt of weathering the dominant valuable minerals are galena and smithsonite. Frequently encrusting the galena, or in crystals upon it, there are some cerussite and less anglesite; with the smithsonite there is some sphalerite. The smithsonite may extend 5 or 10 meters below the level of groundwater; but deeper the oxidized products almost wholly disappear. The smithsonite below the level of groundwater is explained in some cases by the material being along a main channel of downward percolating waters; in other cases by the fact that the level of groundwater is probably now higher than it once was, as a result of depression and valley-filling at the close of the glacial epoch; thirdly, by the well-known general downward movement of oxidizing water somewhat below the level of groundwater; and, fourthly, by reactions between oxidized lead salts and the sphalerite. (See p. 361.) Below the galena and smithsonite is sphalerite, with a large amount of marcasite.† For much of the district the workings have not extended far below the level of groundwater, but in certain parts of the district working has extended for a considerable depth.

While the above general statement is correct for much of the district, it must be understood that a single sulphide does

---

* "The Ore-Deposits of Southwestern Wisconsin," by T. C. Chamberlin, *Geol. of Wis.*, vol. iv., 1882, pp. 380–393.

† Chamberlin emphasizes the inferior position of the zinc as compared with the lead and the association of the zinc and iron, but he does not consider the positions of these compounds with reference to the level of groundwater. *Loc. cit.*, pp. 488–491.

not occur at a given level to the exclusion of the others. Indeed, in many cases all of the sulphides are found at the same level. In many of the smaller veins the sulphides occur in a definite order. The full succession at various openings, from the wall to the druse, is (1) marcasite, (2) ferriferous sphalerite, (3) galena, in cubic crystals, (4) ferriferous sphalerite (subordinate in quantity), (5) marcasite, (6) galena, in octahedral crystals (very subordinate in quantity).* Of this succession at various veins some of these elements are lacking. A very common order is (1) sphalerite, (2) galena, and (3) marcasite.

First Concentration.

No clearer possible illustration could be found of the general principles of ore deposition by the underground waters, and the phenomenon of crustification emphasized by Posepny, than that furnished by this district. The first concentration is believed to be the work of ascending waters, the materials being precipitated in the form of sulphides. It is probable that there was a tendency at the time of the original crystallization for the sulphides to be thrown down in a definite order across the openings, as shown by the phenomena of crustification. Furthermore, it appears that there may have been two main cycles of precipitation, so far at least as the sphalerite and galena are concerned, but the first cycle was by far the more important. It is also possible that there was a tendency for the sulphides to be precipitated in a definite order vertically, as a consequence of which the marcasite was the predominate precipitate at the lowest level, sphalerite at the intermediate levels, and galena at higher levels. Such an order might be explained as a result of the lessening pressure and temperature as the depositing solutions rose in the openings.

Second Concentration.

While it is possible that the vertical order of the minerals is due to a first concentration, it is probable that this is not the most important factor in the regular vertical distribution of the sphalerite and galena. It is believed that the present general order of these materials is mainly controlled by the downward-moving waters combined with denudation.

---

* Chamberlin, *loc. cit.*, pp. 491–497.

It is not necessary to show that the smithsonite above and a short distance below the level of groundwater was largely derived from sphalerite, and that the cerussite and anglesite were largely derived from galena. The details of the relations of the various oxidized and sulphuretted minerals above the level of groundwater are exceedingly complex, and no description of them will here be attempted. Nor in this paper is it necessary to write reactions for the transformation of the sulphides into the oxidized products, since the general characters of such reactions are so well known.* It is, however, necessary to explain how downward-percolating waters may concentrate galena at a high level and sphalerite at a lower level.

Galena.—If it be premised that the ascending waters evenly distributed the sulphides, at least so far as the vertical element is concerned, it is certain that downward-moving waters, combined with denudation, may concentrate the galena at high levels and the sphalerite at lower levels.

The galena is the most difficultly oxidizable of the three sulphides. It is, therefore, the most stable of them. By the oxidation and solution of the sphalerite and marcasite above the level of groundwater the galena would be concentrated. That this process has taken place on an extensive scale is shown by the occurrence of many detached fallen crystals and masses of galena in the openings above the level of groundwater, and also at the bottoms of the wider openings and caves a short distance below the level of groundwater. Indeed, a considerable portion of the lead of the district which has been taken above or within a few feet below the level of groundwater strongly corroborates the idea of concentration as result of solution of the other sulphides which held the galena to the walls, thus permitting the material to drop to lower positions in the crevices.†

While the concentration of the galena is partly explained as above, it may be explained also in part by chemical reactions between the various compounds. In the belt of weathering part of the galena as already noted is being oxidized, as is shown by the incrustations and superimposed crystals of cerussite and anglesite. During the formation of the sulphates and

---

* Chamberlin, *loc. cit.*, pp. 497–509.

† Chamberlin, *loc. cit.*, pp. 453 to 497.

carbonates, a certain amount of these salts is taken into solution and carried downward. These sulphates and carbonates would react upon the other sulphides present and reprecipitate the lead as galena. These reactions might take place to some extent above, but would be especially likely to occur below, the level of groundwater. As a result of the downward migration of the belt of weathering, there would be in the downward-moving waters a continual supply of the sulphates and carbonates of lead. The chief reaction would be that between the lead salts and the dominant iron sulphide. Supposing the iron were in the form of FeS, the reactions may be written as follows:

$$PbSO_4 + FeS = PbS + FeSO_4,$$
$$PbCO_3 + FeS = PbS + FeCO_3.$$

If the iron be supposed to be in the form of FeS_2, as is most likely, oxygen also would be necessary for the reactions. The equations would then be as follows:

$$PbSO_4 + FeS_2 + O_2 = PbS + FeSO_4 + SO_2,$$
$$PbCO_3 + FeS_2 + O_2 = PbS + FeCO_3 + SO_2.$$

However, it has been premised that with the original sulphides zinc sulphide is present, and this may also react upon the lead salts, according to the following reactions:

$$PbSO_4 + ZnS = PbS + ZnSO_4,$$
$$PbCO_3 + ZnS = PbS + ZnCO_3.$$

In the case of the latter reaction, smithsonite would be formed. In this connection it is notable that frequently associated with the galena for some distance below the level of groundwater, smithsonite occurs, as already noted. While a part of the smithsonite below the level of groundwater is of this origin, doubtless the larger portions of it are differently explained. (See p. 358.)

To the foregoing reactions, partly explaining the concentration of galena, objection may be made upon account of the small solubility of lead sulphate and lead carbonate. It is true that these substances are very sparingly soluble in pure water; however, they are sufficiently soluble in waters bearing carbon-dioxide to account for the phenomenon. If this be not the case, the lead may have been carried downward as chloride.

Independent, however, of chemical theory, we know in many districts, and particularly in the lead and zinc district of southwestern Wisconsin, that the galena has been changed to some soluble form upon an extensive scale. As evidence for this inference, galena crystals above the level of groundwater are much corroded, and the amount of cerussite and anglesite associated with them is so small as not to account for the corrosion, and therefore the lead has been transformed to a soluble salt, which has been transported below in important amounts.* So far as my argument is concerned, it is of no consequence whether the lead is as a sulphate, carbonate, chloride or other salt. However, it is believed that these are the forms in which the lead was transferred on the most extensive scale. I regard the cerussite and anglesite as evidence of the partial transfer of the lead as sulphate and carbonate. A large amount of sulphate and carbonate probably formed, but the compounds are so insoluble that a part of the salts produced were not carried downward, but precipitated near the places of formation.

Sphalerite.—Zinc holds sulphur less strongly than lead, but much more strongly than iron. Therefore, the sphalerite would be concentrated in the zone below the galena, the reactions being similar to those producing the galena. They may be written as follows:

$$ZnSO_4 + FeS = ZnS + FeSO_4,$$
$$ZnCO_3 + FeS = ZnS + FeCO_3,$$

or

$$ZnSO_4 + FeS_2 + O_2 = ZnS + FeSO_4 + SO_2,$$
$$ZnCO_3 + FeS_2 + O_2 = ZnS + FeCO_3 + SO_2.$$

Marcasite.—At a certain depth in the openings below the level of groundwater, nearly all of the salts of lead and zinc descending from the belt of weathering would be precipitated by reactions between them and the iron sulphide, as above explained. The remainder of this paragraph cannot be said to apply to the deposits of the upper Mississippi Valley; for the vertical extent of the veins is probably very limited, many of them apparently being cut off by impervious strata within short distances from the surface. However, in veins in which the

---

* Chamberlin, *op. cit.*, pp. 498–499, 500.

first concentration extends to a depth greater than that to which downward-moving waters are effective, only the sulphurets of the first concentration would be found below this level. These sulphurets would consist mainly of marcasite, with subordinate amounts of sphalerite and galena. However, even in this belt, concentration of galena and sphalerite may occur to some extent, although it receives no contribution from the lead and zinc salts from above; for even after the salts of lead and zinc traveling downward from the belt of weathering are all precipitated, the waters may still hold oxygen. This oxygen would, to the largest extent, act upon the marcasite, producing to some extent soluble salts which would be abstracted, and thus reduce the quantity of this material, and relatively enrich the deposits in lead and zinc, although not increasing the absolute amount of lead and zinc present in a given vertical distance. So far as the zinc and lead salts were oxidized by the oxygen-bearing water, these would react upon the iron sulphide again, and they would be precipitated according to the reactions above given.

General.

It is believed that the concentration by descending waters explains, through the reactions given on pp. 106–107, the orderly distribution of the ores in a vertical direction,* although original deposition by ascending waters may have produced its effect. Furthermore, it is believed that this concentration was the final determinative factor in making the ores so rich as to warrant exploitation. This statement in reference to the rich deposits applies both to the oxidized products and to the sulphurets, both above and below the level of groundwater. This process of concentration is primarily chemical, but also to some extent is mechanical, the latter being especially true of the galena loosened by solution from the walls which have fallen to the lower positions in the crevices and caves.

While the reactions of the downward moving oxidized products upon low grade sulphurets, thus producing rich sulphides, have been dwelt upon, it is not supposed that these are the only reactions which have resulted in enrichment. As pointed out by Chamberlin,† organic matter has made its way into the

---

* Compare Chamberlin, *op. cit.*, pp. 551–553.

† Chamberlin, *op. cit.*, p. 544.

openings of the limestone, and as further indicated by Chamberlin,* and emphasized by Blake,† organic matter is abundant in certain of the shaly layers. As argued by Chamberlin and Blake, organic material in the rocks from both of these sources was probably an important factor in the reduction and precipitation of the downward moving sulphates. As pointed out by Blake, the evidence of the effect of this organic matter is especially clear in the cases of the large sphalerite deposits which rest upon the oil-rock at the top of the Trenton as a floor.

My own views in reference to the concentration of the ores in the upper Mississippi valley differ somewhat from those of Chamberlin,‡ Whitney,§ and others, who have held that these ores are products of descending and lateral-secreting waters alone; but still more from those of Percival‖ and Jenney,¶ who have held that the ores were derived from a deep-seated source. The first supposed the transportation to have taken place through igneous, the second through aqueous agencies. Since the discussion of this difference of view involves the influence of some of the special factors considered later, it is deferred to pp. 397–405.

Therefore, so far as practicable, the above statement concerning concentrations by ascending and descending waters and the reactions of the sulphates upon the sulphides is made without reference to the special features of the upper Mississippi valley district. This procedure has been followed because it is believed that in many of the lead and zinc districts of the world the above statement is applicable in its main features.

THE ASSOCIATION OF COPPER AND IRON COMPOUNDS.

Another very general association of metals is that of copper and iron. It is well known, where this association occurs, that

---

* Chamberlin, *op. cit.*, p. 546.

† "Lead and Zinc Deposits of the Mississippi Valley," by Wm. P. Blake, *Trans. A. I. M. E.*, xxii., pp. 630–631. "Wisconsin Lead and Zinc Deposits," by Wm. P. Blake, *Bull. G. S. A.*, vol. v., 1894, pp. 28–29.

‡ Chamberlin, *op. cit.*, pp. 544–549.

§ Whitney, "Geol. of Wis.," vol. i., 1862, pp. 398, *et seq.*

‖ Percival, "Ann. Rept. Geol. Surv. of Wis.," 1855, pp. 30–33; "Ann. Rept. Geol. Surv. of Wis.," 1856, p. 63.

¶ Jenney, "Lead and Zinc Deposits of the Mississippi Valley," *Trans. Am. Inst. Min. Eng.*, vol. xxii., 1894, pp. 219–223.

above the level of groundwater, cuprite (Cu_2O), tenorite (CuO), azurite ($2CuCO_3$, $Cu(OH)_2$) and malachite ($CuCO_3$, $Cu(OH)_2$) are very frequently found. It is further very well known that below the level of groundwater these oxidized and carbonated products occur in greatly diminished quantity, and that rich sulphurets frequently occur, such as chalcocite (Cu_2S), bornite (Cu_3FeS_3) and chalcopyrite ($CuFeS_2$), and sometimes covellite (CuS). Somewhat deeper below the level of groundwater the oxides and carbonates are not found. Furthermore, the chalcocite, covellite and bornite are very generally restricted to the upper part of the belt of groundwater; deeper, the places of these minerals are largely occupied by chalcopyrite. Not only this, but still deeper the chalcopyrite is less prominent in many instances, and the iron sulphides more prominent. In the lower workings of many of the deeper mines the only metalliferous product found is cupriferous iron sulphides, the chalcopyrite having wholly disappeared.

Whether or not this general statement is correct for a particular area, each mining engineer can judge from his own knowledge. There may be exceptions to it, due to various causes, one of which has been alluded to in explaining bonanzas. Thus below cupriferous pyrites there may again be found richer copper sulphides. Indeed, as before stated, ore-deposits vary greatly in their richness both horizontally and vertically,* and the above statement can only be considered as a general average.

The above order is believed to be explained by the work of downward-moving waters. The combinations of lead, zinc and iron were followed from above downward. The reactions which occur in the case of the copper-iron deposits we may perhaps follow, to vary the order, from the base upward. At greater or less depths below the level of groundwater the ores are frequently cupriferous pyrites, the direct deposit of the ascending waters. At a little higher level oxygen from above may have oxidized a portion of the iron and transported it elsewhere, thus relatively enriching the deposit in copper. At a still higher level there will be a contribution of soluble copper salts from above. Since copper sulphate would certainly be the

---

* This volume, p. 264–265.

most common salt, for convenience all the soluble salts will be regarded as sulphates. Reactions similar to those given below may easily be written for other salts.

At the level where salts of copper appear from above, by the reaction of the copper salt upon iron sulphide, chalcopyrite may be produced, the reactions following from the fact that copper-iron sulphides are less soluble than iron sulphides, and from the law of mass action. The reactions may be written as follows:

$$CuSO_4 + 2FeS = CuFeS_2 + FeSO_4,$$

or

$$CuSO_4 + 2FeS_2 + O_4 = CuFeS_2 + FeSO_4 + 2SO_2.$$

Where the iron sulphide is pyrrhotite, intermediate between FeS and FeS_2, the reactions may be written by combining the above equations in proper proportions.

In passing upward from the lowest level at which the chalcopyrite appears, this mineral may steadily increase in quantity until it becomes an important constituent, and finally the iron sulphide may become subordinate. Under these circumstances bornite is likely also to appear. The production of bornite by the direct reactions of the copper salts upon iron sulphide may be supposed to be as follows:

$$Cu_2SO_4 + CuSO_4 + 3FeS = Cu_3FeS_3 + 2FeSO_4,$$

or

$$Cu_2SO_4 + CuSO_4 + 3FeS_2 + O_6 = Cu_3FeS_3 + 2FeSO_4 + 3SO_2.$$

However, the bornite may also be produced by the reaction of the copper salt upon the chalcopyrite itself. For instance:

$$2CuFeS_2 + CuSO_4 + O_2 = Cu_3FeS_3 + FeSO_4 + SO_2.$$

Reactions might also be written for the production of the bornite from the chalcopyrite by the reaction of cuprous sulphate and oxygen. Further reactions might be written as result of which the bornite is derived from chalcopyrite and iron sulphide together; but it is hardly worth while to do this, since no new principle is illustrated.

Passing to still higher levels, with the chalcopyrite and bornite chalcocite may appear. The chalcocite may be produced directly by the reaction of cuprous salt upon iron sulphide, as follows:

$$Cu_2SO_4 + FeS = Cu_2S + FeSO_4,$$

or

$$Cu_2SO_4 + FeS_2 + O_2 = Cu_2S + FeSO_4 + SO_2.$$

Furthermore, the chalcocite may be produced by reactions of the sulphates either upon the chalcopyrite or upon the bornite. In the first case the reaction may be written as follows:

$$CuFeS_2 + CuSO_4 + O_2 = Cu_2S + FeSO_4 + SO_2,$$

or from the bornite by the following reaction:

$$Cu_3FeS_3 + CuSO_4 + O_2 = 2Cu_2S + FeSO_4 + SO_2.$$

Of course, it is understood that these sulphides overlap one another. Before the iron sulphide has wholly been replaced by chalcopyrite, bornite may appear. At the place where bornite has become reasonably abundant, chalcocite may be found. However, certain general statements may be made. If the dominating material is iron sulphide, the copper mineral which is present is likely to be chalcopyrite rather than the richer sulphurets. Chalcopyrite, on the one hand, is likely to be associated with the pyrites, and on the other hand with bornite, or even chalcocite. Bornite and chalcocite are likely to be associated with each other and with chalcopyrite, but with the first two compounds iron sulphide is likely to be subordinate or absent.

At still higher levels in a mine, a moderate distance below the level of groundwater, oxidized and carbonated products may appear with the sulphurets. These mixed products, sometimes called oxysulphurets, are well illustrated in the Appalachian, Arizona and Montana deposits.* Still higher, and especially above the level of groundwater, the oxidized products may become dominant, for there the rich sulphurets which have emerged from the level of groundwater have been directly acted upon by the oxygen and carbon-dioxide. A

---

* "The Copper Resources of the United States," by James Douglas, *Trans.*, xix., 1891, 690, *et seq.*

series of transformations now take place which may result in metallic copper, cuprite, tenorite, azurite and malachite. As in the case of the lead and iron, the nature of these reactions is so well known that they will not here be written out. The oxidation of the sulphur and copper may be simultaneous, or the sulphur may be oxidized first, forming metallic copper, which may later be oxidized in whole or in part. The oxidized products may be first the oxide, cuprite. This may be altered to tenorite, and this, later, may unite with carbon-dioxide and water to form the hydro-carbonates, azurite, and finally, by further hydration, malachite. Illustrating this process, Prof. Penrose has shown me, in a single hand-specimen from the oxidized belt of the Arizona mines, concentrically arranged metallic copper, cuprite, tenorite, and carbonate of copper, the copper being in the core and the carbonate of copper on the outside. The oxidized products may largely remain in place, furnishing rich ores, or they may be almost wholly dissolved and carried to lower levels, to react upon the sulphides, as already explained.

Therefore, largely by processes of oxidation and reaction upon sulphurets, first forming rich sulphurets and later rich oxidized products, there may be concentrated in the upper few, or few score, or few hundred meters of a vein, a large part of the copper produced by a first concentration through a much greater distance. Since the reactions already considered are not the only ones which enter into the second concentration of rich deposits, individual illustrative cases are deferred until after the other factors are considered. (See pp. 383–389.)

By the foregoing it is not meant to imply that each copper sulphide deposit has gone through the entire history above detailed. Indeed, there is no doubt that the general story outlined will need much modification when applied to an individual case. However, it is held that some process of secondary concentration similar to that outlined has been a very important factor in the production of rich copper deposits at many localities.

THE ASSOCIATION OF SILVER AND GOLD WITH THE BASE METALS.

The two common cases of the association of lead, zinc and iron, and that of the association of copper and iron, have now been considered. A similar set of transformations can be traced out in either of these classes of deposits which contain associated silver and gold.

Silver.

In the case of silver, it is well known that the original forms are generally sulphides, sulphantimonites, sulphantimonates, sulpharsenites, and sulpharsenates. Silver sulphide is a compound which holds strenuously to its sulphur. Ordinarily it is not sufficiently abundant to constitute the main mass of an ore-deposit. However, since it holds so strongly to its sulphur, the silver salts are likely to be found, in the case of lead-zinc-iron compounds, most abundantly with the lead, less abundantly with the zinc, and least abundantly with the iron; and in the case of the copper-iron compounds, most abundantly with the copper and less abundantly with the iron. The rich silver compounds, viz., native silver, cerargyrite ($AgCl$), argentite (Ag_2S), proustite (Ag_3AsS_3), pyrargyrite (Ag_3SbS_3), stephanite (Ag_5SbS_3), may be abundantly found in the upper parts of mines, but frequently decrease in amount in passing from the surface deep into the zone of sulphides, and at sufficient depth in this zone these silver minerals may entirely disappear, the products being wholly argentiferous lead, zinc, copper, and iron minerals. In many cases independent silver minerals do not occur at all, all of the silver being in the lead, zinc, copper, and iron compounds. In the case of the lead, zinc, and iron deposits, as the ores become poorer in lead and zinc, they are also likely to become poorer in silver. Also, in case the copper-iron deposits become poorer in copper with depth, the silver will also ordinarily decrease in amount. Therefore the plumbiferous and zinciferous pyrites and cupriferous pyrites deep down are ordinarily lower in silver than the deposits above, which are richer in the base metals.

In this general paper it is hardly worth while to write the reactions for the production of the rich silver sulphurets. Since silver holds to its sulphur more strenuously than any of the base metals with which it is associated, the first of these baser metals which is met in mass will be reacted upon by the silver salts. Suppose, for instance, that in the belt of weathering the silver sulphide is oxidized to silver sulphate or changed to silver chloride. The first of the salts and the second to some extent are taken into solution and pass down where they may come in contact with chalcocite. Argentite would then be precipitated according to the following reactions:

$$Cu_2S + Ag_2SO_4 = Ag_2S + Cu_2SO_4.$$
$$Cu_2S + 2AgCl = Ag_2S + 2CuCl.$$

In a manner similar to the treatment of the other salts, various other reactions could be written between salts of silver and the other sulphides of copper, lead, zinc and iron. For the present purposes, it is only necessary to understand that the silver will be concentrated either as an independent silver sulphuret or as a silver sulphide associated with the rich sulphides of the base metals.

As a case in which silver is concentrated in a sulphide rather than in the carbonate, may be mentioned the Leadville ores. Here, according to Emmons, the galena is much richer in silver than the cerussite. Not only is this so in general, but there are some very interesting special cases. For instance, in the case of five assays of galena nodules which had carbonate crusts, "there are six times as much silver in the galena as in the cerussite."* This discrepancy may be partly explained by the abstraction of the silver as sulphate from the lead carbonate, but I suspect it to be mainly explained by the reaction of the oxidized silver salts upon the galena, producing a galena richer in silver than originally existed.

Above the level of groundwater the silver occurs to some extent in the native form, but more largely as cerargyrite. Silver does not readily unite with oxygen, hence the explanation of the metallic form. However, it does have a strong affinity for chlorine, and where that element is present cerargyrite is likely to be found.

Where the silver is largely changed to the sulphate and chloride, and is not largely precipitated as cerargyrite, the upper part of the silver veins in the belt of weathering may be greatly depleted in silver as a result of this leaching process. That the silver is not thrown down as cerargyrite may be due to a

---

* "Geology and Mining Industry of Leadville," by S. F. Emmons, Mon. No. 12, *U. S. Geol. Surv.*, 1886, pp. 553–554.

deficiency of chlorine in the descending solutions, or to the fact that the solutions are of such a character or so abundant that they are capable of dissolving the silver chloride. Probably illustrating this process of depletion is the Cripple Creek district, where the upper parts of the veins which carry free gold are deficient in silver, while the original telluride contains a certain amount of silver, showing that the silver has probably been leached out.*

Gold.

Gold occurs extensively (1) in the native form, (2) associated with the sulphides, and (3) as a telluride.

In the belt of weathering, gold is very largely found in the metallic form associated with the oxidized products of the base metals, and especially with oxide of iron. Much of such gold has plainly been associated with sulphides or has been united with tellurium.

Below the level of groundwater the most common associations of gold are the sulphides of the base metals. Where base metals other than iron do not occur, gold occurs associated on a great scale with pyrite. In such associations, where the sulphides are abundant, the gold is likely to be plentiful; where the sulphides are deficient, the gold is also likely to be deficient.† This relation is illustrated both by California and Australasia. The relation suggests that the original solution and deposition of native gold is frequently connected with that of the sulphides, and therefore it is reasonable to infer that the same conditions which produced sulphides also resulted in the solution and precipitation of gold.

In various districts in the Cordilleran region, and especially in Colorado, and more particularly in the Cripple Creek district, the original form in which much of the gold was deposited is a telluride.‡

---

* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, pp. 131–132.

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, pp. 124–126. "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans.*, xxvii., 1898, 567.

‡ "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, pp. 119–121.

The original form of the gold of the Judith mountains* is also a telluride. Telluride of gold further occurs in the gold-belt of California,† in the mines of Custer county, Colorado,‡ and in western Australia,§ associated with sulphides. Pearce suggests‖ that the free gold which occurs in various regions may have been originally deposited as a telluride which was later oxidized in the belt of weathering. The Cripple Creek district, in which the gold in the weathered zone is in the metallic form,¶ furnishes an excellent illustration of the formation of free gold from a telluride.

From the foregoing it is plain that gold may be originally precipitated by ascending solutions in a vein as metallic gold, as a telluride, or partly in both forms. Moreover, either one or both of these forms may be associated with the sulphides of the base metals.

Nothing has thus far been said as to the form in which the gold is transported. However, it is certain that gold is soluble in the various underground solutions, and especially in the alkaline sulphides. Moreover, gold readily makes combinations with iodine and chlorine, and as an iodide and chloride is easily soluble. Also alkaline iodides are capable of dissolving gold.** Furthermore, gold is soluble in ferric sulphate. That gold and the salts of gold—one of which we know to exist in nature as a solid, the telluride—are soluble in underground solutions is the main point. Since the modern ideas of physical chemistry have been developed, the form in which the gold is carried is put in a new light. It was supposed that it must be regarded as united with one or more of the other ions present. Since underground solutions of gold are exceedingly dilute, it is highly probable that the gold is ionized or is

---

* "Geology and Mineral Resources of the Judith Mountains of Montana," by W. H. Weed and L. V. Pirsson, 18*th Ann. Rept. U. S. Geol. Surv.*, pt. iii., 1896–97, pp. 589, 591, 597.

† Lindgren, *op. cit.*, p. 117.

‡ "The Mines of Custer County, Colorado," by S. F. Emmons, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, p. 433.

§ "The Superficial Alteration of Western Australian Ore-Deposits," by H. C. Hoover, *Trans.*, xxviii., 1899, 762.

‖ *Proc. Colo. Sci. Soc.*, vol. ii., 1885, pp. 1–6.

¶ Penrose, *op. cit.*, p. 119–120.

** "The Origin of the Gold-bearing Quartz of Bendigo Reefs, Australia," by T. A. Rickard, *Trans.*, xxii., 1894, pp. 308–309.

in the free state. Thus regarded, it would be kept in the ionic state not by any one of the associated acid ions present, but partly by all of them. While the above is true, it is also doubtless true that certain solutions are much more capable of dissolving gold and gold salts than others, and upon this point further investigation is needed.

In whatever form gold is carried, it is known to be precipitated in the first concentration as a telluride, or as metallic gold associated with tellurides or sulphides, or both. Whether it is also precipitated as a sulphide is uncertain. Too little is known about the tellurium salts or the origin of the tellurides to enable one to make any statement concerning the precipitation of gold in this form. However, it is comparatively easy to suggest agencies which may have resulted in the precipitation of gold in the metallic form. When it is remembered that copper is extensively precipitated in the metallic form in the Lake Superior region, and that gold is even more readily reducible, the frequent precipitation of gold in the metallic form need occasion no surprise. Gold would be precipitated in the metallic form by organic matter or by any *ous* salt.

Rickard* calls attention to the frequent association of metallic gold with sedimentary rocks bearing organic matter in Colorado, California, New Zealand, Australia and Tasmania.† The most remarkable case is the concentration of gold in veins where they cross strata of carbonaceous shale, called indicators. Says Don,‡ "Away from the indicator, the greater part of the vein quartz is absolutely barren; but at the intersection with the indicator larger masses of gold (often more than 100 ounces in one piece) have been obtained, and the greater part of the gold extracted from this belt has come from those parts of the quartz veins near some one of the indicators." Furthermore, Rickard§ describes experiments in which the black carbonaceous shale of Rico was placed in silver solutions and in solutions containing Cripple Creek gold-ore.

---

* *Trans.*, xxii., 314–315.

† "The Indicator Veins, Ballarat, Australia," by T. A. Rickard, *Eng. and Min. Journ.*, vol. lx., 1895, pp. 561–562.

‡ "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans.*, xxvii., 1898, p. 569.

§ "The Enterprise Mine, Col.," by T. A. Rickard, *Trans.*, xxvi., 1897, pp. 978–979.

Both metallic silver and gold were abundantly precipitated upon the shale in a short time. In the instances above mentioned it can hardly be doubted that the organic material was an important or controlling factor in the reduction and precipitation of the gold.

Gold would also be precipitated from solutions which came in contact with ferrous oxide, such as magnetite, or by solutions bearing ferrous or cuprous sulphate, or any other ferrous or cuprous salts. When it is remembered that *ous* salts are extensively produced underground (see pp. 348–349), it becomes highly probable that such solutions are frequently the cause of the precipitation of gold with sulphurets. Since iron is the most abundant of all the metals carried in underground solutions, such sulphates would be more likely to be sulphates of iron than any other. If the salts formed in the belt of weathering were ferric sulphates, they would be likely to be reduced to the ferrous condition at depth by the ferrous iron, which is especially abundant in the basic rocks. Indeed, analyses of mineral waters which bear sulphates also ordinarily show ferrous iron.* Therefore ascending waters bearing ferrous sulphate or other *ous* salt might be brought into a lode by side-streams and there precipitate the gold. Such side-channels entering through lateral cracks may, in many cases, explain the extreme irregularity of the distribution of the gold.

Although Lindgren argues to the contrary in the Sierra Nevada,† the suggestion that a part of the gold there has been reduced by ferrous sulphate has extreme plausibility. The gold associated with the pyrites is native. In that district two analyses of the waters of feeding-streams (the only analyses reported) entering the lodes at a depth of 400 feet are given. Both of these analyses show that sulphates and iron are present.‡ According to the analyses the iron is reported as ferric; but apparently no precautions were taken, when the waters were collected, to prevent the oxidation of ferrous to ferric iron. Indeed, the description of the deposits made by the underground springs renders it highly probable that ferrous salts were there contained,

---

* "Mineral Waters of the United States," by A. C. Peale, *Bull. U. S. Geol. Surv.*, No. 32.

† Lindgren, *op. cit.*, p. 181, and pl. v., p. 134.

‡ Lindgren, *op. cit.*, pp. 121–123.

as shown by the precipitates of yellow material, which is partly ferric oxide. Moreover, if these analyses are not sufficient evidence of the presence of sulphates, the clean vein quartz itself, which contains a large number of fluid inclusions, contains sulphates,* showing that sulphate-bearing waters are not exceptional, but must have been present at the time the lodes themselves were formed. Finally, the ore-shoots have great irregularities in richness, for which Lindgren offers no explanation. The suggestion above made that the gold is precipitated in the metallic form by the reducing action of ferrous sulphate explains all of these facts. The deposits are rich where the side-springs issued from cross-fissures and furnished ferrous sulphate to the ascending waters. The gold is in the metallic form because reduced by the ferrous sulphate.

The argillite with which many of the gold-ores of the Sierra Nevada are associated is carbonaceous,† and this carbonaceous material may have assisted in the production of the *ous* salts which ultimately reached the trunk-channels. Indeed, in some places, as, for instance, where the pyrite occurs in a carbonaceous argillite but not in quartz,‡ the gold may have been directly precipitated by the carbonaceous material. But since the gold in the Sierra Nevada is mainly deposited in open fissures,§ the suggestion of reduction of the major portion of the gold by *ous* salts, and especially ferrous sulphate, is thought to be the more plausible, although, as already explained, the formation of the ferrous sulphate may be due in part to carbonaceous material in the country-rock.

It can hardly be doubted that, after a first concentration of gold has taken place, as consequence of descending waters a second concentration may take place. But definite equations cannot be written until it is determined in what form the gold is transported. However, if in the solutions we do not know the acids against which the gold is balanced when transported downward, we may feel sure that, when such solutions reach the sulphide zone, there will be reactions between the acid

---

* Lindgren, *op. cit.*, pp. 130–131, 260, 261.

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, 1895–96, pt. ii., p. 81, 1896.

‡ Lindgren, *op. cit.*, p. 140, pl. viii.

§ Lindgren, *op. cit.*, p. 259.

ions balancing the gold and the bases in the tellurides and sulphides. As a consequence of these reactions metallic gold, and possibly tellurides and sulphides, will be precipitated in a manner similar to that of the precipitation of copper. Individual cases of second concentrations will be considered after other factors influencing concentration have also been dealt with. (See pp. 383–389.)

Concentration by Reaction Upon Sulphides Compared With Metallurgical Concentration.

One of the more common processes of metallurgy for the separation of gold, silver, copper and lead from iron is based upon the principle explaining the second concentration given on preceding pages, viz., that iron holds sulphur less strongly than the other elements named. The sulphuretted ores are imperfectly roasted, thus partly oxidizing them to oxides and sulphates. The ores are then smelted in a furnace with a flux. The oxides of the valuable metals and the sulphates react upon the remaining sulphides of all the metals, producing a matte containing the sulphides of the valuable metals. The iron gets all or nearly all of the oxygen; and the iron oxide unites with the fluxes and passes into the slag.

Other Reactions of Descending Waters.

In the foregoing pages the second concentration of metals by solution, downward transportation and precipitation by reactions upon the sulphides of the first concentration has been emphasized. However, it is not supposed that this is the only process which may result in enrichment in the upper parts of vein deposits by descending waters. The enrichment of this belt may be partly caused (1) by reactions between the downward moving waters carrying metallic compounds and the rocks with which they come in contact, and (2) by reactions due to the meeting and mingling of the waters from above and the waters from below.

(1) The descending waters carrying metallic material dissolved in the upper part of the veins may be precipitated by material contained in the rocks below. This material may be organic matter, ferrous salts, etc. So far as precipitating materials are reducing agents, they are likely to change the sul-

phates to sulphides and precipitate the metals in that form. While sulphides may thus be precipitated either above or below the level of groundwater, they are more likely to be thrown down below the level of groundwater. Other compounds than reducing agents may precipitate the downward moving salts in other forms than sulphides.

(2) In a trunk-channel, where waters ascending from below meet waters descending from above, there will probably be a considerable belt in which the circulation is slow and irregular, the main current now moving slowly upward and now moving slowly downward, and at all times being disturbed by convectional movements. Doubtless this belt of slow general movement and convectional circulation would reach a lower level at times and places of abundant rainfall than at other times and places, for under such circumstances the descending current would be strong. The ascending currents, being controlled by the meteoric waters falling over wider areas, and subject to longer journeys than the descending currents, would not so quickly feel the effect of abundant rainfall. Later, the ascending currents might feel the effect of the abundant rainfall and carry the belt of upward movement to a higher level than normal. However, where the circulation is a very deep one, little variations in ascending currents result from irregularities of rainfall.

In the belt of meeting ascending and descending waters (see Fig. 6), convectional mixing of the solutions due to difference in temperature would be an important phenomenon. The waters from above are cool and dense, while those from below are warm and less dense. The waters from above in the neutral zone of circulation would thus tend to sink downward, while waters from below would tend to rise, and thus the waters would be mingled. Still further, even if the water were supposed to be stagnant at the neutral belt, it is probable that by diffusion the materials contributed by the descending waters would be mingled with the materials contributed by the ascending waters.

Ascending and descending solutions are sure to have widely different compositions, and an accelerated precipitation of metalliferous ores is a certain result. As a specific case in which precipitation is likely to occur, we may recall that waters ascending from below contain practically no free oxygen and are often somewhat alkaline, while waters descending from above are usually rich in oxygen and frequently contain acids, as at Sulphur Bank, described by Le Conte.* The mingling of such waters as these is almost sure to result in precipitation of some kind. Le Conte further suggests† that, by the mingling of the waters from below with those from above, the temperature of the ascending column will be rapidly lessened, and this also may result in precipitation, but the dilution would work in the reverse direction.

The metals precipitated by the mingling of waters may be contributed by the descending waters, by the ascending waters, or partly by each. In so far as more than an average amount of metallic material is precipitated from the ascending waters, this would result in the relatively greater richness of the upper part of veins independently of the material carried down from above.

The above methods of precipitation and enrichment of the upper parts of deposits follow from the reactions of downward moving waters. Their effect may be to precipitate the metals of the ascending water to some extent and thus assist in the first concentration. But the results of these processes cannot be discriminated from the second concentration resulting from an actual downward transportation of the material of the first concentration. *It is believed that the downward transportation of metals is the most important of the causes explaining the character of the upper portions of lodes* (see pp. 355–357)*; but whether this be so or not, their peculiar characters are certainly due to the effect of descending waters.*

SECOND CONCENTRATION FAVORED BY LARGE OPENINGS OF THE BELT OF WEATHERING.

The concentration of large ore-bodies in the belt of weathering is greatly favored by the abundance and size of the openings as compared with the openings existing at greater depths.

The openness of the rocks above the level of groundwater and the comparative lack of openings below the level of groundwater have already been alluded to as general phenomena, and

---

* Compare Le Conte, *Am. Journ. Sci.*, iii., vol. xxvi., p. 9.

† Le Conte, *op. cit.*, p. 12.

an explanation offered for their existence, viz., that in the belt of weathering, solution is the law, and in the belt of cementation, deposition is the law. (See pp. 327–329.) Of course, it is understood that there is usually not a sudden change in the amount of opening space, but that the extremely open upper ground grades into the much less open lower ground at and below the level of groundwater. In some instances the gradation requires some distance. This openness of the belt of weathering and the comparative closeness of the belt of cementation is well illustrated by many limestone regions; for instance, the lead and zinc district of southwestern Wisconsin, already described, pp. 358–364, 397–405. It is also well illustrated by the Leadville district of Colorado, where, Emmons says, "There is a noticeable absence, in the region of greatest ore-development, of channels extending downward."* Thus, so far as the openings are concerned, the conditions for the formation of large ore-deposits are more favorable above the level of groundwater, and as far below the level of groundwater as openings are numerous, than at deeper levels.

The existence of numerous and large openings below the level of groundwater may be explained in individual cases in a number of ways. Of course, the more recent the earth-movements, the more numerous and larger are the openings. In some places the descending waters are not saturated when they reach the level of groundwater, and solution continues for some distance below that level. Furthermore, the level of groundwater varies under different circumstances. Where a region is being uplifted, the level of groundwater, other things being equal, will be descending. Where a region is subsiding, the level of groundwater will be rising. As a result of physiographic changes, there may be alternate valley filling and valley erosion. These changes affect the level of groundwater. In Pleistocene time there was an extensive period of valley filling instead of erosion. Consequent on this, the level of drainage, and therefore the level of groundwater, rose. Also there may be very considerable variations of the level of groundwater, as a consequence of long-con-

---

* "The Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, p. 573.

tinued climatic changes; such, for instance, as the alternating periods of humidity and aridity in the Cordilleras of the West in connection with the Pleistocene.* The annual variations in rainfall cause a less-marked change in the position of the level of groundwater. All these changes favor alternate solution and deposition; solution when the water falls, precipitation when it rises. Where the underground water has been at a low level, this will be favorable to the production of large openings. Where, later, for some reason, the level of groundwater rises, these openings are in a very favorable condition to be filled with ore, as a result of the reactions of the descending solutions on the ores below and of the mingling of ascending and descending waters.

It might be argued that the existence of ore-deposits in the large openings near the surface is evidence that the ores were not first deposited by ascending waters. However, as has been already explained, in the large openings there may be concentrated mineral material originally distributed by ascending waters through a much greater vertical distance. Thus, a very rich ore-deposit, formed by the reaction of descending waters upon a first concentration produced by ascending waters, might be bounded below by a horizon in which the ground is very close, the comparatively small openings which once existed having been cemented by the material deposited during the first concentration by the ascending water.

DEPTH OF THE EFFECT OF DESCENDING WATERS.

For the depth to which downward-percolating waters produce an effect there can be no doubt of their importance in the production of ore-deposits. The only question which remains open is the depth to which this process is effective. This varies greatly in different districts, and in different mines of the same district. In general, the effect is likely to be deep-seated in proportion as the lode worked is on high ground (see pp. 417–418). Also, in arid regions the level of groundwater is deeper below the surface than in humid regions. Moreover, the process of denudation is slower, so that the downward-moving wa-

---

* "Lake Bonneville," by G. K. Gilbert, *Mon. U. S. Geol. Surv.*, No. 1, 1890. "Geological History of Lake Lahontan, a Quaternary Lake of Southwestern Nevada," by I. C. Russell, *Mon. U. S. Geol. Surv.*, No. 11, 1885.

ters have both a wider zone in which to work above the level of groundwater and a longer time in which to work upon a given horizon, and thus in such regions the oxides and carbonates are likely to occupy a considerable zone. This is very well illustrated by the copper-mines of Arizona and New Mexico, and by the colorados of the silver-gold deposits in various arid regions. In humid regions, upon the other hand, the level of groundwater is likely to be near the surface. If this be combined with marked relief so that denudation is rapid, the processes of oxidation and carbonation may not be nearly so complete above the level of groundwater. Indeed, in many cases erosion may be so rapid that the sulphurets do not have time for oxidation, and they may extend nearly or quite to the surface, although in such cases they are likely to be enriched, as explained (pp. 354–357), and it is very uncommon to find a deposit in which no effect of descending waters can be discovered.

It has already been seen that the level of groundwater may vary from the surface to 300 meters or more below the surface. Hence it is certain that, from the surface to 300 meters below the surface, the underground waters may be a potent factor in the production of the rich ore-deposits. The deposits in this belt are particularly profitable, not only because of the accessibility of the material, but because of the fact that there is no expense for pumping; and furthermore, the products are in forms which in most cases are easily reducible. This may be illustrated by the gold and silver deposits. In the former, the native gold is free from its entanglement of sulphurets and tellurides; in the latter the silver is largely in the form of the readily extracted chloride, or in some instances as native silver.

Up to this point there will be no disagreement on the part of any one. But the question now arises as to the depths below the level of groundwater to which descending waters produce their effects. This is a question to be answered not by deduction, but by observation. Even Posepny, who emphasizes the effect of ascending waters, agrees that oxidized products are the evidence of the work of vadose circulation, or the circulation of lateral and downward-moving waters.* Furthermore, Posepny

---

* "Genesis of Ore-Deposits," by F. Posepny (Discussion), this volume, p. 237.

agrees that the iron-mines of the Lake Superior region, which are oxidized products, have been produced by downward-moving waters. A number of these mines have been worked to a depth of 500 or more meters below the level of groundwater. It is, therefore, perfectly clear in these cases that the downward-percolating waters produce an oxidizing effect to a depth of at least 500 meters below the level of groundwater. And this is so in a region in which the level of groundwater is relatively near the land surface, and which is not mountainous. In various other regions oxidized products are also found to a very considerable depth below the level of the groundwater.

In the San Juan district of Colorado, in the Gold King mine, at a vertical depth of more than 300 meters, "the ore taken out is characterized by decomposition, being stained with iron oxide, and showing almost no metallic sulphides."* The author does not state how far this is below the level of groundwater, but merely says that the water-level is deep. Many other veins contain sulphurets, which extend nearly to the surface. In the Cripple Creek district of Colorado and the Judith mountains of Montana—humid areas—oxidized products are found to a depth of 125 meters. The workings at the time when Penrose, Weed and Pirsson† examined the districts had not extended beyond this depth; and therefore we have no knowledge as to the depth at which the last of the oxidized products will be found, or as to the depth to which the sulphides and tellurides have been reacted upon and enriched by the downward-moving solutions from above. This belt of enriched material may be of even greater depth than that of the oxidized products.

As has already been shown (pp. 356–371), where the ores are predominantly lean sulphides in the lower workings of the mines, these react upon the downward-moving oxidized salts of the valuable metals, and thus produce rich sulphurets. It is, therefore, clear that descending waters produce enrichment below the level at which oxidized products are found.

---

* "Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colorado," by C. W. Purington, 18*th Ann. Rept. U. S. Geol. Surv.*, pt. iii., 1896–97, pp. 825–826.

† "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, p. 129. "Geology and Mineral Resources of the Judith Mountains of Montana," by W. H. Weed and L. V. Pirsson, 18*th Ann. Rept. U. S. Geol. Surv.*, pt. iii., 1896–97, p. 592.

Our conclusion is, *that we have positive evidence that the belt in which descending waters are effective in producing rich secondary concentrates, as explained on pp.* 354–378, *extends to very considerable depths.*

ILLUSTRATIONS OF SECONDARY ENRICHMENT AND DIMINUTION OF RICHNESS WITH DEPTH.

The processes have now been explained by means of which a rich upper belt may be produced. If the argument be correct, it is an inference from this that ore-deposits which have undergone a second concentration are likely to diminish in richness with depth, provided a considerable belt be considered. It remains to give instances, the facts of which confirm the actuality of the processes explained, and illustrate diminution of richness with depth.

At Ducktown, Tenn., at the level of groundwater a belt of rich black copper (copper-glance) appears, which varies from less than one to about two and one-half meters in thickness. Above this belt is gossan very poor in copper, below it is a very low grade cupriferous pyrrhotite.* In this instance it can hardly be doubted that originally the lean cupriferous pyrrhotite extended not only to the present surface, but probably much higher than this. The downward moving waters have transported copper to its present locus near the level of groundwater. Here the copper salts have reacted upon the iron sulphide and produced rich sulphurets.

A case which has been, perhaps, more closely studied than that of any other in the United States is that of the deposits of Butte, Montana. Here Douglas states that rich oxysulphurets are found near the surface. These rich oxysulphurets occur in greatest depths and richness on the summit of the hill, "where it seems as if the copper, leached out of the 400 feet of depleted vein, had been concentrated in the underlying ore, and had thus produced a zone of secondary ore about 200 deep, which contains, as might be expected, about thrice its normal copper-contents."†

---

* "The Persistence of Ores in Lodes in Depth," by W. P. Blake. *Eng. and Min. Jour.*, vol. lv., 1893, p. 3. Also, "The Ducktown Ore-deposits and the Treatment of the Ducktown Copper-ore," by C. Henrich, *Trans.*, xxv., 1896, 206–209.

† "The Copper Resources of the United States," by Jas. Douglas, *Trans.*, xix., 1891, p. 693.

Emmons says of the Butte deposits:*

> "Secondary deposition, or transposition of already deposited minerals, has played an unusually important role. In the case of the copper veins it has not been confined to the oxidizing action of surface waters, which has resulted in an impoverishment of the ore-bodies, but below the zone of oxidation it has resulted in the formation of the richer copper minerals bornite, chalcocite and covellite, in part at least by the breaking up of the original chalcopyrite. Unusual enrichment of the middle depths of the lodes has thus been caused. Whether the two processes of impoverishment and enrichment have been differing phases of the action of descending waters, or whether the latter may have been a later result of the rhyolite intrusion, has not yet been definitely decided. It is, however, fairly well determined that the enrichment of the copper deposits is so closely associated with the secondary faulting that it may be considered to be a genetic result of it."

Brown states of the same area that oxidized products extend to the level of groundwater. These oxidized products, according to Brown, promptly change at water level to normal sulphurets. "There follows below a region of varying height, of valuable rock, which again slowly deteriorates in depth; this deterioration, however, being so retarded finally as to be scarcely appreciable."† He further says that above the level of groundwater is gossan "carrying high values in silver, and particularly in gold."‡ Thus at Butte we have in the belt above the level of groundwater enrichment in silver and gold and depletion in copper as compared with the material below the level of groundwater; and at and below the level of groundwater we have rich sulphides of copper which grade into leaner sulphurets. In the case of the Butte deposits it can hardly be doubted that the comparatively lean sulphides in the deeper workings represent the product of a first concentration, and that the modifications of this material found above and below the level of groundwater represent the work of downward moving waters. To account for the high values of gold and silver above the level of groundwater, one must suppose that this belt has received contributions of these metals from the upward extension of the veins which have now been removed by erosion. The great richness of the copper below the level of groundwater Douglas clearly attributes to the downward

---

* "Economic Geology of the Butte District," by S. F. Emmons, *Geol. Atlas of the U. S.*, Butte special folio, Montana, 1897.

† "The Ore-deposits of Butte City," by R. G. Brown, *Trans.*, xxiv., 1895, p. 556.

‡ Brown, *loc. cit.*, p. 555.

transportation of the material from the depleted copper veins. However, a part of this material was doubtless derived from an upward extension of these veins precisely as in the case of the gold and silver. For my own part I have little doubt that the precipitation of the rich sulphides was produced by reaction upon the lean sulphurets, as given in the equations pp. 356, 366–367. Indeed, these equations were written out with reference to the facts of the Butte deposits.

Penrose cites the Arizona copper deposits as instances of secondary concentration. These deposits he regards as produced by leaching of the copper from a lean copper-bearing pyrite, and its segregation at the places where the rich ores occur. In this process Penrose, however, says that the volume of the deposit must be decreased; but he makes the point that the smaller amount of the rich product is more valuable than a larger lean deposit, because more easily mined and more readily reduced.*

This process of concentration is further described by Douglas, who notes, also, that the changes have resulted in the production of enriched sulphides from very lean sulphides in the Copper Queen mine. Here, according to Douglas, a large very low-grade copper-bearing pyrite deposit running from the 200- to the 400-foot level contains rich oxysulphides and black sulphides on the outside, and in the interior is mainly lean pyrite.†

The original material in the Arizona locality is as plainly a lean cupriferous pyrites as in Tennessee. Here, however, on account of the peculiar climatic conditions the alterations have not extended to a uniform depth. Instead of the rich belt being a sheet which diminishes in richness below, it occurs in a zone about the entire residual cupriferous pyrites masses. The principles of concentration are, however, identical, and the rich sulphurets are unquestionably due to reactions between the oxidized salts and the lean sulphides. The rich oxidized products of this area, doubtless, were produced directly from the enriched sulphurets. Therefore, in the formation of the rich oxidized

---

* "The Superficial Alteration of Ore-deposits," by R. A. F. Penrose, *Jour. of Geol.*, vol. ii., 1894, pp. 306–308.

† "The Copper Queen Mine, Arizona," by Jas. Douglas, *Trans.*, xxix., 1900, p. 532.

products there were two stages of alteration; first, the production of rich sulphurets by the reaction of oxidized products upon the lean pyritiferous material, and after that oxidation of the rich sulphurets, which occur partly *in situ*, has also, doubtless, taken place with more or less of transfer of material from one place to another.

An excellent illustration of an enriched upper belt in the case of gold is furnished by the gold-quartz veins of Grass Valley, California, where, according to Lindgren, the decomposed belt of weathering about 50 meters deep contains "from $80 to $300 per ton, while the average tenor in depth is from $20 to $30."* Furthermore, the rich 50 meters, which contains from four to ten times as much gold as the sulphurets below the level of groundwater, is depleted in silver. However, in some veins the sulphurets extend almost to the surface. Lindgren further states that the sulphurets below the level of groundwater continue with undiminished richness to a depth of 500 or more meters.† He adds that the California region is one in which denudation has extended to a depth of 500 to 1500 or more meters.‡ From these facts it is highly probable, as suggested by Lindgren, that the sulphurets similar to those below the level of groundwater were deposited above the present surface of the country. If this were the case the only possible explanation of the belt of weathering rich in gold and depleted in silver is that descending waters have abstracted a large part of the gold from the 500 to 1500 meters removed by erosion, and have deposited it in the belt of weathering. Its precipitation there was, doubtless, mainly due to the reaction of the oxidized products upon the sulphides, producing sulphurets richer in gold. Later, these rich sulphurets have been oxidized, leaving the enriched belt of free gold. The silver apparently has been transported downward to a greater extent in this belt. One would expect that correlative with the belt above the level of groundwater poor in silver, there would be a belt at and below the level of groundwater richer in silver than that above. Upon this point Lindgren does not give us information.

---

* "The Gold-quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geo. Surv.*, 1895–96, pt. ii., p. 128, 1896.

† Lindgren, *loc. cit.*, p. 163.

‡ Lindgren, *loc. cit.*, p. 183.

Another very interesting case of the richness of the belt of weathering in gold, as compared with the unaltered sulphides below, is furnished by the Australian gold-fields, where the belt above the level of groundwater is several times as rich as the unaltered tellurides and sulphides below; some mining men say ounces above to pennyweights below.*

This rich belt is from 50 to 400 feet. In a portion of the mines of some districts—for example, the Kalgoorlie district—when the bottom of the oxidized zone is reached, the ores are so lean as to be valueless, so that mines which were profitable in the weathered zone were not profitable below that zone.† Many of the mines of that district, however, are profitable below the weathered zone. If it had not been for the secondary enrichment of denudation and downward transportation of material, many of the mines would not have been exploited, although Hoover thinks, that in this strange country, the downward concentration is more mechanical than chemical. Thus the secondary concentration by descension is no less an important part of the genesis of the gold-ores of Australia than the first concentration by ascending waters.

The lead- and zinc-deposits of the Mississippi valley (see pp. 357–364), are believed to be clear cases of the importance of the action of descending waters. This has already been shown for Wisconsin. In the lead and zinc districts of Missouri the galena is at a high horizon, and the sphalerite at a low horizon, precisely as in Wisconsin. Moreover, the arrangement of the different kinds of materials in the veins is very similar to that in Wisconsin, the order of deposition of the minerals from above down being (1) blende, (2) galena, (3) pyrite. This corresponds to the order of the more important deposits in Wisconsin, except that before the blende, marcasite formed. (See p. 359.) Lead-bearing ores in Missouri occur in the Cambrian limestones; zinc-ores occur in the sub-Carboniferous limestones; and lead- and zinc-ores occur in the Lower Silurian rocks.‡

---

* "The Genesis of Certain Auriferous Lodes," by J. R. Don, *Trans.*, xxvii., 1898, p. 596.

† "The Alteration of Western Australian Ore-deposits," by H. C. Hoover, *Trans.*, xxviii., 1899, pp. 762–764.

‡ "The Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 1894, pp. 187–188, 197, 199–200.

In Wisconsin the ores occur mainly "in the Galena, Trenton, and, subordinately, Lower Magnesian limestones."* However, in all of these districts the ores which have been taken out are very largely above the 50 meter level. The probable explanation of these relations is as follows: The ores were disseminated in various sedimentary strata, and possibly, also, to some extent in the pre-sedimentary rocks. They were concentrated through a comparatively wide vertical range by ascending waters. But the position of the rich ores near the surface is due to secondary concentration by descending waters, concentration going on *pari-passu* with erosion in such a manner that the rich ores are continuously deposited above and below the level of groundwater, as explained in the previous pages. As denudation passes downward, and thus the level of groundwater descends, the horizon of rich concentrates also descends.

The Leadville deposits furnish an instance of the decrease of the richness in silver with depth. Emmons says: "There is a fair foundation for the generalization that in the deposits, as developed at the time of this investigation, the ores were growing poorer in silver as exploration extended farther from the surface."†

Another case of the diminution of richness of sulphurets with depth is furnished by the nickel mine of Lancaster Gap, which, however, were not worked beyond a depth of about 75 meters, presumably because "the ores decreased in richness as depth was attained."‡

In addition to these specific instances of the production of a rich upper belt, some general statements have been made which need to be referred to. One of these is made by Douglas in reference to sulphuret mines as a whole. Says he, in the conclusion of his discussion as to the copper resources of the United States, with reference to the various Appalachian deposits, "Like all sulphuret mines, they became poorer as depth was attained."§

---

* "Geology of Wisconsin," vol. iv., p. 451.

† "The Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, pp. 554-555.

‡ "The Nickel Mine at Lancaster Gap, Pennsylvania," by J. F. Kemp, *Trans.* xxiv., 1895, pp. 626, 884.

§ "The Copper Resources of the United States," by Jas. Douglas, *Trans.*, xix., 1891, p. 694.

Penrose,* in 1894, discussed the superficial alteration of ore-deposits. He says:

> "As a result of these various changes, certain materials are sometimes leached from the upper parts of ore-deposits, which have become porous by alteration, and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits."†

De Launay,‡ in 1897, emphasizes the frequent occurrence of rich products near the surface, which in some cases are oxidized products, and in others are sulphides. He, however, explains the richness of the deposits by the abstraction of more soluble material. This frequently results in transforming a low grade product into a rich ore. By this process a poor sulphide may be changed to a rich sulphide, as, for instance, cupriferous pyrites or chalcopyrite may be transformed to covellite or chalcocite by abstraction of iron sulphide. It is a natural deduction from De Launay's§ explanation, that the volume of the material is decreased, although he does not make this point.

De Launay further emphasized the point that the ore-material of veins may have been repeatedly transferred from one place to another, and suggests that a part of the material now found in veins may have been transferred from vein material which was once above the present surface of denudation.

While it is believed to be a very general case, if a long enough scale be used, that ore-deposits diminish in richness with depth, it is well-known that above the level of groundwater the valuable materials may be almost wholly dissolved and deposited at or below the level of groundwater by the reactions above stated, as at Ducktown, Tennessee, or partly dissolved and transported below, as at Butte, Montana. Thus, for a certain depth the ores may increase in richness. This exception, however, does not affect the common rule as to diminution of richness with increasing depth.

---

* "The Superficial Alteration of Ore-deposits," by R. A. F. Penrose, Jr., *Jour. of Geol.*, vol. ii., 1894, pp. 288–317.

† Penrose, *cit.*, p. 294.

‡ "Contribution a l'Étude des Gites Métallifères," by M. L. De Launay, *Annales des Mines*, 9th ser., vol. xii., 1897, pp. 151–152.

§ De Launay, *cit.*, p. 194.

GENERAL.

It is apparent from the foregoing that there has been a general understanding that a rich upper belt has been produced in many ore-deposits. Le Conte,* who appreciated this, suggests that the rich belt may be explained by supposing that precipitation by ascending waters does not occur at great depth, because the solutions do not get saturated until comparatively near the level of underground water. However, it is to be remembered that the upper part of a fissure is that receiving abundant lateral waters which have taken a comparatively brief journey under conditions of low pressure and temperature; whereas the solutions lower down have taken a longer journey under conditions of high pressure and temperature. In this connection it might be further supposed that the varying richness could be partly explained by the lessening temperature and pressure of the rising solutions. But if this be true, one would expect the most insoluble constituent to be precipitated deepest down. In the case of the lead-zinc-iron deposits this would make the galena most abundant at depth, the sphalerite most abundant at a higher level, and the iron sulphide the dominating constituent at the highest levels. In the case of the copper-iron deposits, the rich sulphides of copper would be in the lower levels and the cupriferous pyrites at the higher levels.

As already seen, Penrose's explanation of the phenomenon of a rich upper belt is that the concentrates have been produced by downward transportation and precipitation by meeting other solutions. De Launay's explanation of the phenomena is enrichment by the abstraction of the more soluble and less valuable material, thus producing a smaller quantity of relatively rich product.

While the reactions between the oxidized products and the sulphides are emphasized, and are believed to be the most fundamental and widespread, my own explanation† is, mainly,

---

* Le Conte, *loc. cit.*, p. 12.

† Just as I am sending this paper to the press in its revised form (a preliminary proof edition was published and distributed in February, 1900), I am in receipt of a paper upon the "Enrichment of Mineral Veins by Later Metallic Sulphides," by Walter Harvey Weed (*Bull. Geol. Soc. Am.*, vol. xi., pp. 179-206).

that oxidized soluble products are produced in the belt of weathering; that these *in situ* or lower down react upon the lean sulphides. In this way a belt of rich sulphurets is formed. Later, in consequence of denudation, these rich sulphides pass into the belt of weathering. Here they are again exposed to the oxidizing forces, where *in situ* they are largely transformed to oxides, carbonates, etc., and a belt of rich oxidized products above the groundwater is formed. However, in part, when oxidized, they are taken into solution, again transported downward, and again react upon the sulphurets. In arid regions where the amount of downward-moving water is small, the oxidized products formed from the rich sulphurets are likely to remain in large part *in situ*. Where, upon the other hand, water is abundant the sulphides when oxidized are in large measure likely to be carried downward, and again react upon the sulphides below and further broaden and enrich the belt of sulphides. Thus, under different climatic conditions, we may

---

This paper strongly emphasizes the enrichment of an upper belt through the action of descending waters. Moreover, the paper includes the reactions of the oxidized products upon the poor sulphurets, thus producing rich sulphurets. Many occurrences are given which illustrate the enrichment of sulphides by descending waters, including copper, silver and zinc deposits. Some of the illustrations given by Mr. Weed I also have used. Others are additional to those given by me. In general it may be said that Mr. Weed's paper and that part of my own which deals with secondary enrichment by descending waters are supplemental and support each other; since each did his work and arrived at his conclusions in entire ignorance of the fact that the other was working along a similar line.

Upon one point only is there difference of opinion between us. Mr. Weed, in his general statement, says that the part of the veins "below the permanent groundwater level consists of the unaltered sulphides which compose the original ore of the vein. This part constitutes the zone of primary sulphide ore" (p. 181). However, while Weed makes the above general statement, he appears to appreciate that in individual cases rich oxidized sulphides may be produced below the permanent groundwater level, for he says that at Elkhorn, Montana, this level is only 185 to 210 meters below the surface, whereas the sulphides enriched by descending waters extend to the depth of 600 meters (p. 204). If my reasoning be correct, the zone of secondary enrichment by descending waters will ordinarily extend far below the permanent groundwater level, in many instances to the depth of several hundred meters. Indeed, not only the Montana instance, but other illustrations given by Mr. Weed confirm this conclusion. In the pyrite deposits of Spain and Portugal, described by Vogt, the ores decrease in richness to the depth of 350 meters (p. 198). Also in Norway, if I understand Mr. Weed correctly, the diminution of richness of the copper deposits with depth extends from 350 meters to over 700 meters.

have a rich oxidized zone, a rich sulphide zone, or both, in varying proportion.

While the reaction between the oxidized products and the sulphides has been strongly emphasized in this paper because it is believed to be the most fundamental of the causes producing a rich upper belt, it is understood that other factors may also help in this process. As already pointed out, reduction and precipitation of the metals of descending solutions may take place through the agency of organic matter or other reducing materials contained in the rocks, or by meeting ascending solutions carrying precipitating agents; also near the surface more than an average amount of original precipitates from ascending solutions is a possibility in some cases. (See pp. 377–378.)

Summarizing, it appears to me, therefore, that the existence of a rich upper belt in many deposits, and the frequent diminution of richness of the ores in passing downward from the surface to some distance below the level of groundwater, cannot be explained as the work of ascending waters alone or as the work of descending waters alone; but is fully explained as due to the work of ascending and descending waters combined. Ascending waters produce a first concentration. A second concentration by descending waters produces the rich products. Moreover, these rich products are found in the few meters or few hundred meters of the outer crust of the earth. When it is remembered that the greater part of the ores which have yet to be abstracted from the earth will come from the first 500 or 700 meters, and when it is further considered that the effect of descending waters may be felt to these depths, it becomes evident that the process of second concentration by descending waters is a very important one indeed, so far as the economic value of ore-deposits is concerned. Indeed, as a result of it there is concentrated in the extreme outer shell of the crust of the earth a large portion of the products which during the first concentration may in many cases have been distributed over 1500 or 3000 meters or more, but which have now been largely removed by erosion. We therefore conclude that, for a large class of ore-deposits, *a second concentration by descending waters cannot be said to be one whit less important in the genesis of ores than a first concentration by ascending waters.*

It follows from the foregoing that one of the most important classes of ore-deposits is that produced by the joint action of ascending and descending waters.

The Precipitation of Ores by Descending Waters Alone.

For the sake of simplicity and continuity of exposition, the effects produced by descending waters have been applied to deposits which have been first concentrated by ascending waters. However, it is perfectly clear that a concentration by descending waters alone may be adequate to produce ore-deposits. Indeed, this is definitely known to be true of some of the most important ore-deposits, as for instance many of the iron-ores. A conspicuous case is that of the Lake Superior iron-ores, which very well illustrate the process of formation of ores of this class. Since the genesis of the Lake Superior iron-ores is fully discussed by me in the Twenty-first Annual Report of the U. S. Geological Survey, this class of ores is not further discussed here.

Special Factors Affecting the Concentration of Ores.

In Part I. it has been shown that the underground circulation may be effective to the bottom of the zone of fracture, and in Part II. it has been seen that the concentration of ores is an orderly but complex process. However, the discussion has not taken into account a number of the special factors which affect the concentration of ores. The general discussion may need great modification to adapt it to a particular district. To illustrate my meaning, it may be well to consider some of the additional factors affecting the deposition of ores, and to point out the more obvious possible modifications of the general theory which may result from them. The effect of (1) variations in porosity and structure, (2) the character of the topography, and (3) physical revolutions, will be briefly considered.

Variations in Porosity and Structure.

There are many ways in which variations in porosity and structure may affect the concentration of ores by influencing the circulation of waters.* The different strata of the sediment-

---

* Compare Emmons's "Structural Relations of Ore-Deposits," *Trans.*, xvi., 1888, 804–839.

ary rocks vary greatly in porosity. The igneous rocks, and especially the lavas, also vary much in porosity. The metamorphosed equivalents of either sedimentary or igneous rocks may differ in porosity. The contact of rocks frequently furnishes trunk-channels for underground circulation. Bedding partings produced by shearing stresses during deformation furnish sheet channels parallel to the strata, or openings on the anticlines or synclines. Some strata when deformed may yield by fracture, furnishing channels for water-circulation, while interlaminated strata may yield by flowage, thus remaining relatively impervious. These various irregularities may combine in different ways.

All irregularities in porosity and structure may modify, and in many cases profoundly, the simple general statements of the present paper (pp. 309–317, 334–339) concerning the character of underground circulation and the concentration of ore-deposits. At some future time it may be possible to divide the modifications of the general circulation due to variation of porosity and structure into classes, but for the present this cannot be done. The modifications of the general circulation which occur in many individual districts must first be studied and described, after which generalizations may possibly be made. However, some general statements may be made in reference to certain modifications of the general underground circulation.

The Complexity of Openings.—In the general discussion an ore-deposit has been spoken of as if it were a single continuous mass formed in a large opening. It is clear this is not the fact, but, on the contrary, that many ore-deposits have very complex forms. An ore-deposit in a single large opening is exceptional. From large single openings to openings of an extraordinarily complex character, there are all gradations. A trunk-channel of circulation may be a set of distributive faults; it may be a group of parallel or intersecting sets of openings along joints; it may be the minute parallel openings of fissility; it may be a group of openings along bedding planes; it may be the shrinkage openings formed within or along the borders of cooling magma; it may be the openings in an autoclastic rock or reibungs-breccia along a fissure; it may be the multitude of openings of a sandstone or a conglomerate.

Consequent upon the many irregularities, trunk-channels of circulation may vary from vertical to nearly horizontal attitudes. But ore-deposits ordinarily have important vertical components, although they may be found in nearly horizontal positions. In such cases the trunk-channels forming the deposits had probably vertical components somewhere else.

It is hardly necessary to give illustrations of ore-deposits for each of these complex conditions. However, as very excellent illustrations of veins of a very composite character may be mentioned the Cripple Creek deposits* and the gold-quartz veins of Nevada City and Grass Valley, California.† The essential point, so far as the discussion of the foregoing pages is concerned, is that ore-deposits commonly occur at places where there are trunk-channels for ascending or descending waters, or both. In order that metalliferous material shall be brought to a place and deposited in large quantity, there must be long-continued circulation. It matters not whether a trunk-channel is a single passage or is composed of an indefinite number of minor passages, the principles given on the previous pages are applicable to the deposition of ores in such trunk-channels.

In various regions the conditions are so exceedingly complex that ore-deposits close together may differ from one another greatly. This is the best evidence that, notwithstanding their contiguity, the underground trees of water circulation have been, if not independent, at least partly so.

This is well illustrated by the ore-deposits of Butte, Montana. Here, apparently, the metallic contents of the individual feeding streams and even the trunk-channels are very different within short distances. At this place are two main zones of mineralization. The more important product of one of these mineral zones is silver sulphide, which is associated with sulphides of lead, zinc and iron, and with silicate of manganese. The chief product of the other mineral zone is copper, but this copper carries silver in important amounts.‡

---

* "Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95.

† "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1895–96, pp. 158–160, 259.

‡ "Notes on the Geology of Butte, Montana," by S. P. Emmons, *Trans.*, xvi., 54, 1888.

Impervious Strata at Various Depths.—Slichter's theoretical investigations on the motions of groundwaters show that, in order to discuss the flowage under any given set of conditions, it must be assumed that the flowage is limited only by an impervious stratum.* It is, of course, understood that there is no such thing in nature as an absolutely impervious stratum, but there are many strata which are practically impervious. Wherever there is an impervious stratum in a district, this must be counted as the limit of circulation in that direction. The impervious stratum may be a plastic shale which yields to deformation without fracture; it may be a rock intruded after deformation has occurred, thus making a barrier. If an impervious stratum exists at a given depth, the effective underground circulation for that district is there limited or divided, whether the stratum be at the depth of 100 or 1000 or more meters. Of course there will be all gradations, from practically impervious strata to strata which merely check the circulation. It is believed that in the average case the limit of effective circulation is probably much less than the theoretical limit of 10,000 meters given by the depth of the zone of fracture.

However, if an impervious stratum be but 100 meters from the surface and fissures be limited to that depth or interrupted, the laws given pp. 309–317 will commonly apply to the circulation above the stratum. Therefore such a fissure may be occupied by ascending water in the lower part and by descending water in its upper part. Hence an ore-deposit contained in such a shallow fissure may be the result of a single concentration by ascending or descending waters, or of two concentrations, the first by ascending and the second by descending waters.

The foregoing statement in reference to the practical limits of underground circulation for the ore-deposits of a given district may be true even if below the impervious stratum there are other strata, fed from a distance, in which circulation is occurring.

Such lower pervious strata may have circulations of their own independent of the higher circulations, and this circulation may produce ore-bodies. This is beautifully illustrated by the Enterprise mine of Rico, Colo. (see Fig. 9, p. 409), described by

---

* "Theoretical Investigation of the Motion of Ground Waters," by C. S. Slichter, *19th Ann. Rept. U. S. Geol. Surv.* for 1897–98, pt. ii., pp. 329–357, 1899.

Rickard,[*] in which the ore is confined to fissured and broken limestones and sandstones below a black shale, which when bent did not fracture, and therefore afforded no channels for water circulation.

In this connection it may be well to mention the Mercur district of Utah (see p. 411), where a silver ledge and a gold ledge about 100 feet apart each occur in limestone below a shale-like stratum of altered porphyry. Spurr regards the silver ledge as produced by an earlier mineralizing period, and the gold ledge as resulting from a later period of mineralization.[†] It may be suggested that the true explanation of the existence of two mineral ledges so near together and of such different mineral character is that in this district there were two independent circulations separated by impervious strata, the upper one, producing the gold ledge, being between the two impervious porphyry belts, while the lower one, forming the silver-deposit, was below the lower impervious layer.

That a difference of opinion exists as to the source and manner of deposition of the lead and zinc deposits of the upper Mississippi valley has already been mentioned. (See p. 364.) I believe that these deposits furnish an instance of two concentrations where an impervious stratum limiting the concentrating circulation was at a very moderate depth.

The succession for this district in descending order, according to Chamberlin,[‡] is as follows:

Niagara limestone, 137 meters thick.

Cincinnati shale, originally 61 meters thick (in Iowa called the Maquoketa shale).[§]

Galena limestone, bearing organic matter, 76 meters thick.

Trenton limestone, bearing organic matter, 12–30 meters thick, with mean of 21 meters, having at its top an oil-bearing shale,[||] "two or three to several feet in thickness at

---

[*] "The Enterprise Mine, Rico, Colo.," by T. A. Rickard, *Trans.*, xxvi., 1897, 976–977; also Figs. 19, 36, 40.

[†] "Economic Geology of the Mercur Mining District, Utah," by J. E. Spurr, 16*th Ann. Rept. U. S. Geol. Survey*, pt. ii., 1894–5, pp. 367–369.

[‡] Chamberlin, *op. cit.*, pp. 407–419.

[§] "Lead and Zinc Deposits of Iowa," by A. G. Leonard, *Iowa Geol. Survey*, vol. vi., 1897, p. 23.

[||] Blake, *Bull. Geol. Soc. Am.*, vol. v., pp. 28–29; also *Trans. Am. Inst. Min. Eng.*, vol. xxii., pp. 629–632.

points,"* and containing throughout its mass various shaly layers, which, however, are "quite decidedly most prevalent near the base of the formation."†

St. Peter's sandstone, 15–46 meters thick.

Lower Magnesian limestone, 30–76 meters thick.

Potsdam sandstone, 213–244 meters thick.

Pre-Cambrian.

It is to be noted that the Galena limestone is bounded by impervious shales above and below, and that the same statement applies to a less extent in reference to the Trenton limestone. As to the impervious character of the thick Cincinnati shale above the Galena, there is no doubt. One might, however, question the impervious character of the thin bed of shale at the top of the Trenton, but that this is relatively impervious is strongly indicated by the fact that in the Shullsburg and other districts, as pointed out by Blake, the ore-deposits stop at the top of this layer.‡ While in the Trenton the impervious shales are more prominent at the top and near the bottom, there are more or less impervious layers within the Trenton.

The strata dip to the southwest. Chamberlin says for Wisconsin, "The strata on the north side of the lead region are 500 feet (152 meters) higher than those of the south side, and if traced farther the difference in altitude would be found greater. Beds on the eastern side are 350 feet (107 meters) higher than on the west side."§ Superimposed upon the general southwest monocline of the district are a number of subordinate anticlines and synclines, and the ores are mainly confined to the synclines.‖ At the time of this deformation the brittle limestones were probably fractured, producing the present complex system of intersecting joints; but the plastic shales were deformed with comparatively little fracturing. The time at which the deformation occurred is not definitely known, but in all probability it antedated the deep erosion and concentration of ores in the district.¶

---

[*] Clamberlin, *cit.*, p. 412. [†] Chamberlin, *Geol. of Wis.*, vol. iv., 1882, p. 409.

[‡] "Lead and Zinc Deposits of the Mississippi Valley," by Wm. P. Blake, *Trans. Am. Inst. Min. Eng.*, vol. xxii., 1894, pp. 629–632. (Discussion of Jenney's paper.)

[§] Chamberlin, *cit.*, p. 422. [‖] Chamberlin, *cit.*, pp. 432–438.

[¶] "Lead and Zinc Deposits of the Mississippi Valley," by W. P. Jenney, *Trans. Am. Inst. Min. Eng.*, vol. xxii., 1894, pp. 208–209. Discussion of Jenney's paper, by Wm. P. Blake, *op. cit.*, pp. 628–629. Chamberlin, *op. cit.*, pp. 427, 485.

Areally the ores occur to a much greater extent east of the Mississippi river than west of it; that is, mainly east of the main line of drainage. As to horizons, by far the greater quantity of ores which have yet been abstracted were found in the Galena limestone.* However, considerable quantities of ores have been taken from the Trenton, and subordinate quantities from the St. Peters and Lower Magnesian. The ores occur in the Galena from the top to the bottom. In cases where erosion has not cut deep into the Trenton, the ore-deposits are apt to be found near the overlying Cincinnati shale. For instance, in Iowa, where the shales are close at hand as a continuous formation, Leonard† states that the ore occurs "mostly near the top of the Galena limestone, within the upper 50 or 60 feet (15 meters to 18 meters)." Where the drainage lines have cut through the Galena into the Trenton or lower formations, the ores of the Galena are likely, in large measure, to be near the bottom of the formation, and considerable bodies may rest upon the oil-rock which marks the beginning of the Trenton.

Following Chamberlin, I think it probable that a large part of the material of these ores was once disseminated through the sedimentary rocks, and especially the limestones. My conception of the probable process of concentration in the Galena limestone is as follows:

While in the Wisconsin lead district the Niagara limestone and Cincinnati shale are only found on occasional mounds, as pointed out by Chamberlin,‡ there is no question but that these formations once extended over the entire district. As already noted, the Cincinnati shale is a very impervious stratum. Until it was cut through by the drainage, it is probable that effective concentration of the ores did not begin. When it was once cut by erosion, then I conceive the main concentration history of the ore-deposits to have begun. The Mississippi river and areas adjacent were the places where the drainage was the lowest. However, these were not the places first cut through by erosion, for the difference between the level of the Mississippi drainage and the tributaries adjacent is not so

---

* *Geol. of Wis.*, vol. iv., pp. 407, 457, 481.

† Leonard, *cit.*, pp. 43, 61.

‡ Chamberlin, *cit.*, pp. 410–412.

great as the dip of the strata to the southwest. In all probability, therefore, the Cincinnati was first cut through, and the Galena encroached upon by erosion north and east of the lead and zinc district. This is probable from the fact that at the present time the Mississippi river for the most part in the lead district is on the Trenton, and never reaches deeper than the St. Peters; while the majority of the smaller streams in the northeastern part of the lead district have cut into the St. Peters, and the headwaters of some of them, notably the Pecatonica, Platte, the Grant river, have cut through the St. Peters into the Magnesian; while still farther to the northeast, north of the divide, occupied by the Lancaster branch of the C. & N. W. Ry., the strong Wisconsin has cut down to the Cambrian.*

It is to be remembered that the pervious strata overlain by impervious strata along the Mississippi river bear water under pressure, as is shown by numerous artesian wells. The feeding area is the higher ground to the northeast. It is highly probable that the broken brittle Galena limestone was a formation which was capable of carrying water to considerable distances, and in considerable quantities, although probably not comparable in these respects to the St. Peters or Potsdam sandstones. The lead and zinc district of Wisconsin is wholly south of the divide between the Wisconsin river and the tributaries of the Mississippi. When the Wisconsin drainage north of the divide had cut through the Cincinnati shale, this furnished a feeding area to the Galena limestone. When later the Mississippi tributaries south of the divide had cut through the Cincinnati shale into the Galena, the waters entering north of the divide escaped.

As erosion continued, the area in which the Cincinnati was cut through and the Galena penetrated, gradually extended to the southwest until the Mississippi itself had cut through the Cincinnati. During this time the water entered the Galena limestone at the higher elevations, that is, to the north and east, followed along this formation, and escaped at some lower point toward the Mississippi river. While the water to the greatest extent followed the upper portion of the Galena, it is believed that this broken formation was searched to its deepest

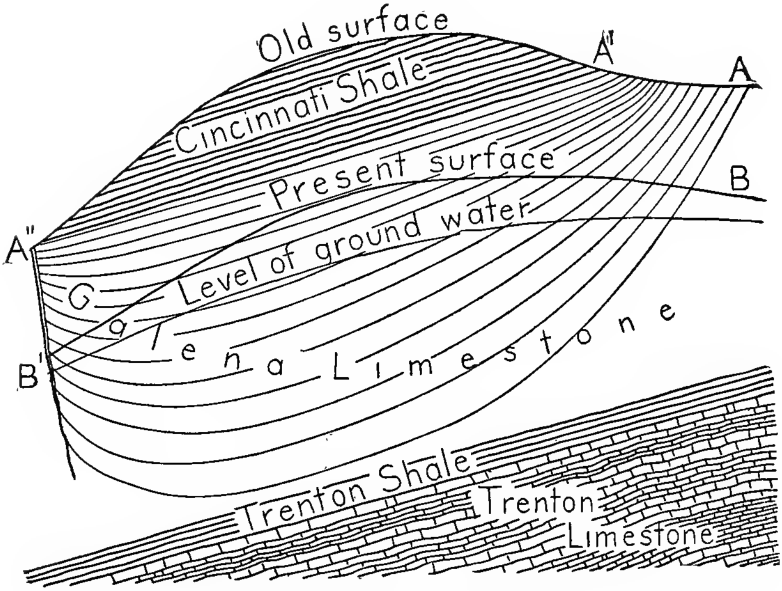
---

* See "Atlas of Wisconsin," pls. i. and viii.

part according to the laws of flowage given pp. 309–317. The places of escape were near the top of the formation, and, therefore, the waters of the trunk-channels leading to these places were ascending.

As erosion slowly progressed, the zone of rising waters and escape slowly migrated from the northeastern part of the lead and zinc district to the southwestern part. The nature of the circulation at a given time is roughly represented by Fig. 7, a northeast-southwest vertical section. The surface of the country is shown by A, A′, A″, in which A, A′ is the cross-section of a northwest and southeast belt, where waters enter, and A″ is in a parallel belt to the southwest, in which the waters escape. The numerous curved lines below the Cincinnati shale are intended to represent the circulation. The downward-moving lateral-moving waters, in the early stages of their journey, were oxidizing and dissolving waters. When, through the organic matter contained in the formation, the oxygen had been exhausted and the oxidized products reduced, the waters were sulphuretted

Fig. 7.



Ideal Vertical Section of the Flow of Underground Water in the Galena Limestone of the Upper Mississippi Valley.

waters, as explained pp. 348–350. The upward-moving waters in the trunk-channels (A″ B′) were precipitating waters, as explained pp. 337–338. And especially the material was likely to be precipitated where the waters came in contact with abundant organic material.

Where the limestone itself contained many carbonaceous substances, the material precipitated might have been widely disseminated; but as the carbonaceous material was more abundant in the clay layers, which, to some extent at least, represented places where clay openings and ore-deposits now exist, the ore material was still more largely precipitated. The transfers of ore material at this time were, indeed, exceedingly complex, but because of a combination of all of the factors considered in the general part of this paper, the material was precipitated to a greater degree in the trunk-channels where the water was ascending than anywhere else.

In an early stage of the process the first concentration by ascending waters took place in the northeastern part of the district. By the time that erosion had cut through the Cincinnati into the Galena in the southwestern part of the district, and ascending waters were concentrating ores, the northeastern part of the district might have been a feeding area where waters were descending, and a second concentration taking place. Therefore, the second concentration by descending waters was going on in the northeastern part of the district at the same time that the first concentration by ascending waters was occurring to the southwest. At the present time the erosion has cut sufficiently deep so that the second concentration by downward-moving waters has extended quite to the Mississippi river, and, indeed, to the west of it. At the present time the condition of affairs, except the circulation, is represented by Fig. 7 below the line B B′, which may be taken as the present surface of erosion.

This general statement as to the order of events concerning the district as a whole would also apply to the local anticlines and synclines. Other things being equal, where there were anticlines there erosion would first cut through the Cincinnati shale, and water make its way into the Galena formation. Later, when erosion had cut deep enough to expose the bottoms of the adjacent synclines, there the water entering at the anticlines arose and escaped, and a first concentration occurred in the synclinal areas. Later, when erosion had cut deeper, a second concentration by descending waters occurred; and thus these concentrations were localized in the synclines, where, according to Chamberlin, they now occur. In this connection it is to be remembered that the anticlines and synclines of the district are very gentle. Therefore, the conditions are here different from those of a district where there are sharp, strongly pitching folds covered by impervious strata. (See pp. 405–412.)

My conception of the process of concentration of ores in the Galena limestones is, therefore, that of a circulation practically limited above by the Cincinnati shale and largely limited below by the impervious oil shale of the Trenton. To what extent ascending waters from the St. Peters, Cambrian and pre-Cambrian rocks under the pressure of considerable head were able to work up through the more or less impervious shales of the Trenton limestone is uncertain. For the purposes of this paper it makes little difference whether during the time of deposition of ores in the Galena limestones by ascending waters the circulation was practically limited by the Cincinnati shale above and the Trenton below, or whether a contribution of waters ascended from greater depths. For a given point where the Cincinnati shale had just been removed, the first concentration occurred by ascending waters, and later when the Cincinnati shale had been removed farther to the southwest the second concentration by descending waters took place. The belt of second concentrates by descending waters slowly migrated downward as erosion extended into the Galena. Where the denudation has gone a little way into the Galena, the ore-deposits are found near its upper part. Where denudation has gone well down into the Galena, the ore-deposits are found near its lower part. Where the lines of drainage are considerably below the Galena the second concentration and downward migration of the ores has resulted in the formation of considerable deposits directly upon the petroleum oil-rock at the top of the Trenton. In these cases the materials exploited are probably the second concentrates from the entire Galena formation.

The precipitation of the lead- and zinc-ores by reactions of the oxidized products upon the remaining sulphides, and by the reducing action of the organic material contained in the rock and the organic material coming down from above, have already been considered. (See pp. 360–364.) However, in this connection it should be noted that the position of the ores upon the oil-rock is probably explained through the reducing action of solutions slowly oozing up through the shale; for the ore is not mainly precipitated in the oil-rock, but immediately above it. In this connection it is to be remembered that all of the pervious strata capped by impervious strata in this region bear waters under pressure. Therefore, water would slowly pass up through the shale, for no formation is absolutely impervious.

It will be seen at once that the above theory of circulation explains the formation of rich deposits near the top of the Galena, as in Iowa, and these deposits are very difficult to account for solely upon the theory of descending waters. It accounts equally well for the formation of rich ores in the middle and lower horizons of the Galena where denudation has gone further. It accounts for the much wider distribution of the ores east of the Mississippi river than west of the Mississippi river, since the strata west of the Mississippi river continue to dip to the southwest; and the drainage west of the river has cut only for a little way deep enough so that the process of concentration as above outlined could occur.

In the parts of the Upper Mississippi valley district where erosion has cut deeply into the Trenton, and especially where it has gone into the St. Peters, a similar history is applicable to the Trenton formation; only the Trenton is more variable in its porosity than the Galena, and the deposits may not have been wholly derived from the Trenton formation, but may have received a subordinate contribution from the Galena formation which has been removed by erosion in part or altogether.

In the application of the foregoing it is, of course, understood that the action of ascending and descending waters in a given fissure is not wholly successive; but is in large measure simultaneous. In the early stages of the deposition of an ore-deposit in a given fissure, ascending water would be likely to be the dominant factor; in an intermediate stage both ascending and descending waters would be at work; and in the later stages of the process, and at the present time, descending waters are the dominant, and, perhaps, in the cases of many of the deposits where the oil-rock of the Trenton is near the surface, almost the sole factor.

At the bottoms of valleys the waters have continued to be essentially ascending instead of descending to the present time. The fact of their present ascension Chamberlin* notes. Thus in these places a second concentration has not occurred, and, therefore, such places are deficient in workable ore-deposits, as noted by Chamberlin.† (See p. 418.)

The case of the lead and zinc district has been dwelt upon, as it seems to me to illustrate almost ideally the practical limitations of circulating water by impervious strata. It shows that precisely the same principles of ore deposition are applicable when the limit of circulation is less than 100 meters deep that apply when the circulation extends to the very bottom of the zone of fracture.

If my views be compared with those of the ascensionists, typified by Jenney, and the descensionists, typified by Chamberlin, it will be seen that I occupy an intermediate position. Upon the fundamental point as to whether or not the ores are derived from a deep-seated source or are derived from sedimentary rocks, I am inclined to follow Chamberlin, although I do not feel certain that some of the material for the ores were not derived from a deeper source.

The account given pp. 357–364, 397–405, in reference to the ore-deposits of the Upper Mississippi valley is not even approximately complete. To give a satisfactory account of the genesis of the ore-deposits of this district, would require a detailed study and a monographic report. Such a report upon many phases of the problem—a remarkable paper—has already been written by Chamberlin.‡ When the study is completed, it will be possible to explain not only the general order of mineral succession vertically, but the multifarious and complex distributions, such as the cycles of depositions already mentioned.

Pitching Troughs and Arches.—Another interesting special case of influence of porosity and structure is that where alternately pervious and impervious layers are in a set of pitching folds. The varying porosity may follow from original difference in the porosity of the layers, or it may result from the deformation itself. The more rigid strata may be deformed by fracture, and the less

---

* Chamberlin, *op. cit.*, p. 565.

† Chamberlin, *op. cit.*, p. 563.

‡ "Ore-deposits of Southwestern Wisconsin," by T. C. Chamberlin, *Geol. of Wis.*, vol. iv., 1882, pp. 365–571.

rigid by flowage. Also, the convex sides of the brittle layers are likely to be more fractured, and, therefore, more porous than the concave sides. This would place the more porous parts of a stratum in contact with the confining impervious stratum below at the synclines and above at the anticlines. Furthermore, where the strata are closely folded, unless there is very great distortion of the strata, openings will form between the layers at the synclines and anticlines, thus furnishing trunk-channels.

Any combinations of porous layers with impervious layers in folds are likely to give trunk-channels for underground water at the troughs above impervious strata, and at the crests below impervious strata. When descending waters come into contact with an impervious stratum, they are deflected toward the synclines, and there finding the trunk-channels, they follow the troughs downward along the pitch. When ascending waters come into contact with an impervious stratum, they are deflected toward the anticlines, and there finding the trunk-channels, follow the arches upward along the pitch. Therefore, ore-deposits produced by descending waters are often found in pitching troughs underlain by relatively impervious strata; and ore-deposits produced by ascending waters are rather frequently found in pitching arches overlain by impervious strata.

The Lake Superior iron-ores furnish an admirable illustration of the concentration of ores by descending waters in pitching troughs which are on impervious basements. Since these ore-deposits, which fully illustrate the principles of concentration of ores by descending water in pitching impervious troughs, are fully discussed elsewhere, ores of this class will not be here further considered.

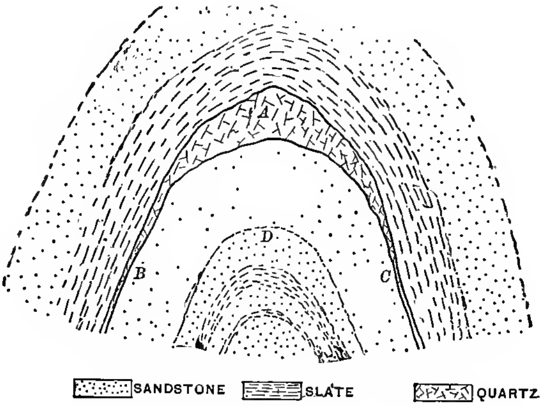
A case in which ore is probably deposited by ascending waters in arches, because there concentrated by impervious roofs, is furnished by the Bendigo gold-district of Australia.* The typical position for the gold in the district, according to Rickard, is immediately below a slate, on top of a sandstone. The slate is the impervious stratum and the sandstone the pervious stratum. The ores are, presumably, in part, in the openings between the

---

* "The Bendigo Gold-Field," by T. A. Rickard, *Trans.*, xx., 1892, pp. 463–545.

layers made by folding.* (Fig. 8.) Moreover, in this district there are a large number of alternations of pervious and impervious strata, as a result of which a number of concentrations have occurred one above the other. While Rickard does not specifically speak of the pitch of the anticlines, the longitudinal sections show that they do have a marked pitch. Rickard's explanation of the location of the ores† is that the apices of the anticlines would furnish more open passages than the synclines, but why at a given level this would be so does not appear. This explanation may possibly be to some extent applicable, but the pitching arches concentrating the ascending solutions below impervious strata are believed to be the main cause of the localization of the gold.

Fig. 8.



SADDLE.

The Concentration of Ore by Ascending Water at a Crest below an Impervious Stratum. After Rickard (*Trans.*, xx., 467, Fig. 2).

Another excellent illustration of ore-solutions concentrated by an impervious roof is furnished by the Mercur district, Utah, described by Spurr,‡ where two ore-bearing beds, one called the silver ledge and the other called the gold ledge, about 100

---

* Rickard, *loc. cit.*, Fig. 2, p. 467. See also Fig. 12, p. 481; Fig 13, p. 483; Fig. 37, p. 499; and Fig. 38, p. 501.

† "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs," by T. A. Rickard, *Trans.*, xxii., p. 319.

‡ "Economic Geology of the Mercur Mining District, Utah," by J. E. Spurr, 16*th Ann. Rept. U. S. Geol. Surv.*, pt. ii., 1894–95, pp. 365–7, 395, 399–401, 449, 454; see also Pl. xxxiv., Figs. 44 and 45, and Pl. xxv., p. 360.

feet apart, occur in a limestone below seams or beds of shale-like material, which, however, is very much altered porphyry. The ores are especially localized where fissures reach these beds, and thus displace them, and in some cases form local arches, although Spurr does not mention this latter fact. Moreover, the entire ore district is located upon a general anticline, furnishing a general pitching arch.

Another exceedingly interesting illustration of the deposition of ores below an impervious stratum in pitching arches is that furnished by the Enterprise mine of Rico, Colorado, described by Rickard in a paper already cited.* In this district above the ore-bodies is an impervious shale which is not broken at all, or very rarely, by the fissures. The ore occurs in two places, (1) in nearly vertical fissures extending indefinitely downward below the shale, but not upward into it. The verticals are cut by cross-fissures, and where the intersections occur the fissures are likely to be unusually rich. (See pp. 340–343.) (2) The larger masses of ore are found in crushed or fractured limestone below the black shale and above the fissures. Moreover, these bodies are narrow laterally, and are parallel to the strike of the verticals and also of the cross-veins. Figs. 9 and 10 show that they occur below anticlinal flexures of the shale made by the deformation resulting in the faulting in the more brittle rocks below. Rickard regards the deposits as the result of ascending waters, since the fissures continue downward but do not extend upward into the shale. It is believed that when the Enterprise deposit is further studied it will be found that the flexures of the shale furnishing the anticlinal arches have a pitch (and indeed this is indicated by Fig. 10), and that the waters issuing from the verticals and the cross-fissures followed these arches upward until the pitch somewhere brought them to the surface, at which places the waters escaped as springs; for the waters of the ascending circulation must have somewhere escaped, and that they could not do through the impervious shale.

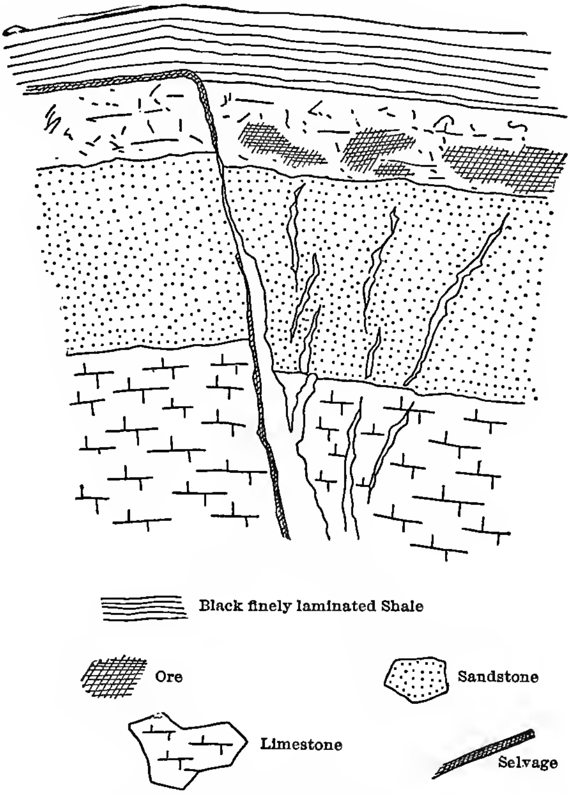
At this point it may be suggested that where ore-deposits occur in connection with pitching anticlines and synclines, that their positions furnish a criterion by which it may be decided

---

* "The Enterprise Mine, Rico, Colo.," by T. A. Rickard, *Trans.*, xxvi., p. 906, *et seq.*

whether their first concentration was accomplished by ascending or by descending waters. Where the ores occur in pitching arches bounded above by impervious strata, the presumption is that they were concentrated by ascending waters; where the ore-deposits occur in pitching troughs bottomed by impervious strata, the inference is that they were concentrated by descending waters; for, as already explained, it is difficult to see how waters can be converged at such positions by moving in the reverse directions. Of course, this criterion cannot be too rigidly applied, for independently of the impervious strata, openings which so frequently occur on anticlines and synclines might

FIG. 9.

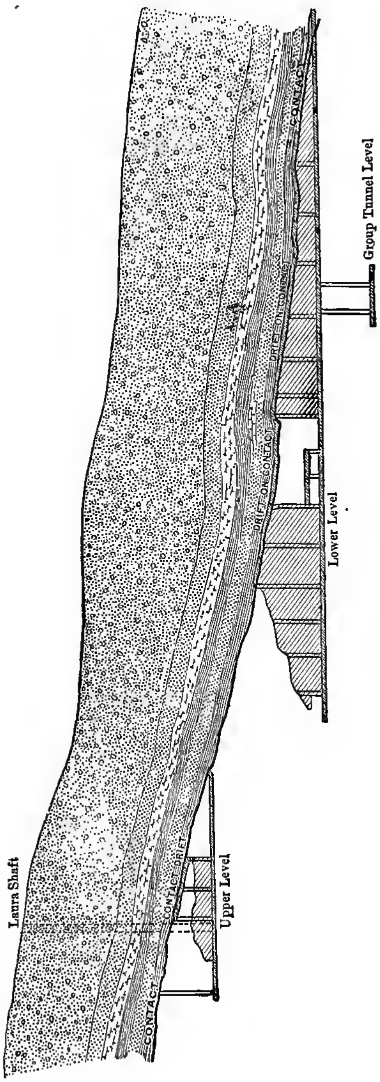


JUMBO NO. 2. VEIN AT THE CONTACT

Ore below a Gentle Arch of Impervious Shale, where the Feeding Fissure Coming from Below Ends at the Bottom of the Impervious Layer. After Rickard (*Trans.*, xxvi., 961, Fig. 36).

furnish trunk-channels which could be taken advantage of by ascending or descending waters. Thus in the Bendigo gold district of Australia, while the more important ore-deposits are in anticlines, occasionally an ore-deposit is found on a syncline.*

Fig. 10.



SECTION ALONG HIAWATHA VEIN.

Scale, 350 feet=1 inch.

Longitudinal Section of the Hiawatha Vein, Enterprise Mine, Colo., Showing the Position of the Ore below an Impervious Stratum, and the Pitch of the Same. After Rickard (*Trans.*, xxvi., 974, Fig. D).

---

* "The Bendigo Gold-Field," by T. A. Rickard. *Trans.*, xx., 1892, p. 484. See Fig. 6, p. 475.

If the above criterion be applied to the Leadville ore-deposits, the conclusion would be that the sulphides of Leadville were deposited by ascending waters, since they mainly occur on anticlines or anticlinoria below a relatively impervious porphyry and in a much-broken limestone, mainly the blue limestone.* The plates of the Emmons atlas show that the ore more largely occurs on anticlines and on the flanks of the folds than in synclines, although some subordinate synclines on anticlinoria contain ore-bodies. When deposited as sulphides the ores were probably somewhat more uniformly distributed than at present along the base of the porphyries. Later, when the second concentration occurred by downward-moving waters, the material which in many places was on denuded anticlines was in part carried down the limbs of the folds under the porphyry into the limestone. At this time doubtless, also, the limestone would be largely dissolved and the materials would be carried not only down along the dip but across the beds, thus producing the very great irregularities which are characteristic of the bottoms of these deposits. If the above explanation be correct, the Leadville ores would present another case in which both the ascensionists and descensionists have had a part of the truth.†

In this connection it may be suggested that the positions of the ores in reference to the limestone and porphyry in the Leadville district are remarkably similar to those of the ores in the Mercur district in reference to almost identical formations. The forms of the deposits, their irregular under-surface in the limestone, and the regular surface at the porphyry are all identical. Both Emmons and Spurr agree that the ore in the Mercur district was deposited as sulphides by ascending waters. If this be true, the same explanation is probably applicable to the Leadville district.

A pervious layer or other opening furnishing a trunk-channel for circulating waters may be bounded on both sides by impervious strata. In this case the ore-deposit may be produced by ascending or descending waters. But where the strata

---

* "Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, 1886, chap. vi., pp. 539–584.

† "Geology and Ore-Deposits of Iron Hill, Col.," by A. A. Blow, *Trans.*, xviii., 1890, 180.

are folded into pitching anticlines and synclines, the positions of the ores with reference to the folds would determine whether the precipitating waters were ascending or descending. An excellent illustration of ore-deposits at the openings of anticlines *between* relatively impervious strata, presumably formed by ascending waters, are the gold-bearing quartz-ores in the slates and quartzites of Nova Scotia, described by Faribault.* Here there are a great many parallel deposits directly at the anticlines or on some parts of the anticlinal folds, the deposits being separated by layers of relatively impervious slate. Furthermore, the largest deposits are located on the great pitching anticlines rather than the subordinate ones.

Porous pitching troughs below an impervious stratum or above an impervious stratum or between impervious strata may have a different origin from those mentioned. Very frequently such troughs are produced in part or in whole by intrusive igneous rocks. For instance, if sedimentary strata have a monoclinal dip and a dike cuts across the strata, a pitching trough may be produced, as, for instance, in the Penokee district.† An intruded igneous rock may follow the contact between folded strata, and thus furnish a trough or arch bounded by an impervious formation. Various other ways will immediately occur to one in which pitching troughs or arches with impervious basements or roofs or both, may be produced. It matters not how the trough or arch be produced, provided a porous stratum or an opening between the layers furnish a trunk-channel, such a trough or arch will be favorable for the concentration of ores. Of course, other favorable conditions must co-operate with these in order to produce an ore-deposit.

Combinations of pervious and impervious strata, united with joints, faults and other structures which affect some impervious strata and do not others, may furnish extraordinarily complex sets of conditions which I am not able to discuss in a general way; but such will undoubtedly yield interesting results when studied in special cases.

---

* "The Gold Measures of Nova Scotia and Deep Mining," by E. R. Faribault, Paper read before the Canadian Mining Institute, March, 1899. Published by the Mining Assoc. of Nova Scotia, 1899. Pp. 11, with plates.

† "The Penokee-Gogebic Iron-Bearing Series of Michigan and Wisconsin," by R. D. Irving and C. R. Van Hise, *Mon. U. S. Geol. Surv.*, No. 19, 1892.

Pre-Existing Channels and Replacements.—When it is understood that ore-deposits ordinarily form in trunk-channels, the question as to whether ores are deposited in pre-existing openings or are replacements is easily answered, as a general proposition. It has been shown that solutions cannot be appealed to to explain the original formation of channels (see p. 295.) The existence of channels for underground circulation must be explained by the original structures of rocks, or by the effects of deformation, as already indicated. It therefore follows that ore-deposits are, to some extent at least, deposited in pre-existing openings. However, the conditions for vigorous circulation are also those for reactions upon the wall-rocks. It has been fully explained that solution and deposition are commonly simultaneous processes. Wherever there is a trunk-channel it is certain that the walls of the openings will to some extent be dissolved, and at the same time or subsequently metalliferous minerals be precipitated. Indeed, either enlargement by solution and subsequent precipitation of ore or synchronous solution and precipitation by which the wall-rocks are replaced in various degrees molecule by molecule by the ore, or both together, are almost universal phenomena.

I therefore believe that the large majority of ore-deposits, if not all, are partly deposited in pre-existing openings and are partly replacements of the wall-rocks. However, in some cases the filling of the pre-existing cavities is the more important or even dominant process, and in other cases substitution for the wall-rocks is the more important or dominant process.

Other things being equal, the main masses of ore-deposits are more likely to be in pre-existing cavities in refractory rocks, such as quartzite, granite and porphyry; and ore-deposits which are largely replacements are more likely to occur in easily soluble rocks, such as limestone. The gold-quartz veins of California give an excellent illustration of the deposition of ores in pre-existing cavities in refractory rocks, such as siliceous argillite, diabase, diorite and granodiorite.* This instance is all the more interesting since the wall-rock itself is greatly modified, and has lost and gained various elements. Ore-deposits which are largely replacements are well illustrated by the

---

* Lindgren *cit.*, pp. 172–257, 259, 261; also pp. 146–157.

silver-lead deposits of Eureka, Nevada, and Leadville, Colorado, and by the gold deposits of the Judith mountains, Montana.*

Replacements are likely to be important also in proportion as the trunk-channels are complex rather than simple. This follows from the law of mass action. In proportion as a trunk-channel is complex, the surface of action upon the wall-rock for a given quantity of solution is large. As conspicuous examples where there are large surfaces of action may be mentioned sandstones and conglomerates, and the reibungs-breccias or crushed rocks along fault zones. Where the trunk-channels are very complex, the rocks even if refractory may be replaced to a considerable extent by the metalliferous ores. A conspicuous instance of this in a sedimentary rock is that of the copper conglomerate deposits of Lake Superior, where many grains, pebbles and boulders of porphyry are partly or wholly replaced by metallic copper. In some places the metallic copper occurs as partial or complete skulls surrounding the boulders of porphyry; in other places these skulls are thicker, and in still other places the entire masses of the boulders, as described by Pumpelly,† are fully replaced by the metallic copper. While the conglomerate deposits of Lake Superior are in part replacements, they also are in large part, fillings of pre-existing cavities between the clastic particles. An excellent example of replacement in igneous rocks where there is complex distributive faulting and thus a large surface of contact for substitution, is furnished by the Cripple Creek district, in which according to Penrose,‡ ore mainly occurs replacing and blending into various igneous rocks.

In case of substitution the entire mass of the rock may be continuously replaced. This is particularly likely to occur

---

* "Silver-Lead Deposits of Eureka, Nevada," by J. S. Curtis, *Mon. U. S. Geol. Surv.*, No. 7, pp. 98–99. "Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, pp. 556, 569. "Geology and Mineral Resources of the Judith Mountains of Montana," by W. H. Weed and L. V. Pirsson, *18th Ann. Rept. U. S. Geol. Surv.*, pt. iii., 1896–97, pp. 594, 598.

† "Copper District," by R. Pumpelly, *Geol. of Mich.*, vol. i., for 1869–1873, pp. 37–38. "Paragenesis and Derivation of Copper," by R. Pumpelly, *Am. Jour. Sci.*, Third Series, vol. ii., 1871, p. 351.

‡ "The Mining Geology of Cripple Creek, Colorado," by R. A. F. Penrose, Jr., *16th Ann. Rept. U. S. Geol. Surv.*, pt. ii., pp. 140–141, 144–146, 161–162.

where the rock is uniform in structure and composition, as limestone or dolomite. Where, however, the rock is of complex composition such as granite or porphyry; or where there are different kinds of rock present, as, for instance, diorite and granite, the replacement will usually be largely selective. This selective replacement may apply to the mass of the wall-rock, to the individual fragments of it, to clastic fragments of sandstones or conglomerate, to the different constituent minerals in a single fragment. The particular minerals or masses which are most soluble in the solutions present will be most rapidly dissolved.

Where the wall-rock varies greatly in the solubility of its minerals, the selective replacement of the country-rock may extend for some distance from the central deposits. The readily-soluble minerals are dissolved, and in place of them there are precipitated the metalliferous minerals. This process is ordinarily called impregnation. Selective replacement of this kind is well illustrated by the Butte, Montana, granite, in which "the basic constituents of the granite are naturally attacked first, then the feldspars, and finally the quartz itself may be removed, so that in some parts there are found large masses, composed entirely of metallic minerals."*

In the variable solubility of the country-rock lies the partial explanation in regions of heterogeneous rocks of the frequent occurrence of the main masses of the ore-deposit in the more soluble rock. For instance, where limestone and sandstone, limestone and quartzite, limestone and diorite, limestone and trachyte, limestone and porphyry, limestone and granite, or limestone with almost any other rock occur in intimate association and ore-deposits are found, the ore is likely to be largely in the limestone.† The partial explanation of this relation is undoubtedly the more ready solubility of the limestones. However, other factors enter into the matter. It has already been explained that the country-rock may furnish solutions which

---

* "Notes on the Geology of Butte, Montana," by S. F. Emmons, *Trans.*, xvi., 1888, 57.

† "The Copper Ores of the Southwest," by Arthur F. Wendt, *Trans.*, xv., 25–77. "Silver-Lead Deposits of Eureka, Nevada," by Jos. Story Curtis, *Mon. U. S. Geol. Surv.*, No. 7. "Geology and Mining Industry of Leadville," by S. F. Emmons, *Mon. U. S. Geol. Surv.*, No. 12, p. 540.

react upon the mineral-bearing solutions, and thus cause precipitation (see pp. 317–319). Furthermore, where limestone and stronger rocks are deformed together, the limestone, having less strength, is more likely to be crushed and broken in a complex manner and thus furnish trunk-channels for circulation.

In conclusion, I insist that ore-deposits form where there existed original trunk-channels of circulation. These trunk-channels may have been greatly enlarged by solution. This, indeed, is the general tendency above the level of groundwater, but the general tendency below the level of groundwater is to cement rather than to enlarge the openings (see p. 329). Ore-deposits formed along trunk-channels will commonly, if not universally, be to some extent in pre-existing openings and to some extent as a substitution for the wall-rock. Where the trunk-channels are simple and the rocks are refractory the ore-deposits to a large extent are likely to be in pre-existing openings. Where the trunk-channels are complex and the rocks soluble the ore-deposits to a large extent are likely to be replacements.

Character of the Topography.

Effect of the Vertical Element.—Where the topography is marked the underground circulation is likely to penetrate much deeper than in regions where the variations in topography are slight.

In mountainous and elevated plateau regions the lithosphere is likely to have more numerous, larger, and deeper openings than in low-lying areas. Elevated areas are those of comparatively recent orogenic or epeirogenic movement. Therefore they are regions in which the rocks have recently been deformed and fractured, and hence the processes of cementation would have been less likely to have closed the openings. In regions of very steep topography the tendency for the material to glide down the slope under the stress of gravity also tends to widen openings which have been once formed. Such movements are known to be effective to the depth of hundreds of meters. It is hence clear that elevated and rough regions are those in which the underground circulation is likely to find large, numerous, and deep openings.

Furthermore, elevated and mountainous regions are those in which the underground water has the greatest difference in head, and this is favorable to deep circulation.

Thus, in mountainous regions, like the Cordilleras, it would be expected that the underground circulation both ascending and descending would be effective to greater depths upon the average, than in regions of gentle topography like that of the lead and zinc district of southwestern Wisconsin (see Fig. 7, p. 401), where it is perhaps probable that the scope of the effective circulation, ascending and descending, is confined to a vertical distance of 500 meters or less.

Unfortunately, the majority of descriptions of mines do not say anything as to the level of groundwater. In the San Juan district of Colorado, which is a region of very rugged topography, Purington states* that the level of groundwater is far below the surface, and that oxidizing effects are produced at a depth of 300 meters or more, thus confirming the conclusion that the zone of descending water is increased by rugged topography, and it can hardly be doubted that the zone of effective ascending circulation is equally increased.

Effect of the Horizontal Element.—The horizontal position of an ore-deposit with reference to topography often has an important influence upon its richness and magnitude. If the correct theory of circulation of underground waters and the deposition of ores has been given, certain corollaries follow from this theory with reference to this point.

(1) Commonly ores deposited by ascending waters would be formed below the valleys, or at least below the lower parts of the slopes; for these are the places where waters are ascending in the trunk-channels. (2) Commonly ores deposited by descending waters would be formed below the crests or below the upper slopes of elevations; for these are the places where water would be descending. Probably the upper slopes would be more favorable places than the crests; for at an annular belt upon the upper slope of an elevation the quantity of descending waters would be greater than at the crests. (3) Commonly ores which receive a first concentration by ascending waters and a second concentration by descending waters would be on the slopes,

---

* "Preliminary Report on the Mining Industries of the Telluride Quadrangle, Colorado," by C. W. Purington, *18th Ann. Rept. U. S. Geol. Surv.*, pt. iii., 1896-97, pp. 825-827.

probably in many instances nearer the valleys than the crests. At such places the meteoric waters falling at the higher elevations would have sufficient head to deeply search the zone of fracture for ores. Therefore, the ascending circulation in trunk-channels would be strong. Furthermore, at such places the level of groundwater would be a considerable distance below the surface, and abundant descending waters would be concentrated in the upper parts of the openings. (See Fig. 6, p. 336.) The downward migration of the belt of weathering would furnish the final favorable condition for the accumulation of a large amount of second concentrates by descending waters.

Admirable illustrations of ore-deposits corresponding to the second of the corrollaries are furnished by the iron-ore-deposits of the Lake Superior region. These are the products of descending waters, and the great majority of the ore-deposits are found near the tops of hills or upon the upper slopes.

An excellent illustration of the third corrollary is furnished by the lead and zinc district of the upper Mississippi valley. Chamberlin* notes that in the valleys of the Wisconsin part of the district the waters generally ascend to the surface; therefore, at such places only a first concentration would be expected, and it is the general impression among miners that a lode makes better on the slope of a hill "than at the summit or at the foot of a hill."† Furthermore, it is held by the miners that the lodes which run parallel to a contour of a hill "like an eave-trough," are more likely to be rich than those which run toward the summit of the hill.‡ Both of these practical conclusions of the miners are fully explained by the theory of a first concentration by ascending waters, and a second concentration by descending waters when considered in connection with the topography.

The above conclusions concerning the relations of ore-deposits and topography are only perfectly applicable in regions in which the drainage lines have been reasonably stable. The Lake Superior region and the lead and zinc district of the upper Mississippi valley are regions of stable topography. The main drainage lines have probably not been greatly modified

---

* Chamberlin, *cit.*, p. 565.

† Chamberlin, *cit.*, p. 563.

‡ Chamberlin, *cit.*, p. 563.

since they were established at the close of the Cretaceous period of base levelling. This is certainly true of the lead and zinc district; but in the Lake Superior region the drainage lines have been to some extent modified by the glacial invasions.

In regions in which there have been recent important changes in the positions of the drainage lines and elevations, the generalizations are only partly applicable. It is well known, in consequence of the varying hardness of rocks, in consequence of their structure, in consequence of the unequal strength of streams and unequal declivity, that drainage lines are almost constantly shifting, and in many regions somewhat rapidly. Consequent on this shifting, many ore-deposits which, when below valleys, received a first concentration by ascending waters, are now well up on slopes or even at crests. A change of this kind would be especially favorable to the development of ore-deposits which are due to two concentrations, the first by ascending and the second by descending waters. In an early stage of the history of a deposit it would be in the most favorable place to receive a first contribution of ore. Later, when, as a consequence of a topographic change, it was on higher ground, it would then be in a favorable place for the work of descending waters. Although it is difficult to prove, I have little doubt that many ore-deposits have had this very favorable history.

Many other ways could be suggested in which changing topography would be favorable or unfavorable to further concentration of ores. However, I shall not attempt this, but suggest that geologists in various regions study the ores in connection with the topographic development of the region. Such studies will furnish facts upon which safe generalizations may be made.

Physical Revolutions.

The genesis of many ore-deposits is undoubtedly further complicated by physical revolutions of various kinds. After an ore-deposit has partly formed, either by ascending or descending waters or both, the region may go through a physical revolution, and after the revolution the concentration of the ores may again be taken up by Nature's processes.

After an ore-deposit has been formed the country may be reduced to the level of the sea either by denudation or subsidence; there be deeply buried under sedimentary rocks; may be again uplifted, and undergo a second cycle of reactions which affect the nature of the ore-deposits. An ore-deposit partly formed may be buried deep under volcanic rocks. This undoubtedly has occurred on a great scale through the great period of Tertiary vulcanism in the Cordilleras of the West. The ore-deposits there buried are placed in a new environment, and are undergoing a second cycle of concentration or depletion. When in the future denudation shall have stripped off these volcanics, these ore-deposits will be at the surface. This may not occur while man occupies the earth, but doubtless similar things have occurred with reference to extensive areas where mines are now being worked. It is well known that when fissures once form, these are places of weakness, and that movement has again and again recurred along the old planes. Thus, where the conditions once become favorable for ore-concentration they may recur in the same places through various revolutions. Physical changes of various other kinds may take place. Each of the complex changes in physical history will produce its effect upon an ore-deposit.

General.

It is clear from the foregoing that an ore-deposit may not represent the work of a single period of ascending waters, but may include several alternating periods of ascension and descension, and in this way irregularities in certain of the ore-deposits in very ancient rocks may be explained. However, it appears probable in many cases that the main work of ore deposition has been the result of a single concentration by ascending waters and a single concentration by descending waters.

Any of the special and local factors above discussed and others may in an individual case be so conspicuous as to appear to be a controlling factor in the formation of an ore-deposit. One might say that the existence of a given trough was the cause of the production of an ore-deposit. The truer statement would be that the factor under consideration is one essential factor among many. The porosity of a formation, the existence of a pitching trough, favorable topography, the presence of igneous rocks furnishing heat to make the waters active, and many other special factors, may, in a given case, all be essential factors, without the help of any one of which an ore-deposit would not have been produced. But no combination of these special factors will form an ore-body, if a source of the metal is not available upon which the underground waters may act. In short, each case of the formation of an ore-deposit requires the fortunate combination of many favorable factors, working harmoniously together, the absence of any one of which may prevent the concentration of the ore-deposit.

ORE-CHUTES.*

No fact is better known concerning ore-deposits than that they vary in the most remarkable fashion, both in size and richness. Moreover, these variations are both vertical and horizontal. Frequently rich deposits decrease in size or are wholly cut off with extraordinary abruptness. Other equally rich deposits may appear somewhere else on the same level or on another level in an equally strange and apparently inexplicable manner. The ore-masses of exceptional richness are generally called ore-chutes. Sometimes they are spoken of as pay-streaks, at other times as bonanzas, at other times as chimneys. In this paper ore-chute is used as a general term to include all deposits of exceptional richness or size, of whatever origin. At various places in this paper factors have been mentioned which produce ore-chutes. However, because of the very great economic importance of ore-chutes, it seems to me advisable to consider under one heading some of the more prominent of these factors, even at the risk of repetition.

Ore-chutes may be grouped into those which are largely explained (A) by structural features, (B) by the influence of the wall-rocks, and (C) by a secondary concentration by descending waters.

(A) One large class of ore-chutes may be explained principally by structural features. These structural features may be (1) the varying size, (2) varying complexity, (3) flexures, (4) intersections of fractures, and (5) later orogenic movements.

(1) A fracture through a mass of rocks is necessarily uneven. Where there are movements, it follows that the walls will not

---

* For a general discussion of ore-chutes in fissures, see "The Mining Geology of the Cripple Creek District," by R. A. F. Penrose, Jr., *16th Ann. Rept. U. S. Geol. Survey*, part ii., 1894–1895, pp. 162-166.

be adjusted to each other. Where projections or complex surfaces are opposite each other, the fissure may be represented by a mere seam. Where, on the other hand, depressions or two concave surfaces are opposite each other, a widening may occur which in some cases is sufficient to produce a great room. Rooms may be partly or largely produced by solution. Rooms may be connected by comparatively large channels. Thus there may be in a single mine a succession of rooms filled with rich deposits connected with rich chimneys. It is evident from the above that there may be every variation in the width of an ore-deposit due to this factor, from zero to many feet.

It has been shown, other things being equal, that the underground circulation will follow the largest openings. Thus, wherever there are rooms, and especially where there are rooms with connecting passages of considerable width, there the most abundant circulation will be converged. Moreover, the solutions of this circulation will be derived from various sources. Hence, in the large openings more ore and very frequently richer ore will be deposited than in the narrower openings, where the solutions are both less abundant and less complex.

(2) Ore-chutes are frequent where the fractures, instead of being simple, are complex; that is, where there is a crushed zone, or zone of brecciation and mashing. It has been pointed out pp. 343–345) that some ore-deposits are largely due to reactions between the solutions and the rocks through which they pass. Such an ore-deposit is most likely to be rich at a crushed zone, where there is every opportunity for much greater interaction between the solutions of the trunk-channels and the rocks through which it circulates than where there is a single fracture, even if the space furnished by the latter is greater than that furnished by the multitude of smaller openings. (See p. 414.)

(3) Very frequently the rich chutes of ore are located by flexures, the ore being either at the crests of anticlines or at the bottoms of synclines. As pointed out (pp. 405–412), this is especially likely to be the case where, in connection with the folds, there are impervious strata. Under such circumstances, as has already been fully explained, ore is likely to be converged from ascending solutions in the arches of pervious

strata below impervious strata, and by descending waters in troughs of pervious strata above impervious strata. In the cases cited, such as those of Australasian and Nova Scotian gold-ores and the Lake Superior iron-ores, these relations are perfectly clear; but doubtless in many mines there are minor flexures which have been overlooked, but which may be sufficient to control the movement of the circulation, and thus produce the chimneys of ore. These minor flexures may be parallel with the dip of a deposit, or they may pitch to the right or to the left of a deposit as one looks down the dip.

(4) The intersections of fractures furnish one of the most frequent explanations of ore-chutes. The intersections may be those of faulted fissures; those of fissures and joints, or the intersections of joints. In many instances one set of fractures carries the larger ore-deposits, and the intersecting set or sets of fractures are known as side fractures. In other instances the main deposits may occur in more than one set of fractures, and still other sets of less importance constitute the side fractures.

In all cases where intersecting fractures occur, there solutions will be contributed from two or more sources. The solutions will invariably have different compositions, and, therefore, precipitation will be likely to occur at the junctions. In some cases more than one set of fractures may furnish metalliferous material, while in other cases the metalliferous material may be contributed by one set of fractures and the precipitating agents by the others. In these instances where the intersecting veins all carry ore, it is easy to see why the deposits at the intersections should be unusually large and rich. However, where the side veins are small or are wholly filled with gangue material, their importance in the genesis of ore-deposits has been very generally overlooked. In many instances there is little doubt that the metallic material has been precipitated in a main fissure at or near where the side veins join through the influence of the solutions contributed by the latter veins. A very clear case of the influence of side veins is that already cited of the Enterprise mine, of Rico, Colorado, where the pay-chutes are especially rich in the main fissures at the places where barren side veins intersect them. Where ore-chutes are found to be connected structurally with barren side veins, a consideration of the minerals themselves and the minerals in the side veins ought to lead to more exact knowledge concerning the manner of the precipitation of the metal; for presumably the precipitation of the metals was connected with some of the compounds which occur as gangue in the side veins.

Side fractures may be at right angles to the main set of fractures or incline to them. They may extend directly down the dip or pitch to the right or left along the dip. Therefore, almost any curious distribution of the rich chutes may occur. In some cases a side stream either bearing metals or precipitating agents, or both, may not issue equally all along a fault or a joint, but may be largely converged into a single channel or strong spring which enters a fissure. In such cases, especially if the spring empties where there is a room produced by the structural features discussed under (1), bonanzas may be formed, such as those of the Comstock lode.

While the relative influence of the different sets of intersecting fractures is very complex, in an individual mine a close study of the number, order and relations of the fractures and joints, many of which are, perhaps, almost imperceptible, may furnish rules which will enable one to more intelligently search for ore.

Between the two cases of a trunk-channel produced by flexure, described under (3), and by cross fracture described under (4), there is complete gradation.

(5) Late orogenic movements explain certain ore-chutes. After openings have received a first contribution of ore, and are, perhaps, fully cemented by ore and gangue materials, orogenic movements frequently recur, which again fracture the ground and produce openings. Some parts of a deposit may escape fracture, while other parts may be broken. The fracturing of the broken parts may be simple or complex. The complex fracturing may produce zones of parallel fractures, zones of intersecting fractures, brecciated zones, or even zones in which the material is finely mashed. Between the parts of the deposit which have no fracturing and those in which the fracturing is of the most complex sort, there may be all gradations. The fractures may be confined to a narrow belt of a deposit or to one side of it. It may be confined within varying limits laterally or vertically. All of the above statements in refer-

ence to the main deposits apply equally well to intersecting sets of deposits; also, entirely new sets of openings may be produced. Therefore, an ore-deposit which has received a first contribution, and again is subjected to orogenic movements, is in such a condition that it may again receive a contribution of ore material under the same complex laws as at first. This ore material will be distributed in the same irregular manner as that of the first contribution. Therefore, the new material will not only be distributed irregularly, but will be superimposed upon the old material, which also had an irregular distribution, and thus there will be extraordinary variations in richness.

(B) Ore-chutes in many cases are explained by the influence of the wall rocks. It is well known that where ore-deposits intersect a complex set of rocks, that the pay-chutes are likely to have a decided preference for one rock rather than the others. For instance, if a fissure passes from granite to diorite, or from either of these to limestone, or from any of these to sandstone, the character and richness of the deposit may vary greatly as the rock changes. For this variability, due to the character of the wall rocks, different explanations apply in different cases. (1) In some instances the restriction of the ore-chutes to one rock is largely explained by the more ready solubility of that rock. This is particularly applicable to the substitution deposits, the wall rock being dissolved *pari-passu* with the deposition of the ore. By the solution of the soluble rock sufficient room is furnished for a large ore-deposit. The above is undoubtedly the partial explanation in many cases of the preference of the ores for limestone rather than to the adjacent more insoluble rocks. (2) In other instances the preference of the rich and large bodies to one wall-rock rather than another is due to the fact that the wall rock itself, by reaction upon the solutions, precipitates the ore material. This may also partly explain the preference of certain ore-deposits for limestone. (3) In still other instances the wall rock itself furnishes solutions containing metalliferous material which is precipitated in the trunk-channels, or furnishes solutions capable of precipitating metalliferous material in the trunk-channel.

(C) A third class of ore-chutes are those produced by the processes which have been so fully explained in this paper, viz.:

the secondary enrichment of a deposit by descending waters, the first enrichment of which was produced by ascending waters. By this process rich ore-bodies, either oxidized or sulphuretted, or partly each, which are limited in depth by the distance to which the descending waters are effective, are formed.

General.—Of necessity, in this analysis, the various factors which may produce ore-chutes have been separately treated. However, in a given case it is rare, indeed, to find that the entire explanation lies in the application of a single one of them. To explain an ore-chute of an individual mine, ordinarily a number of the above causes need to be combined, and in some cases, doubtless, other causes which have not been treated. No study is more important economically, more fascinating, or more difficult in a given district or mine than to ascertain the particular combination of factors which produce the ore-chutes.

From the foregoing it is plain that no general statement can be made in explanation of ore-chutes. In each individual district, more, in each individual mine, still further, in each individual part of a mine, all the phenomena there occurring must be closely studied in the light of a correct theory of ore-deposition in order to reach an explanation applicable to the particular case.

It is well known in the districts which are mineralized that the workable ore-deposits are ordinarily confined to relatively small areas, although, so far as one can see, the amount of metalliferous material to furnish ore-deposits may have been the same throughout the districts. The explanation of the lack of workable ore-deposits for larger parts of the districts ordinarily lies in the lack of the favorable combination of the various special factors mentioned, and doubtless many others which have not been considered. As better illustrating my meaning, I may again mention the iron-ores and copper-ores of the Lake Superior region. The iron-bearing formation has an extensive occurrence throughout the Lake Superior region. The workable iron-ores are, however, confined to small areas, in which there have been happy combinations of ancient and recent metamorphism combined with favorable structural features. The Lake Superior copper-deposits equally well illustrate the principle. All of the mines now being exploited are confined to an exceedingly narrow area on Keweenaw Point. But the copper-bearing rocks occupy an extensive area about the entire Lake Superior basin. Moreover, these copper-bearing rocks are mineralized in many places, as is shown by the widely disseminated copper. But, unfortunately, in many areas a little copper is concentrated in many amygdaloid or sandstone belts rather than in a single amygdaloid or sandstone. For instance, in certain districts scores of amygdaloid beds lie upon one another. The scoriaceous upper surface of each of these beds bears metallic copper, but none of them in sufficient amount so that the copper is a workable deposit. Had the copper deposited in a number of these amygdaloid formations been concentrated in one of them, a workable ore-deposit would have been produced.

From the foregoing it is clear that an investigation of the local factors in a district should include both those which are favorable to concentration of ores and those which prevent the concentration of ores, for a study of the latter in many districts may prevent the expenditure of large sums in exploration where the mineralization is general but the conditions are not such as to have concentrated the valuable material in sufficient quantity at any one position to warrant exploitation.

A treatise on ore-deposits, including descriptions of individual districts, necessarily deals in each area with the special factors which are important in that district. These special factors may be considered so conspicuous that the entire attention is given to them. However, it is to be remembered that each of these is subordinate to the general principles controlling the deposition of ore-deposits in all districts.

THE CLASSIFICATION OF ORE-DEPOSITS.

Before giving the classification of ore-deposits which follows from the foregoing treatment, it may be well to briefly recall the most fundamental features of the water circulation which produces the ore-deposits. First comes the action of the downward-moving, lateral-moving waters of meteoric origin which take into solution metalliferous material. These waters are converged in trunk-channels, and there while ascending the first concentration of ore-deposits may result. After this first concentration, many of the ore-deposits which are worked by man have undergone a second concentration not less important than the first, as result of descending, lateral-moving waters. In other cases a concentration by descending, lateral-moving waters alone is sufficient to explain some ore-deposits. It, therefore, appears more clearly than heretofore that an adequate view of ore-deposits must not be a descending water theory, a lateral-secreting water theory, or an ascending water theory alone. While an individual ore-deposit may be produced by one of these processes, *for many ore-deposits a complete theory must be a descending, lateral-secreting, ascending, descending, lateral-secreting theory.* The descending, lateral-moving, and ascending waters are alike driven by gravity. Each performs its own work.

We have now only to bring together in summary the different groups and classes of ore-deposits which have been considered to have a satisfactory genetic classification of ores deposited by underground waters. As already noted, ore-deposits may be divided into three groups: (A) ores of igneous origin, (B) ores which are the direct result of the processes of sedimentation, and (C) ores which are deposited by underground water.

Since the ores produced by igneous agencies and those produced by processes of sedimentation have not been considered in this paper, a subdivision of these groups will not be attempted.

Ores resulting from the work of groundwater, group (C) above, may be divided into three main classes:

(a) Ores which at the point of precipitation are deposited by ascending waters alone. These ores are usually metallic, or some form of sulphuret; but they may be tellurides, silicates or carbonates.

(b) Ores which at the place of precipitation are deposited by descending waters alone. These ores are ordinarily oxides, carbonates, chlorides, etc.

(c) Ores which receive a first concentration by ascending waters and a second concentration by descending waters. The concentration by ascending waters may wholly precede the concentration by descending waters, but often the two processes are at least partly contemporaneous. The materials of class (c) comprise oxides, carbonates and chlorides above the level of groundwater, and rich and poor sulphurets, tellurides, metallic ores, etc., below the level of groundwater. At or near the level of groundwater these two kinds of products will be more or less intermingled, and there will frequently be a transition belt of considerable breadth.

How extensive are the deposits of class (a) I shall not attempt to state. Indeed, I have not such familiarity with ore-deposits as to entitle me to an opinion upon this point. However, a considerable number of important ore-deposits belong to this class. This class is illustrated by the Lake Superior copper-deposits.

The ore-deposits of class (b) are important. Of the various ores here belonging, probably the iron-ores are of the most consequence. A conspicuous example of deposits of this kind are the iron-ores of the Lake Superior region.

It is believed that the ore-deposits of class (c) are by far the most numerous. I suspect that a close study of ore-deposits in reference to their origin will result in the conclusion that the great majority of ores formed by underground water are not the deposits of ascending waters alone, but have by this process undergone a first concentration, and that descending waters have produced a second concentration, as a result of which there is placed in the upper 50 to 500 or possibly even 1000 meters of an ore-deposit a large portion of the metalliferous material which originally had, as a result of the first concentration, a much wider vertical distribution.

To the foregoing classification objections will at once occur. It will be said that there are no sharp dividing lines between the groups and classes. To this objection there is instant agreement. Transitions are everywhere the law of nature. In another place* I have explained that there are gradations between different classes of rocks, and this statement applies equally well to ore-deposits. I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies, and those which may be explained wholly by the work of underground water, or by processes of sedimentation. Ore-deposits which have received a first concentration by igneous agencies or by processes of sedimentation are sure to be reacted upon by the circulating underground waters, and thus a second, or even a third concentration may take place.

---

* "The Naming of Rocks," by C. R. Van Hise, *Journ. of Geol.*, vol. vii., 1899, pp. 687–688.

The first concentration by igneous or sedimentary processes may be the more important or dominant process, or the additional concentration or concentrations by underground waters may be the more important or dominant processes. In some cases, therefore, the ores may be referred to as produced by igneous agencies, in others as produced by processes of sedimentation, in others as produced by these in conjunction with underground waters, and in still others as produced mainly by underground waters. Moreover, there will be found to be undoubted gradations between the different classes of deposits formed by underground waters. Ore-deposits which are precipitated almost solely by ascending waters will grade into those in which descending waters have produced an important effect, and thus there will be transition between classes (a) and (c). Similarly there will be every gradation between classes (a) and (b), and between classes (b) and (c). If this be so it will not infrequently happen that a single fissure may fall partly in one class and partly in another. Thus, a single ore-deposit may belong partly in class (a) and partly in class (c). However, in most cases a deposit will primarily belong to one of the three classes. Indeed, not only are there gradations between different varieties of the ore-deposits among themselves, but there are gradations between the ore-deposits and the rocks, for the ore-deposits, in many cases, are not sharply separated from the country-rocks, but grade into them in various ways.

In answer to the above objection concerning gradations, it may be said that I know of no classification of ore-deposits which has yet been proposed to which the same objection may not be urged with equal or greater force.

However, this retort does not give any criterion by which the usefulness of the above classification may be tested. The test is, does this classification give us a more satisfactory method of studying ore-deposits than has heretofore been possible? Will an attempt to apply this classification assist mining engineers and geologists in accurately describing ore-deposits? Will the classification, to a greater extent than any previous one, give engineers rules to guide them in their expenditure in exploration and exploitation? By these criteria I am willing that the classification shall be tested.

As an illustration of the practical usefulness of the classification, is the connection between genesis and depth. Where the ores are deposited by ascending waters alone it has been pointed out that this is favorable to their continuity to great depth. Therefore, where a given ore-deposit has been shown to belong to this class, the expenditure of money for deep exploration is warranted. Where a deposit is produced by descending waters alone, the probable extent in depth is much more limited. In such cases, when the bottom of the oxidized product is reached, it would be the height of folly to expend money in deep exploration. Where the ore-deposit belongs to the third class, that produced by ascending and descending waters combined, there will again be a richer upper belt which we cannot hope will be duplicated at depth. However, this class of deposits may grade into first class, and after the transition the deposit may be rich enough to warrant exploitation at depth; but if such work be undertaken it must be done with the understanding that the rich upper products peculiar to the belt of weathering will not be reduplicated at depth. It, therefore, appears to me that the determination to which of the classes of ore-deposits produced by underground waters a given deposit belongs has a direct practical bearing upon its exploration and exploitation.

It is my hope that mining engineers and geologists will study ore-deposits in various regions in reference to the principles discussed in this paper. It appears to me that he who does this will be capable of interpreting better than before the phenomena which he finds in the ore-body or bodies with which he is particularly concerned. Of course, it is fully understood that few ore-deposits will illustrate all of the principles above given. It is appreciated that for a certain ore-deposit some few of the principles given on the foregoing pages may be the dominating ones, and that others are unimportant. But this is precisely what I should expect.

In addition to the points specially emphasized in this paper, accurate descriptions should be made of the relations of the different minerals of ore-deposits; of the occurrence of each mineral with reference to the wall-rocks; and their variations in composition, relations and richness at various depths, reckoning both above and below the level of groundwater. Moreover, such a study should include close observation of the gangue-minerals in their relations to one another and to the valuable minerals; for in many instances they may give important testimony as to the origin of the ore-deposit. In this paper, the gangue-minerals have been altogether ignored. Furthermore, a study should be made of the changes of country-rocks and wall-rocks. When a comprehensive study of various ore-bearing districts has been made, including all of these factors, and the special factors discussed on pp. 393–421, it is believed that a more satisfactory treatise upon ore-deposits may be written than has yet appeared.

Such a study of ore-deposits must be a difficult one, involving as it does, a working knowledge of petrography, of mineralogy, and of modern physical chemistry. Undoubtedly, the story of many ore-deposits will be found to be exceedingly complex, and not to come fully within the scope of the principles discussed in this paper. So far as any ore-deposit fails to do this, it will give us data upon which to state a more nearly complete theory of ore-deposits than that here proposed.

The Secondary Enrichment of Ore-Deposits.*

BY S. F. EMMONS, WASHINGTON, D. C.

(Washington Meeting, February, 1900.)

It was said by many who discussed Professor Posepny's admirable paper on the "Genesis of Ore-Deposits," read at the Chicago meeting of the Institute, in 1893, that its most valuable feature was the clear distinction which it drew between the influence upon ore-deposits of the "vadose" circulation of waters descending directly from the surface, and that of the deep underground circulation of waters generally coming from the depths, and assumed by the author to be ascending through more or less open spaces under the influence of heat. A little later the effect of the oxidizing action of the vadose circulation upon ore-deposits was ably and exhaustively treated by Prof. R. A. F. Penrose, in a paper on "The Superficial Alteration of Ore-Deposits"†—the only one, so far as I know, which has been exclusively devoted to this important subject.

My own first detailed study of ore-deposits was made at Leadville, in 1880, at a time when almost the only minerals visible in those deposits were in oxidized forms. That this form was the result of the alteration of earlier sulphides by surface-waters had to be proved at the time by induction or analogy, the general correctness of which was, however, abundantly confirmed by subsequent developments. Thus I was early impressed with the importance of distinguishing, in the study of an ore-deposit, the alteration-products, resulting from the action of oxidizing waters descending from the present surface, from the earlier-formed sulphides; and, assuming that the latter were primary or original, I called the former secondary. I also went so far as to say‡ with regard to oxidized ores passing into sulphides in depth:

> "So generally is this accepted as a rule in ore-deposits that it would require special demonstration to prove beyond a doubt that the native metals or their

---

[*] Published by permission of the Director of the U. S. Geological Survey.

[†] *Jour. Geol.*, vol. ii., April–May, 1894, pp. 288–317.

[‡] *U. S. Geol. Sur.*, Mon. xii., p. 562.

oxides and chlorides (except perhaps gold, tin, and the platinum group of metals) are, in any particular case, original, and not the result of secondary alteration from sulphides."

Admitting fully the general truth of the statement that the descending surface-waters exert an oxidizing action, and hence that oxidation-products within the reach of surface-waters are the result of alteration by the latter, I have been led to believe, by observations now extending over a considerable number of years, that, under favorable conditions, the oxidation-products may be changed back again into sulphides and redeposited as such, thus producing what may be called a sulphide-enrichment of the original deposits. Penrose, perhaps, admits this when he says that "the action of surface influences is, in rare cases, one of reduction, which, however, often follows a previous oxidation;" but he gives no instances, and apparently has in mind only those cases in which oxides are reduced to sulphides in the presence of organic matter. Posepny, on the other hand, strong in the conviction of the correctness of his theoretical views, does not recognize any exceptions to the general rule. With him, apparently, the fact that a deposit consists of sulphides is sufficient proof that it has been made by the ascending currents of a deep underground circulation, and cannot have been made by vadose or descending waters. Being rather a searcher after facts than a theorist, I am not deterred from accepting what may appear to me the correct reading of observed facts because it seems to contradict generally accepted theories.

In geological observation, however, especially underground, where the field is often very limited, it is not always possible to be certain of the correctness of one's interpretation of a given phenomenon, especially when one is confined to a single district or group of mines. Another observer might construe the evidence otherwise. It is only by multiplying observations in different and widely separated localities, and by finding in all the same sequence of phenomena, to which the same interpretation applies, that one arrives in time at what may be considered, from a geological standpoint, a reasonably certain conclusion.

In the present case, I could have wished to multiply my observations much further, and to obtain more light upon the probable chemical processes involved than I have as yet been able to find in chemical literature, before committing myself to a public statement with regard to them. I have hoped, moreover, to have some experimental chemical work carried on upon lines suggested by my observations in the laboratory of the U. S. Geological Survey; but the limited force and space available for such work have rendered it thus far impracticable.

I find, however, among many mining engineers an increasing conviction that the rich concentrations found in many deposits of both copper- and silver-ores, are the results of secondary enrichment. Moreover, Mr. Walter H. Weed, who was associated with me in the geological study of the Butte region in 1896, and, during the summer of 1899, in underground work there, submitted at the recent meeting of the Geological Society of America, an article on the "Enrichment of Mineral Veins by Later Metallic Sulphides,"* which contains much that I had intended to write on the subject. Hence, I feel it necessary, in self-defense, to publish something in the nature of a *caveat*, to show that my attention has been directed to this subject for some time past, even though the evidence for the conclusions I have reached is not yet as complete as I could wish.

Premises of Belief.

To avoid misunderstanding it may be well to state, at the outset, the premises of my belief. In the first place, I eliminate from this discussion the ore-deposits formed exclusively by magmatic differentiation, and first brought into prominence by the Scandinavian geologist Vogt—not that I deny the importance of this mode of ore-concentration as a possible first cause, but because, in my 20 years' study of ore-deposits, I have not yet had an opportunity, as I have elsewhere stated,† of seeing any which were not due, in the condition in which they now exist, "to further concentration, perhaps many times repeated." Hence, I assume that the majority of ore-deposits, as at present found, owe their existence to the agency of circulating waters; and it is of these only that I speak in this paper.

Circulating Waters of Surface-Origin.—I am inclined to limit my subject further by excluding those water-formed deposits,

---

* *Bull. Geol. Soc. Am.*, vol. xi., 1900, pp. 179–206.

† This volume, p. 201.

which, according to the theory of some French geologists, have been deposits from solution in waters originating or occluded in igneous magmas, or, as the Scandinavian geologists express it, by pneumatolysis, since such waters cannot have formed an essential part of the circulation, properly speaking.

I have found no reason to change essentially my early belief that the waters which have been the principal agents in forming ore-deposits came originally from the surface. As I then expressed it:*

> "There are, therefore, both upward and downward currents; it being generally assumed that the latter are surface-waters sinking under the influence of gravity, and the former, the same waters rising under that of the internal heat of the earth."

Rickard uses a very suggestive, though homely metaphor, to illustrate the manner of this circulation, when he says:†

> "We may compare the circulation of water up and down through the earth's rocky exterior, to that of the ordinary heater in a house. The water circulates, because, when hot, it rises through the length of pipe, and, when cool, it falls back to be reheated."

It is the difference of temperature produced by internal heat that causes the water to rise, though gravity is still the impelling force, since the colder surface-water is descending to take the place of that which rises. Only occluded water could find its motive power, independently of gravity, in the rock-mass in which it originated.

Groundwater-Level.—Posepny, as I have already remarked, has strongly emphasized the distinction between the vadose or descending circulation and the profound or ascending circulation, the separating line between which is called the groundwater-level. Lest my statement that he did not recognize the formation of sulphides by the vadose circulation may be deemed too sweeping, I will quote (not finding a direct declaration on this point from him) Dr. Raymond's exposition of his meaning:‡

> "2. Concerning the condition (the vadose circulation above groundwater-level) which is most open to our observation, we know a great deal. We know, for instance, from an overwhelming number of observations, that the solutions of

---

* *U. S. Geol. Sur.*, Mon. xii., p. 570.

† This volume, p. 220.

‡ This volume, p. 254.

> the vadose circulation are oxidizing, and that (apart from the, probably rare, reformation of sulphides by the action of organic matter) they do not precipitate sulphides, but, on the contrary, attack and decompose them."

It is evident from Posepny's remarks on different deposits (*e.g.*, those of Wiesloch, in Baden*), that this is a correct presentation of his views. While this distinction of Posepny has been very useful, undoubtedly giving to many students a clearer conception of the relative influence of waters descending from the surface, and those arising from the depths, I believe that in this, as in most geological generalizations, the lines should not be drawn too strictly, but must be susceptible to considerable modification under varying conditions. Inasmuch as both ascending and descending currents are part of the same general circulation, there must also be a vast amount of nearly horizontal or lateral movement. Moreover, in our western mountain-regions the groundwater-level is not, so far as my experience goes, the definite horizon predicated by Posepny, which bears a comparatively uniform relation to the existing surface; nor is the oxidizing influence of surface-waters always strictly confined to the region above it.

Very early in my studies of ore-deposits, in writing on a typical instance of the secondary alteration of ore-deposits, I defined the groundwater-level thus:†

> "The permanent water-level at any point beneath the earth's crust, and within the range of human observation, is evidently that level to which water will rise by the filling of a hydrostatic basin (which may consist of any system of channels permitting its ready circulation, such as joints, fissures, bedding-planes or porous rocks) up to the point of its overflow, or where it would drain out either to the surface or into another hydrostatic basin. The water filling such basins is originally supplied from the surface, but after a comparatively long passage through the rocks, during which its oxidizing agencies, such as air, organic acids, etc., may be supposed to have become neutralized, or to have exhausted their power upon the rocks through which they have passed. The water or moisture which furnishes the active agencies of secondary decomposition of ore-bodies must, on the other hand, come to them directly from the surface, and not be neutralized by a long passage through rock-material, or by mingling with a large body of already neutralized water, such as that which exists below the water-level. This seems to me to be the explanation of the fact that surface-waters act as oxidizing agents above water-level, and as a protection against such action below the water level."

Since then, I have observed many instances in which the

---

* This vol., p. 69.

† *Proc. Colo. Sci. Soc.*, vol. ii., Part II., p. 102. 1886.

zone of oxidation, as defined by the water-level, is not a generally even surface, more or less conformable to the surface of the ground. The most striking that I recall now, is in the Tintic district of Utah, where, in the deposits in the limestones, the limit of oxidation had not been reached at 1600 ft. below the surface, while, in veins in the igneous rocks, scarce half a mile away, the groundwater-level and zone of unaltered sulphides were met within 200 to 300 ft. of the surface.

Deposition of Oxides below Water-Level.—Winchell calls attention to a striking instance of oxidizing action extending below the groundwater-level when in his discussion* of Posepny's paper he speaks of the Lake Superior iron-ore deposits:

> "The ore-lenses lie in basins of greenstone schists or other rocks, and occur at various depths to at least 2000 feet. At the lower edges of some of these lenses are found deposits of silica, kaolin, etc., which have plainly been removed from the ore-body above in process of concentration. This is much below the vadose circulation, as the immense pumping-engines and the rivers of water which they throw the year round testify; but it is an instance of the formation of ore-deposits on the largest scale by descending waters."

In my own experience, I have met many instances of oxidizing action below the groundwater-level, but nothing on the scale of these Lake Superior deposits. They were generally very local in their development, and I have been accustomed to look, with more or less success, for their cause in a recently formed water-channel down which the surface-waters were able to descend freely and with relative rapidity.

It is not, however, the oxidizing action of surface-water that is in question here, though that process is highly interesting, and has had great influence upon the relative richness of ore-bodies. Moreover, notwithstanding our pretty clear comprehension of it, many new data might be cited concerning it. But the question under discussion is, to what extent sulphides may be deposited from descending surface-waters, and under what conditions.

Deposition of Sulphides.—Prior to my studies at Butte in 1896, I am free to confess, I had not given much thought to the possible deposition of sulphides from surface-waters. The fact that, in the presence of organic matter, oxides may be reduced to sulphides was of course well known; and the few

---

* This volume, p. 229.

instances of the formation of pyrite in this manner that came under my observation, were noted as curiosities rather than as matters of economic importance. The sulphides that I found within the oxidized zone and distinctly above the groundwater-level (mostly small masses of galena and pyrite, but in some cases very considerable bodies of the latter) were generally explainable as material so dense that oxidizing waters had not yet penetrated into the interior of the mass, and were, to my mind, simply an additional proof that the groundwater-level was not an absolute line of division between oxides and sulphides, but that under favorable physical conditions the latter might exist above it, as the former could extend below it. There were, it is true, occasional occurrences that could not be explained on the ground of imperfect oxidation through physical obstacles; and these were stored in my memory, until sufficient evidence should have accumulated to indicate some general explanation. Of such was the observation made during my Leadville work,* that, in the kernels of partially altered galena surrounded by a crust of cerussite, which were found in the oxidized zone, the galena was abnormally rich in silver, containing more than five times as much as did the cerussite resulting from its alteration, the tenor of silver in which was nearer to the normal or average proportion.

In the same way, according to Blow,† "the small seams found penetrating the limestone at the bottom of the ore-body are often formed of galena-ore, and are always richer than the lead-sand and cerussite-ore above." In these cases it is evident that the action of the surface-waters has been to concentrate the silver in the sulphide-ore, not in the oxidized product.

Again, the oxidized ores observable at the time of my study of the Leadville deposits carried abundant iron, lead and silver, but scarcely a trace of zinc; yet it was assumed, and soon found to be the fact, that the sulphide-ores consisted of mixtures of pyrite, galena and zinc-blende, the latter in fairly equal amount. The far greater solubility of the zinc-salts, over those of lead, would account for the latter's remaining to a great extent in their original position; but the question was, what had become of the zinc? Mining in the sulphide-bodies in later years has shown

---

* *U. S. Geol. Sur.*, Mon. xii., p. 553.

† *Trans.*, xviii., 169.

that, immediately below the zone of oxidation, the bodies of mixed sulphides are far richer in zinc-blende than the average of those enormous bodies mined at greater depths. Blow, as a result of his nine years' work in the ore-bodies of Iron Hill, draws the following conclusion from these facts:*

> "It seems probable that a large proportion of the zinc, which was totally removed from the carbonate ores, has been redeposited as a sulphide, and principally just below the line of complete oxidation, by surface-waters, and such redeposition has advanced and increased *pari passu* with the limit and extent of such oxidizing action."

There are many other instances in which suggestive remarks have been made upon the probable deposition of sulphides by descending surface-waters, as will be shown later. Most pertinent at the present moment is that made by our President, Dr. James Douglas, in 1890,† with regard to the Butte copper-mines. In speaking of the vertical distribution of the various kinds of ore, he says:

> "It seems as if the copper, leached out of the four hundred feet of depleted vein, had been concentrated in the underlying ore, and had thus produced a zone of secondary ore about two hundred feet deep, which contains, as might be expected, about thrice its normal copper contents."

Such suggestions as these are useful, however, rather as confirmatory data, and hardly form a sufficient basis on which to found any definite generalization or theory. For this, one needs to have the results of a systematic study of an important district, based on accurate and detailed maps, on which the underground observations are worked out with the aid of careful microscopic and chemical examinations of the material gathered.

INSTANCES OF SECONDARY ENRICHMENT.

It was during the study, in 1896, of the Butte district, and especially of its copper-bearing veins, that such definite evidence of the secondary enrichment of sulphides on a considerable scale was first obtained by me.

Conditions at Butte.—The following is a brief statement of the conditions which presented themselves as a result of these studies at Butte. There is evidence in this district of several

---

* *Trans.*, xviii., 172.

† *Trans.*, xix., 693.

successive rock-fracturing movements. In regard to the earlier movements which produced the primary sulphide-deposition it is not always possible to differentiate clearly one from the other in point of time. It is, however, possible to distinguish another set of fractures, which I have called secondary* or post-mineral fractures, because they are distinctly later than the original deposition of sulphides, since the fissures contain within them dragged-in and more or less rounded fragments of these sulphides together with quartz and country-rock.

There are two sets of secondary fractures or faults: first, those which run east and west, and are generally parallel to and more or less coincident with the original east and west vein-systems, which I have called "strike faults;" and, second, the transverse fractures or cross-faults which strike between northwest and northeast, and have, as a rule, a shallower dip than the east and west fractures. The second class have caused an evident displacement of the veins, sometimes amounting to several hundred feet. Whether the first have been accompanied by any considerable movement of displacement cannot be determined on account of their parallelism to the veins. No definite proof has yet been found to determine whether the two systems of fractures were formed contemporaneously or not; my general impression has been that the shattering of the country was produced by successive dynamic shocks of increasing intensity, which first formed fractures along the lines of the existing vein-systems, with slight movements of displacement and consequent shattering and grinding of the material traversed, and finally resulted in a cross-fracturing accompanied by a certain amount of lateral displacement of veins. The strike-fractures or faults, which, in the nature of things, are the most open to observation, being constantly exposed by the mine drifts, vary in size from thin clay-selvages

---

* My use of the word "secondary" in this connection has been criticised as liable to misconstruction, because it has hitherto been used to designate the alteration by surface-waters, and applied exclusively to oxidized forms of mineral-deposition. It is further said that one has no right to assume that only one fracturing and ore-deposition has preceded those thus designated "secondary." While admitting the force of these criticisms, I have been unable to find another satisfactory word, because I am not yet sure in my own mind that all the successive processes that have taken place in these deposits are known, and having committed myself to the use of this word in print, think it best to continue it until our knowledge is more complete.

to broad breccia-zones up to 15 or 20 feet thick, but are most commonly seams a few inches thick carrying small rolled fragments of granite, quartz and ore in a soft, wet kaolin-mud. They are found in foot- or hanging-wall, or within the vein itself, often several to a given cross-section, and extend in depth as far as the explorations have yet reached. Except in the case of a few breccia-zones within an original vein-system they do not ordinarily carry pay-ore.

The cross-fractures or faults have been quite extensively developed since our field-work was completed as the result of the many law-suits that have sprung up in the district, and have been carefully studied by the many experts engaged in investigating the geological conditions bearing upon the different questions in dispute. In some cases they are known only as planes of movement cutting off the veins; in others, they have been found to contain so much dragged-in ore from the various veins they cross, as to constitute valuable ore-bodies. In the opinion of some of the experts, they also contain considerable newly-deposited ore in the sulphide form. This, I have not yet had an opportunity of verifying from personal observation.

Paragenetical study of the ore-deposits shows that the earliest-formed minerals are quartz, pyrite, chalcopyrite and enargite. Enargite is in some cases later than chalcopyrite. Veins composed mainly of enargite have been found cutting the siliceous pyritic veins. The richer sulphides, bornite, chalcocite and covellite, which, with enargite, constitute the most valuable ores of the middle levels of most of the mines, are of later origin, their order of deposition being, as far as microscopic observations enabled us to determine, that in which they are named. Little opportunity was had of studying the oxides and carbonates of copper which are characteristic of the zone of oxidation, and would normally be considered of an entirely later formation.

The prominent characteristics of the Butte copper-lodes are, first, an upper oxidized zone extending down from 200 to 400 feet from the surface which contains less than 1 per cent. of copper on the average, the value being principally in silver. It is a mass of crumbly, honeycombed quartz, singularly free from metallic oxides when one considers the great mass of the original sulphides found in the veins in depth. Second, below this is a rather ill-defined zone characterized by great values in the rich copper sulphides, bornite and chalcocite or copper-glance, associated with pyrite and chalcopyrite. The proportion of these rich sulphides gradually decreases with depths until in some mines the ores consist only of pyrite with a slight admixture of chalcopyrite. Enormous amounts of copper-glance were found in many of the mines; generally in the upper levels of the sulphide zone. Sometimes they constituted solid masses fifteen feet or more in thickness, in which, however, close examination showed a sprinkling of chalcopyrite or pyrite in minute, irregular, and often pitted grains throughout the mass of the glance; not infrequently the cleavage faces are coated with very thin films of native-silver.

The fact that struck me most forcibly with regard to the rich bodies of glance, was that one or more secondary fractures are invariably found in their immediate neighborhood, though not necessarily in direct contact with them. In a few instances, at depths of a thousand feet or more, considerable bodies of the richer sulphides were found within a breccia zone. The largest masses of the comparatively rare mineral, covellite, were found on the 1100-foot level of the East Gray Rock mine lying in a mass of breccia, with a kaolinized clay matrix so soft that it would run when opened. In the comparatively solid veins, however, glance is generally found as a streak a few inches to a foot or more in width, grading off into siliceous pyritous ore, with a thin secondary seam near it, sometimes in foot- or hanging-wall, more often in the vein-material itself. This is rather a bald statement of the leading facts which led me to the conclusion that there is a genetic connection between the secondary fractures and the rich copper sulphides; a conclusion that is confirmed, so far as I know, by all geologists who have had opportunities of studying these veins. It is generally agreed that most of these sulphides are enrichments of the earlier vein-deposits by solutions that followed the water-channels afforded by some of the secondary fractures.

The next question that presents itself is, whether this enrichment was produced by vadose, or by deep underground-waters; in other words, from waters that have been descending through the oxidized portions of the lode, or from a new set of ascending currents acting since the secondary fractures were formed.

Although, at the time of the publication of the Butte Folio, there were many facts that pointed to the former conclusion, I hesitated to give a decided opinion on the question; first, because of the unfavorable influence it might have on mining in general, and copper mining in particular, especially in this important district (for some might be led at once to adopt the conclusion that the rich sulphides would not be found in depth beyond the reach of such descending currents); and in the second place, I wished to accumulate more knowledge myself before propounding a theory so distinctly opposed to that generally received.

The deposits of Butte are exceptional, so far as my experience goes, in the depth to which the richer copper sulphides have been found to extend; for, though not forming the large bodies they did at 200 to 400 feet below the water-level, they are still found here and there at 1500 feet or more below this level, though in apparently decreasing amount as compared with the immense thickness of pyritous ore.

It should be noted in this connection, however, that there is evidence that the groundwater-level was once very much lower than it is at the present day. It is proved quite conclusively by Mr. Weed's surface studies of the region that the granite hills to the east of Butte, known as "East Ridge," and which rise abruptly about 2000 feet above Meaderville in the valley of Silver Bow creek, owe their present elevation to a north and south faulting along their steep western face. The evidence of faulting and consequent relative change of level between the area in which the mines occur and the adjoining East Ridge is mainly derived from the physiography of the region beyond the latter to the eastward; but it is confirmed by the discovery, through mine-shafts, that the actual rock-bottom of the Meaderville portion of Silver Bow valley slopes downward nearly to the foot of the steep western slope of the ridge, reaching a depth of 300 to 400 feet below the surface of the present valley opposite Meaderville, and probably a still greater depth further south. This old depression, which seems independent of present drainage-systems, is now filled up by talus from the East ridge. Its rock-surface was once probably higher than the eastern face of the East ridge, and formed a continuous slope with it, although the actual date and the amount of the displacement caused by the faulting cannot be accurately determined. It must have occurred in comparatively recent time, geologically speaking, and have caused a raising of the water-level in the depressed region, or area, of the present mines, of as much as 1000 or 2000 feet. This fact is mentioned to show, that, even if the objection generally presented to the possibility of the descent of oxide-bearing waters below the groundwater-level be admitted to be valid, it would not necessarily prove that the sulphides, at present below that level, could not have been enriched by descending waters, since before the faulting they may have been above it.

Since my first examination of Butte, I have had opportunities of seeing most of the important copper-deposits of the West, and my associate, Mr. Weed, has visited many in the Appalachian region; I have also examined the literature of the subject for facts bearing upon the question under consideration. Although no case has come under my notice in which the development of secondary sulphides has been comparable, either in extent or in amount, with that of Butte, a brief mention of the prominent facts is made as confirmatory evidence.

Western Copper-Deposits.—In the first place, it should be stated that the occurrence of a belt of rich sulphides immediately below the water-level is by no means universal. It is not found, as far as I know, in the massive pyrrhotite-deposits of Canada, in which one passes directly from a relatively thin gossan into unaltered copper-bearing pyritous ore. The most obvious explanation of their absence there would at first appear to be the cold climate and the comparatively recent planing off of the surface by the continental ice-sheet. I should be inclined to consider the dense charcter of the material of the deposits, and the possible absence of recent fractures, which would have admitted an easy access of surface waters, as equal, or possibly more important factors.

In the arid climate of Arizona and New Mexico, on the other hand, and still more in Old Mexico, it is often difficult to find the zone of unaltered sulphides, so deep has the oxidizing action penetrated. A recent note on the mines near Mapimi in the State of Durango states that this zone had not been reached at a depth of 2500 feet.*

---

* H. Van F. Furman, *Proc. Colo. Sci. Soc.*, Jan., 1900.

Wendt, in his review of the copper-deposits of Arizona and New Mexico,* makes some very suggestive remarks as to the chemistry of the deposits, though he does not always seem to appreciate to their full extent their geological bearing. He notes, as a general fact, that the ores in limestone are mainly carbonates and oxides, while, in the comparatively acid eruptive-rocks at corresponding levels, they are more likely to be sulphides. In several cases he suggests the probability of secondary migrations. For instance, with regard to the limestone-deposits of the Bisbee district, he says :†

> "Contrary to the generally accepted theory of the occurrence of oxidized copper-ores, the writer has doubts whether the ores of this district, as far as known, have ever been sulphurets in their present position. The whole deposition tends to prove that the ores are not a secondary decomposition or alteration of what was formerly sulphurets, but have been precipitated as carbonates from an acid-solution which carried them from the depths below."

In speaking of vertical lead-bearing veins in the limestone at a higher horizon than the copper-deposits, he says :‡

> "In depth the lead-carbonates have invariably given out, and what ore is found in depth in these vertical fissures is copper-ore. It is probable that these veins are spurs of the great bed-veins opened in the Queen, Prince and other mines."

Of the veins in porphyry in the same district, he says :§

> "The oxidized copper-ore, as usual in siliceous rocks, changed into copper-glance but little below the outcrop. At an inconsiderable depth it became very much impoverished and pinched. In fact, here as elsewhere, the copper-glance appears to be not a true ore at all, but a product of decomposition and of secondary origin derived from the leaching of the vein above and subsequent concentration at a lower point. To those conversant with the beautiful process of kernel roasting, the presence of a zone of copper-glance presents a similar phenomenon on the grand scale of nature's work. The oxidation of pyritous croppings is but a roasting carried out during ages by the combined action of air and moisture."

In his recent paper on the Copper Queen mine,‖ Dr. James Douglas gives it as his opinion that the deposits in limestone were "originally more or less compact iron pyrites carrying a small percentage of copper;" and that during the progress of alteration "the copper by a process of segregation, akin to crystallization, was concentrated and collected into areas of limited size, thus constituting the comparatively small bodies

---

* *Trans.*, xv., 25.

† *Op. cit.*, 55.

‡ *Op. cit.*, 59.

§ *Op. cit.*, 57.

‖ *Trans.*, xxix., pp. 511, 531, 534.

of oxidized ores which are disseminated irregularly through the very large masses of ledge-matter." More pertinent to the question under discussion, however, is his description of the great mass of compact pyrites extending from the 200 to the 400-foot level on which "a string of stopes, nearly 500 feet in length, has been opened," which is decomposed on the exterior and surrounded by a zone of altered limestone and of aluminous matter, generally barren of copper. "Roughly speaking," he says, "the mass is enveloped in a shell of oxysulphide, and streaks of similar black copper-ore of good grade intersect it; but the core consists of compact bisulphide of iron very lean in copper." Oxidized ores extend to a considerable depth below this mass, for which he offers the same explanation that I do: namely, that the pyrite mass was more dense and impermeable than the rock mass below, and that the oxidizing waters penetrated it but slowly.

I have given priority to the observations of these gentlemen where they confirm my own, because they are the result of much more extended studies than it was possible for me to make in the limited time at my command.

Of the four great copper-producing districts of Arizona, three, namely, Bisbee, Globe and Clifton-Morenci, resemble each other, in that the deposits occur in a region of limestones and intrusive eruptive-rocks and under climatic conditions of extreme aridity. The fourth, the United Verde mine, near Prescott, which has a somewhat greater precipitation, owing to its vicinity to the Plateau region of northeast Arizona, is in a vertical-shear zone of old (probably Algonkian) slates and intruded dioritic rocks, the neighboring limestones being of later age, unconformably superposed, and apparently having no connection with the deposits. The physical conditions there more nearly resemble those of Butte than at either of the other localities, and an underground study would probably have been most instructive. Unfortunately, the policy of the exclusion of visitors pursued by the owner was strictly enforced in my case, and I could only determine that rich sulphides do occur beneath the gossan.

At Bisbee the Copper Queen deposits, which include all that were actively worked at the time of my visit, are in flat-lying limestones which are underlaid by quartzites and have not been developed to any great vertical depth, so that I can only confirm the evidence already presented that there have evidently been considerable migrations in the ore since they were originally deposited, and that their original form was probably low-grade pyritous masses of great size, the ores at present worked, both oxides and sulphides, being concentrations produced by these migrations.

At Globe, the principal copper-deposits lie along a great east and west fault-plane, through the displacement of which limestones have been brought down in juxtaposition to underlying quartzites and intruded sheets of dioritic rock. Some isolated bodies of ore are said to occur in the dioritic rocks, and, according to Wendt, these are mostly sulphides. Those which I saw, and which constitute the main mass of the copper-ore, are in the limestones on the south of the fault. The ores thus far opened have been mainly carbonates and oxides, but in the lower levels, 400 to 500 feet below the surface, the latter are passing into the dull earthy-looking glance, called "black sulphide," which is the characteristic alteration product at the line between oxides and sulphides. The original ore-deposition appears to have occurred mainly along the great fault-fissure, and secondary migrations to have taken place along subordinate fractures either nearly parallel or at right angles to it, which evidently formed channels for the surface-waters. It was noticeable that here, as Dr. Douglas has stated to be the case at Bisbee, cuprite and native copper are more common in the lower part of the oxidized zone, and the carbonates nearer the surface.

In the Clifton-Morenci district, near the borders of New Mexico, the area of mineralization is much larger and the geological conditions are more complicated. A series of quartzites and limestones resting on granite have been extensively cut through by igneous intrusions of both basic- and acid-eruptives, and since broken by a complicated system of faults. The original mineralization apparently took place along shear-zones or faults; the ore is found both in the eruptive-rocks and in a certain horizon of limestone.

The mines were long worked for the rich carbonate ores near the surface which are now in great measure exhausted, so that at present the most common ore is the so-called "black sulphuret," the dull-black glance above mentioned. This, I found, as in Globe, immediately below the ores of cuprite and native-copper. In the larger veins, spots of pyrite can be detected within the glance which constitutes the rich ore. In the porphyry adjoining is a net-work of narrow veins or joints filled with glance. This constitutes the lower grade, or concentrating-ore which is remarkably free from other metals than copper, and appears to have been formed by migration from a main body. Below the ore-bearing zone, the limestones are impregnated with practically barren pyrites, and the porphyry below the ore-bearing zone has its joints also filled with pyrites. In some cases the direct passage of the glance into the low-grade pyrites could be observed.

The Coronado mines, famous in the early days, but now abandoned, exhibited a vertical ore-body within a dike of quartz-porphyry which cuts through the basal granite. Of this ore-body Wendt says:*

> "Whenever the copper-glance in the Coronado mines has been followed down, it disappears at a depth of 150 or 200 feet from the surface, and either the vein becomes barren, or the glance is replaced by yellow sulphurets sparingly disseminated through the gangue."

In New Mexico, the Santa Rita mine is famous as having been worked at a profit early in the past century under Mexican rule. It lies about 15 miles east of Silver City, N. M.; the ore is found in a white quartz-porphyry which was evidently once covered by horizontally bedded limestones that still lie round the rim of the shallow basin where it occurs. The richest ores have been removed from the surface, and, as the underground workings were inaccessible, my hastily-formed opinion of the deposits would not be of much value, except that I came to it fresh from an examination of others in which many analogous conditions occur. As at present seen, the porphyry at the surface is impregnated with a thin coating of azurite on joint-faces and in spots through the mass of the rock. At some depth below the surface cuprite and native-copper are associated together, largely as the filling of narrow joint-seams, and pass still lower down into the dull copper-glance similarly distributed. From the evidence of the dumps, pyrite occurs at still greater depths, but in quite limited quantity.

---

* *Trans.*, xv., 38.

My judgment was, that most of this ore had been formed by leaching down from the low-grade pyritous body in the limestones which once covered the porphyry. Considerable bodies of hematite-ore, evidently the result of oxidation-in-place of bodies of pyrite, are frequent in the limestones of this region; and, in the Hanover mine, it is said that copper-ores have been found in the pyrite immediately under the hematite.

In Bingham Cañon, Utah, where the climatic conditions are intermediate between those of Butte and of Arizona, old mines, which were once worked for the value of their pyritous ores in lead and silver, are now being reopened, because the same pyrite-bodies are found in depth to contain enough copper to pay for working under present economic conditions. The ores occur as a replacement of certain limestone-beds in a great series of quartzites that are cut by intrusive bodies of porphyry and have subsequently been faulted.

In the Highland Boy mine, which I visited last summer, I found a large body of pyrite replacing limestone in the immediate vicinity of a body of quartz-porphyry. Portions of this body, which were compact and unaltered, were too lean to work. Along certain lines of post-mineral fracturing or faulting, however, the mass was found to be altered and constituted an ore that was said to average 8 per cent. in copper. In those places where the enrichment was visible to the eye, a little copper-glance, with the dull earthy appearance that is characteristic of the recently formed secondary mineral, could be distinguished.

Western Silver Deposits.—Instances of probable secondary enrichment of silver-bearing deposits from my earlier examinations, now occur to me as I look back, but as they were not examined critically with a view to this explanation of their formation, I place less weight upon them.

Most famous, in view of the enormous values taken from them, are the rich silver-bodies of the Mollie Gibson and Smuggler mines of Aspen, Colo.; but, in their case, there is sufficient organic matter present to explain the reduction of the oxidized solutions to sulphides.* They occur along a vertical fault formed since the original mineralization of the district,

---

* *U. S. Geol. Sur.*, Mon. xxxi., Aspen Mg. Dist., p. 183.

and consist of great masses of polybasite and pink barite, which, in places, have been further reduced to native-silver. On one wall of the ore-body is the limestone, of which it is a replacement, and on the other, a black bituminous shale.

In the San Juan region of Colorado, there is a very strong belief held by some of the more experienced and thoughtful mining engineers, that the rich silver-minerals in their veins, such as ruby- and brittle-silver, are the result of secondary enrichment by descending waters. The most notable instance presented (which, however, I have not yet had opportunity of verifying by personal observation) is that of the famous Smuggler-Union vein, which has been opened for some four miles on the strike, and in places to a depth of nearly 1,000 feet. The main vein has a width of several feet of comparatively low-grade concentrating-ore, while on the foot-wall is a streak a few inches thick of rich "shipping" ore, which carries the rich silver-minerals. The main vein has been displaced about 50 feet by the Pandora vein, which crosses it at right angles and carries gold-values, though not in paying quantity.* According to my informants, the foot-wall streak is not sensibly affected by the faulting; and they reason that it is a plane of recent movement, on which the silver-minerals have been concentrated by a secondary migration from the main vein.

In several important veins in the San Juan region, I observed secondary or post-mineral fractures parallel, and more or less coincident, with the plane of the vein, but no detailed studies have yet been made that would determine whether there has been an enrichment of the minerals, or not.

In unpublished notes on the once famous, but now abandoned, Yankee Girl mine, in the Red Mountain district of the same region, I find mention of a phenomenon which then appeared unexplainable, but which it now appears might be accounted for on the theory of secondary enrichment. In the upper levels, the ores, down to about 200 feet from the surface, were mainly silver and lead, galena and pyrite being the principal minerals. Below this zone, the ore is mainly composed of stromeyerite, bornite, chalcocite, with some gray-copper and barite, yielding about 30 per cent. of copper, and little or no

---

* *U. S. Geol. Sur.*, 18*th Ann. Rep.*, Pt. iii., p. 834.

lead. In depths below 600 or 700 feet, the ore in this and adjoining mines is said to have gradually turned into a low grade pyritous ore, which was of too low grade to work at a profit, and caused the mines to be closed down. The ores in the copper-bearing zone had been exceptionally rich, carrying several thousand ounces of silver to the ton in carload lots. The waters in this region, both mine-waters and spring-waters, are unusually acid, the latter forming abundant deposits of limonite, while the former rapidly corrode any metallic iron-materials, such as water pipes, that are exposed to their action.

The most definite instances of secondary enrichment of silver sulphides are, however, those described by Weed, in the mines of Neihart, Mont.* There the veins have suffered later fracturing and secondary enrichment of the zone at or below the water-level, with the deposition of silver sulphides "as crusts or crystals lining cavities, or as films or thin coatings along fractures of the primary ore." The primary minerals are galena, blende and pyrite; the secondary sulphides are polybasite, ruby-silver, more rarely a pure transparent blende. Under the microscope galena is seen altering to a spongy polybasite. Polybasite and pyrargyrite are seen as crystalline aggregates and crusts on all other minerals, but in no case coated by other minerals. The immediate products of superficial alteration, the gossan, are largely removed and make up a zone at most only a few feet thick. Beneath this is an irregular accumulation of sooty black ore, consisting of manganese and silver sulphide. Where the vein is well-defined the secondary antimonial sulphides occur below, at first, in considerable abundance, but deeper down, only in crevices or fissures partly or wholly lining filled fractures, so that they become less and less abundant in going down on the vein.

Eastern Examples.—In his description of the lead- and zinc-deposits of the Mississippi,† W. P. Jenney notes interesting instances of deposition by descending-solutions below the zone of oxidation.

Among minerals of secondary deposition he enumerates "blende, galena, chalcopyrite and greenockite, produced by

---

* *U. S. Geol. Sur.*, 21*st Ann. Rep.*, Pt. iii. "The Geology of the Little Belt Mountains," by W. H. Weed, p. 421.

† *Trans.*, xxii., 199.

alteration from the primary ores in the zone of oxidation in the upper part of the ore-bodies, and re-formed as sulphides by the reducing action of organic-matter in the deeper levels."

Iles* and Robertson† have also described secondary deposits of zinc-sulphide which are assumed by them to have been deposited from a sulphate solution through the agency of sulphuretted hydrogen.

In the Southern Appalachian region are many copper-deposits which show excellent instances of secondary enrichment through the agency of mineralizing waters. Most of these have recently been examined by Mr. Weed,‡ and, as detailed descriptions of them will be found in his paper on "Types of Copper-Deposits in the Southern United States," presented at this meeting, only a brief mention of the salient points need be made here.

Best known are the deposits of Ducktown in the extreme southeast corner of Tennessee, which have become classic in the literature of ore-deposits for their black copper-ores which form a narrow band between the gossan and the unaltered pyritous ore beneath. The gossan-ores are immense masses of porous iron-oxide which are so free from impurities as to be used in large quantities in the blast-furnaces of Tennessee and Virginia. The original ore is an irregular mixture of pyrrhotite and chalcopyrite, quite massive and free from vertical fracturing. The comparatively thin zone of black ore has been considered to be a mixture of black oxide and sulphuret of copper; but chemical examination of the specimens brought in by Mr. Weed and those in the National Museum show only copper-glance and no tenorite. The ore is impregnated with copper sulphate, showing that the process of concentration is still going on, and recently-formed amorphous black sulphuret is found in clefts in the upper surface of the pyrrhotite.

When the black ores were first developed many curious speculations were current as to their origin; but Whitney§ early recognized their true source, as is most evident in his reply to Tuomey in 1855, where he ascribes these rich sulphides

---

* *Eng. and Min. Jour.*, vol. xlix., 1890, p. 499.

† *Am. Jour. Sci.*, 3d series, vol. xl., p. 160.

‡ *Bull. Geol. Soc. Amer.*, vol. xi., pp. 179-206.

§ *Metallic Wealth of the United States*, p. 322.

to an enrichment of the original ore through the decomposition of the zone above (now gossan).*

Sterry Hunt† makes allusion to this, and similar deposits, at Ore Knob, N. C., and in Carroll county, Va., as owing "their origin to the reduction, in some imperfectly explained way, of the sulphates formerly generated by oxidation in the upper portion of the lodes," and Olcott‡ confirms his view as to the Ore Knob deposit. In all these cases, however, the enrichment is assumed to have taken place at or above the water-level, and there is no question of its extending to any considerable distance below it.

In the Union Copper Company's mine at Gold Hill, N. C., as reported by Mr. Weed, the ore-body is fractured by vertical planes which penetrate to some depths below the oxide zone. There are here no such great masses of pyritous ore as at Ducktown, the primary ore being vein-quartz carrying a small amount of chalcopyrite. Owing to the vertical fractures the lower limits of the brown oxidized ore are very irregular, extending in places down to 180 feet or more below the surface and half that distance into solid unaltered quartz-ore. The surface-ores were originally worked for gold, but the increase of copper with depth interfered with amalgamation.

The workings now extend to a depth of over 250 feet. In the main part of the vein are rich masses of chalcopyrite in quartz which, when altered, change directly into chalcocite; the latter is often surrounded by a film of cuprite, which, in turn, changes to fibrous malachite along cracks in the quartz. Where the alteration has proceeded further, specimens are found showing copper-glance coated with crystalline cuprite and native silver; others show crystalline glance passing directly into native copper, which forms a thin felty covering up to a quarter of an inch thick. Nearer the oxide zone, a sooty black mass is often found directly replacing the chalcopyrite.

Specimens from the Blue Wing mine in the Virgilina district on the borders of Virginia and North Carolina, taken from below the oxide zone, show bornite surrounded by a shell of dull glance with iron oxide outside. Other specimens from below

---

* *Amer. Jour Sci.*, 2d series, vol. xx., p. 53.

† *Trans.*, ii., 127.

‡ *Trans.*, iii., 392.

the water-level show bornite altered to chalcocite, while the iron is concentrated in the form of nests of specular iron in the quartz. These ores extend to the present limits of the workings 300 feet below the surface. That they will pass, like those of Gold Hill, into chalcopyrite in depth, cannot yet be predicated with certainty.

Foreign Authorities.—Although it was the Austrian geologist, Posepny, already cited, who most strongly emphasized the distinction between the results of the action of surface- and deep-seated waters, European geologists seem to have been, as a rule, slower to recognize this distinction in their practice than American mining geologists, whose views are generally gathered from a wider field of observation.

The brilliant French writer, DeLaunay,* has been cited by Mr. Weed as one who seems to have conceived the idea that the enrichment of sulphides by descending surface-waters has been an important element in the formation of ore-deposits; and indeed the title of his most recent theoretical discussion of the question gives ground for this supposition.

A careful reading of this and his other papers, however, leads rather to the conclusion that the secondary migrations he contemplated were confined to the zone above the groundwater-level, or oxidized zone, in which sulphides have always been known to occur. The novelty of his view would appear to be that they are not necessarily residual masses of sulphides that have not been completely oxidized, but that in many cases they result from an actual transference of material and a re-deposition as sulphides. Thus, in closing his discussion on the origin of copper and ore-deposits,† he says:

> "What is the origin of the modifications which have been noted in a general way in the upper part of a vein; modifications undoubtedly connected with nearness to the surface, and which disappear in depth? Is it possible that these modifications have sometimes been produced contemporaneously with the filling of the vein, or are they always, as is incontestably the case in many instances, the result

---

* "I. On the importance of deposits by magmatic inclusion and segregation in a classification of ore-deposits.

"II. On the part played by the phenomena of superficial alteration and the renewal of movement (migrations) in the formation of ore-deposits."—*Ann. des Mines*, 9th series, xii., 1897, p. 119–228.

† Gîtes Minéraux et Métallifères, Paris, 1893, vol. ii., p. 232.

> of much later action; especially of the introduction of surface-waters down to a certain level called hydrostatic?"

In his later paper, after describing the succession of minerals found in the silver-deposits of Mexico and South America as an upper zone of chlorides and native metals, and below this a bonanza-zone, where the silver and copper "coming in part from the surface" are concentrated by a sort of cementation as rich sulphides, etc. (both, however, being above the water-level), he speaks of the chemical processes that have probably gone on, as follows:

> "The atmospheric-waters reached the deposit by descending and filtering down slowly along the plane of the vein to ascend again to the surface only after a circuit that is more or less long and complex. It results that the elements dissolved are not absolutely lost to the vein, but, on the contrary, a great part of them are only slightly displaced from above downward, and are re-precipitated in depth in contact with unaltered sulphides in the form of insoluble sulphides. This secondary phenomenon, which is particularly marked for copper and silver, often brings about a special concentration of these two metals at a certain distance below the surface, so that below the oxides and carbonates that characterize the actual outcrop is found a very rich zone, or, as the miners of the New World express it, a bonanza, in which copper forms gray-copper, glance, bornite, etc.; while silver separates as argentite, brittle-silver and ruby silver."

European Deposits.—The great pyrite-deposits of Rio Tinto, Tharsis, etc., in the Huelva provinces of southern Spain, are enormous bodies, analogous in geological conditions to those of Ducktown, but of even greater volume. The gossan, which extends down to a depth of 130 to 150 feet, consists mainly of iron oxide, with 50 to 55 per cent. iron, a little sulphur and arsenic, and only a trace of copper. Between this and the solid pyrite below is a very regularly distributed zone of earthy, porous material, from a few inches to a foot in thickness, carrying an average value of about $35.00 per ton in gold and silver. These values it is assumed by Vogt,* who has last written upon the region, have been brought down in solution by ferric sulphate which, in contact with the underlying pyrite, has been reduced to ferrous sulphate, with precipitation of the gold and silver. It is in the pyrite-mass below the "iron hat" that the copper-values are found; and these gradually decrease with depth from 4 to 5 per cent. in the upper 100 to 200 feet

---

[*] *Zeitschr. Prak. Geol.*, July, 1899, pp. 249, 250.

to 1¼ per cent. at the depth of 900 feet—varying somewhat with local conditions. The geologists who have studied the region account for this decrease by assuming that, during the oxidation of the gossan, the original copper-contents were leached down and re-precipitated in recent fractures and clefts in the pyrite mass, thus enriching its upper part. Says Vogt:

> "In point of fact we find such minerals—copper-glance, bornite and chalcopyrite, sometimes with galena, zinc-blende and gray-copper, and, as a rule, accompanied by quartz—very often in clefts and cracks in pyrite, and these minerals are, without doubt, of younger (secondary) formation. At times these clefts are so large that they can be separately mined; thus, the old Roman mining was done chiefly on these richer clefts within the poorer mass of pyrite. Most commonly, however, they are quite small and constitute a strongly branching network in the normal pyrite-mass; and that the copper-content of these secondary minerals is derived from the weathered, superficial mass is shown quite simply in the fact that these veins are most common in the zone immediately under the 'iron hat.' They extend downward something like a hundred meters or more, and then commences the solid pyrite-mass, little fissured and comparatively barren of copper."

He also mentions a decrease of copper-contents with depth in the great vertical pyrite-deposits of Vigsnäs, in Norway, and Fahlun, in Sweden, of which the former has been worked to a depth of 735 meters and the latter to 350 meters.

At Monte Catini, in Italy, the rich copper-ore occurs in masses sometimes of several cubic metres in size with an arrangement of concentric zones which grow successively richer in copper towards the periphery. These masses are sometimes isolated; sometimes connected with metalliferous veins. Balls of glance occur sometimes the size of a man's head. The larger masses consist of chalcopyrite at the center, surrounded first, by bornite, and then on the outside by chalcocite, which sometimes passes into native-copper. These rich masses occur in a zone of recent movement which is easily penetrable by surface-waters. In depth the rich sulphides cease and the ore consists of chalcopyrite and pyrite, the latter becoming more and more predominant with depth.

There are many other European examples which would doubtless show evidence of secondary enrichment, if examined with that question in view. In the great zinc-, lead- and silver-deposits of Laurium, in Greece, for instance, it seems that this process might explain some of the phenomena about which there has been so much difference of opinion among those that have examined them.

Deposits in Arid Regions.—De Launay, who has studied the literature of Mexican and South American mines very extensively, makes the following general statement as to the average conditions of the silver-ores in those countries from the surface downwards:

> "Near the surface the silver in the veins is in the native state, with chlorides, bromides, iodides, etc., associated with oxides of iron, manganese and often of copper; if the gangue is siliceous, it shows a honeycomb aspect, resulting from the removal of the sulphides which it formerly held; frequently red and gray clays are associated with it. These ores are the *pacos*, *cascajos*, *colorados*, etc., of the Spanish-American miners, which are designated by the general term *metales calidos* (free milling ores), but whose tenor in silver is often small compared to the rest of the deposit.
>
> "Lower down, at about 80 to 150 meters, appears the bonanza-zone of the Mexicans, where by a sort of phenomenon of cementation is concentrated the silver, coming in part from the surface (often with the copper, if this is abundant in the deposit). The silver is here in the state of sulphide (Ag_2S); the copper as chalcocite, gray-copper (itself often argentiferous) and bornite; iron is wanting or is in the form of oxide; lead, not abundant, is mostly in the state of carbonate.
>
> "Finally, when one passes below the hydrostatic level, which is rarely lower than 400 or 500 meters, one finds the complex vein-filling of sulphides, antimonides and arsenides, which in their primitive form extend indefinitely in depth; that is, one has, in proportions varying with different deposits, galena, more or less argentiferous, iron and copper pyrites, arsenopyrite, blende, etc., with less abundant silver-minerals."

My personal observations in these countries have been very limited, being confined to a few weeks' visit in Peru and the State of Chihuahua, Mexico, respectively. In Peru, I saw a dull-black copper-glance, brought from the famous Cerro de Pasco mining-district, where silver-mining has been extensively carried on for centuries. This ore is said to be found wherever the workings have been carried down below the water-level, and is estimated to constitute a zone of great extent and value beneath all the old workings. It is evidently a concentration by leaching of the small amount of copper that was disseminated through the now oxidized ores above.

In Chihuahua, I had no opportunity to examine the silver-deposits below the water-level; but in the middle levels of the mines, at 200 to 300 feet below the surface, oxidized and unaltered sulphide ore-bodies were not infrequently found side by side, so to speak, on the same level. The former, generally in a foot-wall streak, constitute the *colorado* ores of the Mexican miners, and carry rich silver-minerals in a red clayey material that contains rolled fragments of quartz and ore, and is evidently on a plane of movement subsequent to the mineralization. The latter, which consist of pyrite, galena and blende in a dense hard matrix, occur in greater bulk than the richer ores, and apparently owe their escape from oxidation to their impenetrability to surface-waters. The sulphide is so much lower in grade than the *colorado* ore, that it was generally left by the early miners, and now constitutes a concentrating-ore. Evidently the foot-wall streak, which often opens out into great "bonanzas," was enriched by the leaching of such parts of the other ore as had been thoroughly decomposed.

In Australia, the arid climate of which presents similar conditions to those found in Arizona, Mexico and South America, we would expect, as in the latter regions, to find abundant evidence of secondary alteration of ore-deposits. In point of fact, the descriptions of many of the important mines of that region make mention of phenomena which seem to be most readily explainable on this theory, although, until they have been examined with this end in view, one cannot be sure how far all the evidence will support it. In the famous Broken Hill lode, as described by Jaquet in the memoirs of the Geological Survey of New South Wales, certain occurrences are definitely described by him as secondary sulphides.* The primary sulphide-ore is an intimate mixture of argentiferous galena and zinc-blende, with quartz, garnet and feldspar, and pyrite, chalcopyrite, arsenopyrite, wulfenite and fluorite as accessory constituents. These ores contain on an average 5 to 36 oz. of silver per ton, 7 to 50 per cent. of lead, and 14 to 30 per cent. of zinc. Mr. Jaquet says:

> "Sulphide-ore, secondary, occurs as a thin layer, varying in thickness from 3 inches to 6 feet, which coats the ordinary sulphides at all points where dry ore, rich in silver, comes in contact with them. Resembling soot somewhat in appearance, it has been named 'sooty sulphide-ore' by the miners. It is, without doubt, ordinary sulphide ore altered and enriched by contact with dry ores."

These enriched ores carry up to 250 oz. silver per ton and 12

---

* *Mem. Geol. Sur.*, *New South Wales*, Geology, No. 5, Sydney, 1894, p. 88. See also *Zeitschr. Prak. Geol.*, vol. v., p. 95. 1897.

per cent. of copper. The dry silver-ores are the antimonial and arsenical sulphides of silver, polybasite, stromeyerite, dyscrasite, proustite, pyrargyrite, stephanite, etc., which occur in the lower part of the kaolin-ore that forms the bulk of the oxidized zone in the locality described, and carries oxidized minerals of iron, manganese, lead and copper. This, also, is of much lower grade than the enriched sulphide. It is very evident, therefore, that in the process of alteration by surface-agencies the oxidation products—especially the silver- and copper-combinations—have been leached down and redeposited as sulphides, and are most abundant in contact with the original sulphides of the deposit.

It does not appear from the descriptions that the enrichment has extended to any considerable distance below the contact-zone of altered with relatively unaltered material. This may be due to the absence of later fractures which would admit the descending solution; or it may be that enrichments do exist which have not yet been detected through want of systematic search.

In the neighboring Broken Hill Consols mine, as described by Mr. George Smith,* there is evidence of still more extensive secondary enrichment of sulphides, the silver-minerals being mainly in the rather rare and unusually rich forms of stromeyerite, dyscrasite, fahlerz and antimonial silver chloride. Although occurring in the same country rocks as the main Broken Hill deposit, instead of being, as in that case, in the form known as "saddle reefs," which conform with the schistosity and are of great size, they are found only in comparatively narrow veins which distinctly cross the schistosity. The vein is mineralized only at the intersection of what is known as cross-veins, and, of the rich silver-minerals mentioned above, some "have not been met with in the lower workings, though each has been found at some distance below the water-level;" while those that are found at greater depth occur there in smaller quantities and "have been found to assume a distinct track and are evidently the continuation of the larger deposits worked in the upper levels." The so-called cross-veins are described as "a succession of rock-joints formed along a line of weakness and enlarged in places by a process of removal and

---

* *Trans.*, xxvi., 69, 71, 73.

replacement." The more important one, which is figured (p. 73), falls vertically on the lode which has a shallow dip near the surface, and immediately below it in the main vein is an accumulation of stromeyerite, dyscrasite and more or less oxidized material impregnated with silver chloride. The cross-veins carry in some cases blende and galena; in others only pyrite.

While Mr. Smith has recourse to secondary concentration for the enrichment of the oxidized zone, it does not seem to have occurred to him that the concentrations of rich mineral below this zone might also have been produced by solutions along the main fissure from the cross-veins. He brings forward a theory of electro-magnetic currents to account for the precipitation of the minerals at these intersections.

It is always unsafe to theorize on the observations of others; but in the present case, it seems legitimate to offer the suggestion that, even admitting the possibility of electric action as a stimulant to the chemical reactions, it is necessary to predicate previous conditions which will render the reactions possible. In the case of these cross-veins, as in those of the indicators of Ballarat, and the similar fahlbands of Norway, which are all zones of relatively barren pyritiferous materials crossing the ore-bearing veins, it seems, in a general way, that reactions between salts of the metals and their sulphides have been the underlying cause of the concentration of the more valuable metals at or near the intersection. There will have been a great number of differing conditions in such districts, or groups of deposits, and it does not seem absolutely necessary that we should have recourse to descending solutions for the salts of the metals in every case; they may have been contained in ascending solutions. An instance where it seems probable that there has been enrichment from ascending salt-solutions is the Geyser mine at Silver Cliff, Colorado,* where, in a narrow vein at 2000 feet in depth, is an unusually rich and very recent-looking body of sulphides of silver, lead, zinc and copper. The ascending waters which issue from the parallel and adjoining fissures are highly charged with carbonic acid, and carry, apparently in the form of carbonates, small amounts of the metals found in the veins. What-

---

* *U. S. Geol. Sur.*, 17*th Ann. Rep.*, Part ii., p. 456.

ever may have been the original form in which the metallic minerals were brought to this deposit, it seems evident that at the present day they must be coming in as carbonates and be deposited as sulphides in contact with the already existing sulphides, thus enriching the latter.

SUMMARY.

From the foregoing geological evidence, which could be doubtless very much enlarged, it appears to be fairly well established:

1. That descending waters not only cause migrations, or transference and reconcentration, of the alteration products of the original vein-materials in oxidized form, producing in one place an enrichment, and in another possibly an impoverishment of the original deposit, but that in their further downward course the oxidized forms are frequently reduced and re-deposited as sulphides, thereby producing a sulphide enrichment of the original vein-materials.

2. That this secondary enrichment of sulphides is not necessarily a reduction in the presence of organic matter, but is frequent where no organic matter can be supposed to be present; it occurs mainly in contact with the original sulphides of the deposits, and is, presumably, a result of chemical reaction between these sulphides and the materials brought down in solution by the descending waters.

3. That while this re-deposition of sulphides in many cases appears to commence at or near the groundwater-level, it does not appear to have a necessary connection with that level, and may under favorable conditions extend below that level for a distance as yet undetermined, the most important favoring conditions appearing to be recent or post-mineral fractures, which have admitted a relatively free and uninterrupted descent of these waters.

In endeavoring to trace back the processes by which the results have been brought about, it is important to bear in mind the physical changes that may be assumed to have taken place during the time that has elapsed since a given ore-deposit was originally formed and before it reached the condition in which it is found at the present day. These changes necessarily vary with each mining region or district, being in some cases very considerable, in others relatively slight. They may be classed under two general categories:

First, the rock shatterings resulting from dynamic force connected with earth-movements or eruptive action. These have opened channels for the entrance of surface-waters within the rock-mass and thereby extended the areas to which the chemical actions produced by the latter may have extended.

Second, the erosion or denudation to which the region has been subjected, and which has gradually worn down the original surface to its present configuration. As a result of this wearing down the lower parts of an ore-deposit have been continually approaching the surface, and in no case, probably, is what was originally the superficial portion of an ore-deposit still in existence. The amount of the wearing away is not always determinable, but it may have been very large; thus, at Leadville, I estimated that in round numbers a thickness of about 10,000 feet of rocks had been worn away in order to bring the ore-bodies at present exposed to the surface.

In the Butte district, where there are no stratified rocks, there exists no criterion by which to estimate accurately the amount of denudation, but the readily disintegrable character of the granite country-rock and the faulting to which I have already alluded show that it must have been very considerable. There the ore-deposits occurring along nearly vertical fissures, and the later shattering having produced extraordinarily abundant secondary fissures nearly coincident with the earlier ones, the conditions were unusually favorable for an abundant leaching down of the material taken up in solution by the surface-waters. As the surface gradually lowered we may conceive that the insoluble materials were carried off mechanically; of the soluble minerals, however, but a relatively small proportion would have been removed by the actual surface run-off. The greater portion would have been carried back to lower levels before they came near enough to the actual surface to be taken up in the run-off.

It will aid our conception to divide the veins theoretically into three horizontal zones. The upper- or surface-zone, that which immediately adjoins the present surface, is necessarily the zone of highest and most recent oxidation. Any sulphides found in it will simply be residual masses which, for some reason, the oxidation has not completely penetrated. The changes which have taken place in this zone will have been mainly of removal, rarely of addition, and any enrichment that will have come about in this zone will have been, as a rule, differential, resulting from the greater proportion of valueless or base metals removed.

The second or intermediate-zone may be called the zone of oxide-enrichment. In this, the less soluble or more readily precipitable metals which have been brought down from the zone above, are found as carbonates or oxides, or in some cases as native-metals.

The third zone may be called the zone of sulphide-enrichment, in which the materials brought down in solution, and not deposited in the zone next above, are deposited as sulphides (also as sulph-arsenides and sulph-antimonides) or in some cases as native-metals in contact with the original sulphides of the deposit.

The presence of organic matter would hasten the reduction to sulphide, and might cause the deposition of the latter, under favorable conditions, even at the surface, but it should be considered as an accidental, rather than an essential occurrence.

These zones are, as has been said, a theoretical conception; in practice they are rarely well-defined, and in many cases one or more may be wanting. One will run into the other, and, as denudation progresses, a lower zone is slowly changing to the one next above it; thus, as time goes on, it will be a constantly richer zone that rises to the surface to be oxidized, and has part of its oxidation products carried back and re-deposited either as oxides or sulphides. Hence, other things being equal, the longer a deposit has been subjected to denudation the greater will be the enrichment below the surface-zone. The rate of denudation may also have influence upon the amount of enrichment, for it can be conceived that the surface-rocks may be so readily disintegrable and the rate of erosion under favoring climatic conditions may be so rapid, that the surface-removal of the oxidized material, both mechanical and chemical, may proceed so much faster than the downward seepage along the plane of the ore-deposit, that little or no enrichment of the interior portion of the deposit may have taken place.

Such a rapid denudation may be conceived to have taken place on exposed points during the ice-invasion of the glacial period, at which time, moreover, under the low surface-temperatures chemical decomposition would have been relatively sluggish. In arid regions, on the other hand, where the great heat would render chemical decomposition more energetic, and where there has been not only no ice-action, but also comparatively little erosion by water to wear down the surface, we should expect the zone of oxide-enrichment to extend down to great depths, but if the aridity were so great that there was very little water percolating through the rocks in depth, there might be but little sulphide-enrichment.

Chemical Processes Involved.—I do not feel prepared to discuss in detail the chemical processes that are involved in the changes which are shown to have taken place by the above quoted observations. They necessarily vary from one deposit to another under the varying mineralogical and physical conditions that prevail in each place. Moreover, the chemical reactions that are suggested by previous investigations should be tested experimentally before any one can state with any degree of confidence what the succession of chemical processes in a given case has been; for these investigations have generally been conducted with another object in view, or with a different conception of the actual conditions in nature.

Mr. Weed, in his paper already cited, has given quite full quotations from all the authorities that bear upon this subject, and I shall, therefore, not repeat them, but only give a brief general statement of the main processes that may be supposed to have contributed to the mineralogical conditions that are found in the ore-deposits cited above, laying more stress on the natural occurrences that illustrate the actual changes.

The most common sulphide-minerals in original ore-deposits are the iron sulphides, pyrite, marcasite, pyrrhotite, chalcopyrite and arsenopyrite; and next to these, galena, zinc-blende and various copper sulphides. While there is a great variety of other metallic compounds in ore-deposits, yet in most deposits the greater bulk is so far formed by one or more of the above minerals that the chemical changes will be largely governed by the reactions to which these appear to be subject. Of these sulphides marcasite is the most readily decomposed, while pyrite, if occurring by itself in pure crystals, often proves very resistant to alteration. Where there are mixed sulphides, however, the oxidation is observed to proceed more rapidly and all are readily attacked.

The actual changes observed by me in a great body of pyrite carrying galena in a limestone country-rock, which had undergone partial decomposition from the periphery inwards, are as follows:* The original fresh pyrite or marcasite crystals are first disintegrated and slightly pitted on the surface, then changed to melanterite or hydrated ferrous sulphate and the galena becomes anglesite. In the outer or more fully oxidized zone the iron-vitriol has changed in part to yellow basic sulphate; in part to limonite with a separation of native sulphur.

The theoretical changes that are assumed to take place by the action of waters carrying oxygen or oxidizing agents are: first, an alteration of the iron sulphide to ferrous sulphate with the formation of sulphuretted hydrogen and sulphur which may have oxidized to sulphuric or sulphurous acid. By further oxidation the ferrous sulphate will become, in part at least, ferric sulphate, and this in its turn will react upon the remaining ferrous sulphate, or upon the sulphides, and form more ferrous sulphate or sulphates of the other metals which are present. By this cycle of reactions a supply of both ferric and ferrous sulphates would seem to be provided in the oxidized zone, but the extending downwards of the ferric salts would decrease as the supply of oxygen in the waters became less abundant.

It may be assumed that the sulphates of the metals thus formed would be transported for greater or less distances, generally in proportion to their solubility, the iron sulphates being the most soluble; next, those of copper and zinc; silver sulphate is less soluble and also more readily decomposed, while lead sulphate is extremely insoluble.

This accords with the facts generally observed in nature. Thus, from the gossan, which is generally a porous siliceous mass stained by the limonite or hematite resulting from the decomposition of part of the iron sulphate, the copper- and zinc-salts may have been more or less completely removed or transformed to less soluble carbonates and silicates. Where galena has been present in considerable amount the sulphate (anglesite) is generally found quite near the surface or forming a coat-

---

* *Proc. Colo. Sci. Soc.*, vol. ii., p. 104.

ing around residual masses of galena which some think it has protected from oxidation. Where carbonate of lime is present, as in limestone deposits, it is transformed to the carbonate (cerussite) which is more soluble, especially in the presence of an excess of carbonic acid, and may be transported from its original location and concentrated in bonanzas of more or less crystalline mineral. The silver sulphate formed near the surface is generally transformed to the chloride, but is not infrequently reduced to the native state. Gold probably does not form a sulphate, but when combined, as in the form of the telluride, is directly reduced to the metallic state. It is, however, to a certain extent soluble in ferric sulphide, and would in part be transported by this solution until it is precipitated by the reduction of the ferric to the ferrous condition which may occur in contact with the sulphide or with ferrous salts.

Under certain conditions ferric sulphate will decompose the metallic sulphides with the formation of ferrous salts and sulphates of the metals; possibly also with a solution of part as sulphides. Actual test has shown that it acts with great readiness on the iron sulphides, but much more slowly on silver sulphides. The action of copper sulphide has not been tested, but is probably intermediate between the two.

It would naturally be expected that the oxygen included in surface-waters would gradually be eliminated with depth, and Lepsius* has shown by actual experimental tests of waters taken from bore-holes that there is a gradual and fairly uniform decrease of contained-oxygen in the waters with depth. The oxygen would be more rapidly exhausted in a region of active chemical action, such as an ore-deposit in process of alteration; hence it may be assumed that in each case there will be a certain depth at which, owing to the absence of free oxygen, the general tendency in the reactions which take place will be reducing rather than oxidizing, and when no organic matter is present we must look to the original sulphide minerals to furnish the necessary agents for reducing the sulphates to sulphides again, or to the native state.

The most pertinent investigations bearing upon the reactions that would take place are those undertaken by E. F. Anthon†

---

* *Ber. d. Deutsch. Chem. Gesellschft.*, vol. xviii., p. 2487. 1885.

† *Jour. f. Prak. Chem.*, vol. x., No. 6, p. 353.

in 1837, primarily for facilitating analytical work in the laboratory, which were continued later on the same lines by E. Schürmann,* for which reason they are generally known as the "Schürmann" reactions. By these it was established that in the presence of the sulphides of certain of the metals the salts of other metals would be decomposed and the metal precipitated as sulphide, indicating thus that the latter metal possesses a greater affinity for sulphur than the former, and thus the following series of the more common metals was established in the order of their affinity for sulphur: Mercury, silver, copper, bismuth, cadmium, antimony, tin, lead, zinc, nickel, cobalt, iron, arsenic, thallium, and manganese. In other words, a salt of any metal in the series would be decomposed by the sulphide of any succeeding metal, and the first metal precipitated as sulphide. Thus, from silver- or copper-salts the metal would be precipitated as sulphide by lead, zinc, or iron sulphides.

Sulphuretted hydrogen is an important agent for the precipitation of metallic sulphides, and this is not infrequently found in mine-waters. It is assumed to be given off in the deposition of the various forms of pyrite, and qualitative tests in the laboratory of the Survey have shown that it is evolved in the treatment of pyritous ores by very dilute sulphuric acid, though less freely with pure pyrite than with mixed sulphides.

Ferrous sulphate will also precipitate many of the metals from their solutions in the native state; possibly in some cases as sulphides with the formation of ferric sulphate, and it is probable that other ferrous combinations will act in a similar manner. Thus, in the mines of Kongsberg, Norway, which are remarkable for the abundance of native-silver below the water-level, Vogt† assumes, for the occurrences of the metal, as it is sometimes found in fine cracks in the country-rock and even in garnets, that it has been precipitated from its solution through the reducing action of ferrous silicates.

The reaction of ferrous sulphate on a solution of silver-salt is easily tested in the laboratory. The silver is readily precipitated in the metallic state and the solution colored brown by the ferric sulphate formed. With an excess of ferrous sulphate present, as near the out-crop of ore-deposits, this might account

---

* Liebig's *Ann. d. Chem.*, vol. 249, 1888, pp. 326–350.

† *Jour. f. Prak. Geol.*, April, 1899, p. 118.

for the separation of native-silver from silver-salts, while on the other hand with an excess of ferric oxide the silver might be carried further down in solution.

In the copper-deposits, to which my studies have been more especially directed, one often finds a black sooty alteration product in pyritous ores just at the water-level which it has been the custom to call an "oxysulphuret," but which, so far as tested, has always proved to be amorphous copper-glance. It is evidently a very recent formation and it might be reasoned that it has not yet had time to become crystalline. On the other hand, chalcopyrite is by some considered to be a compound of cuprous sulphide (Cu_2S) and ferric sulphide (Fe_2S_3) as bornite is, in a similar way, considered to consist of cuprous (Cu_2S) and cupric (CuS) sulphides with ferrous sulphide (FeS). In the attack by a solution of ferric sulphide the iron molecule would first be removed, and in the case of chalcopyrite the Cu_2S might be left in the amorphous powder above noted. If, however, the attack was continued until copper sulphate was formed, this being precipitated either by sulphuretted hydrogen or in contact with unaltered sulphide, by analogy with results obtained in the laboratory the precipitated sulphide would be a black amorphous powder. Such a precipitate was obtained by A. P. Brown* by the action of powdered pyrite on a neutral solution of copper sulphate under pressure during his investigations, by which he proved, as he assumed, that marcasite is largely composed of the ferrous sulphide, and pyrite contains more ferric sulphide.

Bischof† states that the amorphous precipitates from solution by sulphuretted hydrogen gradually assume a metallic luster and tend to become crystalline when extremely dilute solutions are used and the reagent is passed sufficiently slowly over the precipitates. In other words, under conditions more nearly approaching those that may be assumed to exist in nature.

In recent years Dr. C. Doelter has made a series of synthetical experiments in which, by treating metallic salts by sulphuretted hydrogen solutions, he has succeeded in producing in crystalline form most of the common sulphide minerals: namely, pyrite, chalcopyrite, bornite, chalcocite, covellite, galena, bournon-

---

* *Proc. Amer. Philos. Soc.*, vol. xxxiii., No. 145, p. 240. 1894.

† *Lehrbuch d. Chem. u. Phys. Geol.*, Second edition, Bonn, 1866, vol. iii., p. 721.

ite, miargyrite, jamesonite* and pyrrhotite.† The experiments were conducted at moderately elevated temperatures; generally about 100° C. Such temperatures are used in the laboratory to hasten the chemical action, but it is probable that the same effects would be produced at the ordinary temperatures, such as would be found in ore-deposits, if sufficient time could be allowed. In nature it is probable that changes in temperature may have been an important factor in producing solution or precipitation of minerals, for it has been found that a mineral-salt which was taken up in solution at a given temperature is sometimes redeposited under a change in temperature.

More significant, however, than laboratory experiments, are the synthetical processes of nature, which, as shown by Daubrée and other European geologists, have been detected in the many thermal springs, where Roman metals and coins of copper and other metals have lain for centuries subjected to the action of waters containing feeble solutions of mineral sulphates. Among the minerals thus formed crystals of tetrahedrite, chalcocite, bornite, chalcopyrite and others have been recognized. At the Springs of Bourbon l'Archambault,‡ the succession of mineral coatings around the metallic copper of the coin is the exact reverse of the series which has been noted above in copper-mines as the normal change in waters by secondary changes; namely, next the metallic-copper, first, black copper-glance; then bornite; then chalcopyrite.

That the reactions necessary to produce these changes have taken place in nature in a certain regular series is, in itself, fair ground for assuming that under possible variations of conditions, the same changes might take place in reversed order; for it is recognized by modern chemists that the reactions between two substances which produce two other substances are part of a tendency to establish a condition of equilibrium, as it is called, between the substances involved, and that this tendency can be modified by different conditions of concentration, temperature, pressure, etc., so that it is conceivable that the reaction will proceed in one direction under one set of conditions, and in the reverse direction under another.

---

* *Zeitsch. f. Krystallogr. u. Mineral.*, vol. xi., p. 40.

† *Miner. u. Petrog. Mitth. v. Tschermak*, vol. vii., p. 535.

‡ *Comptes Rendus*, vol. lxxx., January–June, 1875, p. 1297.

I am indebted to Mr. H. N. Stokes of the U. S. Geological Survey for the following concise statement of the present views of chemists on this subject:

"It is now generally recognized by physical chemists that no reaction is complete in the sense expressed by chemical equations. Every reaction tends to a condition of equilibrium lying between the two extremes; sometimes at an appreciable distance from both; sometimes so close to one that for practical purposes the reaction may be regarded as complete. This condition of equilibrium may be varied as follows:

"(1) By an increase of the relative concentration of one of the terms of the equation which tends to shift equilibrium to the other side. This may be effected either by relative concentration of one term on the same side, or by removing the reaction products as fast as formed.

"(2) By an increase of temperature which, besides increasing the reaction-velocity, shifts the equilibrium more or less, and always toward that side of the equation which contains the most energy. The reaction velocity is the speed at which the system approaches equilibrium. In some cases this is immeasurably great, in others so small as to require ages. It is always more rapid at first, slowing down as the reaction approaches equilibrium.

"(3) By increase of pressure which shifts the equilibrium towards that side of the equation which naturally occupies less volume.

"(4) By substances foreign to the reaction which may retard or accelerate the reaction velocity, without, however, influencing the final state of equilibrium (catalytic action)."

A practical instance of the reversal of the direction of chemical reaction is furnished in Vogt's* description, already cited, of the famous silver-mines of Kongsberg, Norway. In these mines silver is in actual bulk the predominating metal. As mined, it is found mainly in the native state and very largely as wire-silver. This wire-silver, Vogt proves quite conclusively, is the result of alteration from silver-glance (argentite). He gives drawings of specimens in which the native silver is found growing out of a base of silver-glance, and in some instances still retaining small particles of glance on the ends of the wires. On the other hand, some instances are found where the

---

* *Op. cit.*, p. 119.

wire-silver has been later changed back to silver-glance, the latter retaining the form of the wire-silver. Thus, three processes are shown in the same mine; the original deposition as glance; the change from glance to native-silver, and the reversal of this process in the change from native silver back to silver-glance.

Conclusions.—Until a much larger number of ore-deposits have been studied with a definite purpose of determining how far they have been subjected to secondary enrichment, it does not seem safe to draw any far-reaching conclusions from the observations and suggestions noted above. It has long been recognized that the superficial alteration of ore-deposits has often produced a very considerable modification of the original constitution of the deposit, and its alteration has so frequently been in the nature of an enrichment in the more valuable metals relatively to the original tenor of the ores that it has given rise to the very hasty decision that all ore-deposits necessarily become poorer in depth, which is almost as unjustifiable as the old assumption by the miner, that the nearer he got to the source of his ore in the unknown depths, the richer it would become.

The fact that ores under some conditions may be removed and re-deposited as sulphides, even below groundwater-level, opens a wide field of possibility in accounting for the unusually rich bodies of ore that are in some mines found in the middle levels, and have been fruitlessly sought for at greater depth. In many cases these have undoubtedly resulted from a concentration of material leached down from the upper portions of the deposit as they have been gradually worn down and carried away by denudation. Especially in the case of large bodies of pyritous ore carrying small proportions of more valuable metals, is a concentration of those metals by downward percolating solutions to be looked for. It is, however, not yet safe to say that all rich bonanzas in vein deposits have necessarily been formed in this way.

Although not yet supported by definite evidence, the impression is very strong with me that not infrequently the ascending currents have also produced migrations of already formed deposits and local enrichments under favoring conditions. What these conditions are, and what are the criteria by which they may be distinguished from concentrations by descending waters, it remains for future investigations to determine.

The Enrichment of Gold and Silver Veins.*

BY WALTER HARVEY WEED, BUTTE, MONT.

(Washington Meeting, February, 1900.)

INTRODUCTION.

IN a previous paper upon the enrichment of mineral veins by later metallic sulphides,† the writer has shown that certain masses of rich ores, such as are found in many mines, either near the water-line or as bonanzas in depth, are of secondary origin, and are due to a leaching of lean ore and the concentration of the material by reaction between the solution and the unaltered ore below. The geological and mineralogical evidence is believed to form an adequate basis for a chemical and physical explanation of the phenomenon. In the present paper the writer will give a brief synopsis of this theory, and will apply it more particularly to deposits of the precious metals, laying special emphasis upon the dependence of such enrichments upon the presence of iron sulphide (as pyrite, etc.) in the primary ore, and upon structural features which control the circulation of the enriching solutions below the water-level. It is believed that many, though not all, of the bonanzas and pay-shoots of rich sulphide ores, especially those carrying gold and silver, which are encountered in ore-deposits, are of such secondary origin. Apparently it is essential that the occurrence and structural relations of such ore-masses should be understood, as the success of the mine is often dependent upon the finding and extraction of these ores. A legitimate deduction, too, is that such ore-deposits decrease in value with depth.

As my own studies have been mainly in Montana, my illustrations must be drawn from the ore-deposits of this and adjacent States, with such as I have noted in hurried visits elsewhere. The literature of ore-deposits doubtless affords also

---

* Published by permission of the Director of the U. S. Geological Survey.

† *Bulletin Geological Society of America*, vol. xi., pp. 179–206, 1900.

many illustrations of secondary deposition besides those quoted by me in this paper. The recognition of secondary enrichment as a factor, and the chief one, in the genesis of many rich ore-deposits was forced upon me several years ago by my study of the Neihart, Mont., silver-gold veins. Since then it has proved to be of frequent occurrence in many mines, and its study has led me to the theory of secondary enrichment propounded in a previous paper, and especially applied to precious metals in this paper.

Statement of the Problem.

The fact that masses of very rich ore often occur near the water-line in many mines, but do not continue in depth, and the occurrence of pay-streaks and bonanzas in deep mine-workings, is a matter of history in many regions. The problem is to explain the genesis of such ores. The theory here presented accounts for such ores as enrichments formed from bodies of lean ore of complex composition, which have been lixiviated, the gold, silver and copper being carried downward below the water-level and precipitated as high-grade sulphide ores. The evidence is mainly mineralogical and geological; but it is in entire accord with chemical tests and reactions, which have been carried out in the laboratory or are too well known to be called into question.

Surface-waters are believed to be commonly the means by which the lean ores are leached and the metallic contents carried down and redeposited. In some cases, however, concentration has probably been effected by new fractures, resulting, in the cases known to the writer, from later volcanic activity and faulting, and serving as channels for upcoming hot waters. As commonly understood, "surface-waters" are those which have so recently left the surface as to still retain constituents common to waters now found at or near the surface (free carbonic acid, organic acids, chlorides, etc.), and which produce an oxidation. Thus the effect of superficial alteration, as described by most writers, has been the production of carbonates, chlorides, oxides, etc. In those instances where surface-agencies have had a reducing effect, it has been commonly ascribed to organic matter, though Penrose cites the formation of native copper by the action of "a ferrous salt on certain copper salts," as an instance where the primary chemical action is one of partial oxidation, and the reducing action follows, as the effect of one of the partially oxidized compounds on the other. In this sentence lies the pith of the whole subject of enrichment, since when the leaching of lean ore is performed by oxidizing surface-waters the resulting solutions percolate downward as deoxidized waters, carrying soluble salts that are the result of oxidation, and enrichment is the result of a reaction between these substances in solution and the unaltered ore with which they come in contact in their downward course. Above the ground-water level there is a constant movement of the water downward, but below that level the free oxygen has commonly been used up.*

THE ZONES OF WEATHERING, OF ENRICHMENT, AND OF PRIMARY SULPHIDES.

At the outset a sharp distinction must be drawn between the secondary or later enrichment herein described, which occurs in part at the water-level but usually below it, and the enrichment due to simple weathering or superficial alteration of the ore. In the latter case the gold or other values remain, while the worthless constituents are in large part removed, thereby greatly increasing the value per ton of the weathered part of the vein. This process, usually known as superficial, is a common and now well-known feature of ore-deposits the world over.

In order to describe the different parts of veins here under discussion, the writer will follow common usage in calling the upper weathered part the zone of weathering. Beneath this lies the zone of enrichment, underlaid in turn by the zone of primary sulphides. The term " zone " is, of course, only used for convenience, since it is well known that weathering extends down along fractures and other channels for circulating waters, sometimes for hundreds of feet into a mass of otherwise unaltered ore. The zone of enrichment is even more irregular, and may, as illustrated in the ideal conditions represented in

---

* It should be noted that the word *oxidation* is here used in its original restricted sense, as it is commonly understood, and not in the extended sense used by chemists to express the converse of reduction, as, for instance, Cu_2S to CuS, where no oxygen is present.

the diagram, Fig. 1, be separated by unaltered ore from a bonanza mass of secondary ore beneath.

The occurrence of enrichments between altered and unaltered vein-matter is one that has not escaped the attention of previous writers; but they have all, so far as known to me, limited such enrichment by the ground-water level. Thus, Penrose says:*

> "As a result of these various changes, certain minerals are sometimes leached from the upper part of ore-deposits which have become porous by alteration and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits."

This author, it is true, recognized that surface-waters pass below the zone of oxidation and may gradually sink to very great depths below the permanent water-level. But he expressly declares that the results of such circulation do not relate to superficial alteration,† which he limits to that of deposits that remain *in situ*.‡ De Launay, in his very interesting and valuable essay,§ has given us a chemical theory, to the support of which he has marshaled all the facts gathered in the preparation of his great monograph on ore-deposits. This author distinctly recognizes a zone of enrichment, but, like Penrose, limits it by the permanent water-level (*niveau hydrostatique*).

Leaching in the Zone of Weathering.

In the sulphide enrichment here discussed, the enriched material is in most cases derived by the leaching out of the metals from the portion of the vein lying above ground-water level. This leaching is due to superficial alteration, and leaves the iron as a gossan while the waters carrying the gold, silver, copper and other metals in solution trickle downward through the partially altered ores into cracks and water-courses which penetrate the ore-body below the water-level. The first part of the process is, therefore, the leaching of the lean ores which occurs

---

* *Journ. Geol.*, vol. ii., 1894, p. 294.

† *Loc. cit.*, p. 298.

‡ *Loc. cit.*, p. 302.

§ "Contribution a L'Etude des Gîtes Métallifères," *Ann. des Mines*, 9th series, vol. xii., 1897, pp. 119–227.

in the superficial alteration of the vein. This has been discussed by many writers, particularly by Penrose, who, however, does not make any attempt to state the chemical reactions involved. These reactions are complex, and the mass results depend upon the laws of physical chemistry; yet the general changes involved may be expressed by equations showing end reactions.

FIG. 1.

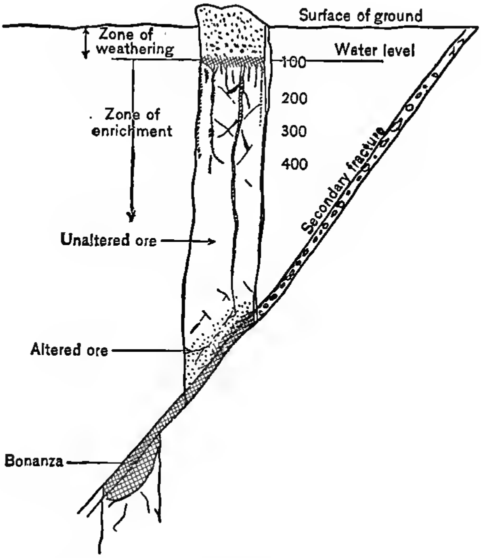


Diagram Showing Relative Positions of Zones of Weathering, Enrichment and Unaltered Ore, and of Bonanzas Formed Along Fault.

The chemistry of weathering, concisely expressed, is as follows: In an ore consisting of either one or all of the following sulphides:—pyrite, arsenopyrite, chalcopyrite, blende, galena, tetrahedrite,—the minerals will oxidize according to their relative affinity for oxygen and inversely as their "affinity" for sulphur.* All the sulphides will be attacked simultaneously,

---

* This statement is sufficiently accurate for the purposes of this discussion. As the mineral decomposition is affected by physical structure, as well as chemical, and by relative amounts of each present, it is apparent that there are many qualifying factors. The "relative affinity" of the metals for sulphur is 1 Hg, 2 Ag, 3 Cu, 4 Sb, 5 Sn, 6 Pb, 7 Zn, 8 Ni, 9 Co, 10 Fe, 11 As, 12 Mn. This is the order in which a salt of one metal will be decomposed by any subsequent one in the series and the first metal precipitated as sulphide. (See *E. and M. Jour.*, Oct. 25, 1890, p. 484. See also *Jour. of Soc. Chem. Ind.*, vol. xi., 1892, p. 869.)

but, inasmuch as pyrite consists of 4 parts ferric and 1 part ferrous sulphide,* and parts with a portion of its sulphur very readily, this mineral will be most attacked. This decomposes first to FeS and S. The sulphur usually forms H_2SO_4; the FeS forms $FeSO_4$. The latter changes to H_2SO_4, $Fe(OH)_3$ and $Fe_2(SO_4)_3$. The sulphuric acid attacks more iron sulphide and forms more $FeSO_4$ together with H_2S—the latter, in the presence of abundant oxygen, forming H_2SO_4. The $FeSO_4$ changes to $Fe_2(SO_4)_3$, which attacks the sulphides of copper, lead, zinc, etc., in a reaction which can be most simply expressed as follows:

$$Cu_2S + 5Fe_2(SO_4)_3 + 4H_2O = 2CuSO_4 + 10FeSO_4 + 4H_2SO_4.$$

The H_2SO_4 in mine-waters will attack both copper and iron sulphides and form sulphates without the formation of H_2S or the liberation of free S; and the iron sulphate, oxidizing the iron, is precipitated as limonite. The oxygen may come from either air or water. $PbS + Fe_2(SO_4)_3 = PbSO_4 + 2FeSO_4 + S$; or $PbS + 4Fe_2(SO_4)_3 + 4H_2O = PbSO_4 + 8FeSO_4 + 4H_2SO_4$. And $ZnS + Fe_2(SO_4)_3 = ZnSO_4 + 2FeSO_4 + S$, or, more probably, $ZnS + 4Fe_2(SO_4)_3 + 4H_2O = ZnSO_4 + 8FeSO_4 + 4H_2SO_4$.

The above equations simply show that ferric sulphate can oxidize the various sulphides to sulphates, and is itself reduced to ferrous sulphate. However, the sulphuric acid formed by the oxidation of pyrite in the upper zone can also attack sulphides, and the H_2S which is formed may be oxidized by the ferric hydrate into sulphuric acid. This method is probably more likely of occurrence, but no one can say that the oxidation is exactly according to any set of equations, as many other reactions are possible.

The laws of physical chemistry, verified by experiment, show that blende is more easily attacked by oxidizing waters than galena, and the latter mineral decomposes more readily than chalcocite. The general order of attack of the sulphides is therefore arsenopyrite, pyrite, chalcopyrite (FeS removed, leaving CuS), blende, galena, chalcocite, while tetrahedrite, being a complex substance without definite percentage-composition, has no fixed place. Gold, if present, may be attacked by $Fe_2(SO_4)_3$ in which it is well known to be readily soluble, and silver goes

---

* "The Chemical Composition of Marcasite and Pyrite," by Amos P. Brown, *Proc. Am. Phil. Soc.*, vol. xxxiii., p. 225, 1894.

into solution as sulphate. The lead, which as sulphate is nearly insoluble and remains about its parent-mineral galena, can only migrate when reduced to carbonate (by calcite, etc.), in which condition it is readily carried off by carbonated waters.

Where these are the only reactions, the outcrop is leached of all its metallic matter, and its soluble gangue-minerals are reduced to a porous spongy mass of silica, such as is sometimes seen. Commonly the iron is not all removed, since the ferrous sulphate, which is the most abundant product of the leaching, absorbs oxygen and water and forms limonite, $2Fe_2O_33H_2O$ (or rarely a basic sulphate of iron), forming the iron-stained quartz or limonite gossans, the "iron cap" of so many vein outcrops. This leaching of the ores is therefore seen to depend upon the tendency of the iron salts to form $Fe(OH)_3$ as an ultimate product which is precipitated from the solution; thus renewing the $FeSO_4$, which renews the ability of the solution to attack more pyrite and metallic sulphides. This cycle of change can be tentatively expressed as follows: Ferric sulphate forms by the oxidation of the iron sulphide of the original ore. This salt attacks pyrite and other sulphides, and is itself reduced to ferrous sulphate. The latter oxidizes to ferric sulphate, which is partly changed to limonite and sulphuric acid, while the remainder begins anew the cycle of change. Ferric sulphate is the main vehicle by which the sulphides are dissolved. The $Fe(OH)_3$ is *in part* eliminated as a precipitate, while a part is acted upon by the sulphuric acid with the production of a solution holding $Fe_2(SO_4)_3+FeSO_4$, these iron sulphates being in the approximate proportion of 3:1. The $FeSO_4$ takes up oxygen and forms $Fe(OH)_3$, and the ultimate production is a yellow basic sulphate insoluble in H_2SO_4. The result of these changes, due to water and abundant oxygen, is the leaching out of all the constituents of the vein in the weathered zone except iron and silica. The solutions seeping downward contain various metallic sulphates and much sulphuric acid, the amount of the latter being increased by that formed by hydrolysis from the sulphates, since copper sulphate in solution yields sulphuric acid.

Precipitation in the Zone of Weathering.

Not all the material leached out in the zone of weathering migrates below to the zone of enrichment; for the surface-waters commonly contain carbon dioxide, some chlorides, organic matter, etc., resulting in the formation of carbonates, chlorides, etc., and of the native metals. Thus, copper can be formed from the oxide by reaction with either free sulphuric acid or iron sulphate (both abundant in the lower part of the superficial zone), viz.: $Cu_2O + H_2SO_4 = Cu + CuSO_4 + H_2O$; and $3Cu_2O + 6FeSO_4 = 6Cu + Fe_2O_3 + 2Fe_2(SO_4)_3$. The latter reaction accounts for the cement-copper associated with iron sesquioxide at Ducktown, Tenn., Gold Hill, N. C., and elsewhere. Native silver is also formed in films and crystalline masses by reduction through ferrous sulphate, viz.: $Ag_2SO_4 + 2FeSO_4 = 2Ag + Fe_2(SO_4)_3$. Gold probably sometimes occurs in the native state because it has not been attacked and is simply left behind, though it is also deposited by precipitation from the ferrous sulphate solution.

The Zone of Enrichment.

The surface-waters which have leached the vein in the zone of weathering seep downward along cracks and crevices, or along trunk-channels, into the primary ore below. The origin and occurrence of such fractures will be mentioned later. They very commonly exist in ore-deposits, and convey waters downward far below the so-called ground-water level. As we have shown, these waters not only carry various metals in solution, chiefly as sulphates, but they are no longer oxidizing, but are of acid reaction. Penetrating the primary ore, they come in contact with the unaltered metallic sulphides. In such masses pyrite and, more rarely, pyrrhotite are very commonly abundant; and a reaction at once occurs between the iron sulphide and the metallic salts (mainly sulphates) held in solution, resulting in their decomposition and the precipitation of new sulphides which encrust the walls of the fractures. This, in the case of copper, is shown by the following theoretical equation, which expresses end reactions only, viz.: $4CuSO_4 + 3FeS_2 + 4H_2O = 2Cu_2S + 3FeSO_4 + 2H_2SO_4 + 2H_2S + S$; or, more simply, copper sulphate and pyrite yield copper sulphide and ferrous sulphate.* This Cu_2S would react in turn upon silver sulphate, $Ag_2SO_4 + Cu_2S = Ag_2S + Cu_2SO_4$, while the pyrite

---

* The apparent anomaly of cupric sulphate and pyrite giving ferrous sulphate is explained by the chemical composition of pyrite as 4 parts ferric sulphide and

itself will decompose the silver as well as other sulphates, owing to the relative affinity of the metals for sulphur. Chloride or carbonate of silver would be similarly decomposed. For the rich antimonial sulphides of silver various reactions are possible, the pyritous ore reducing the minerals from a solution holding antimony and arsenic derived from impure pyrite. This process is probably aided by the free sulphuric acid brought down in the waters and as hydrolization-product of intermediate steps of above reactions; since a dilute solution of sulphuric acid attacks iron sulphide, forming iron sulphate and sulphuretted hydrogen; the latter of which would form sulphides of lead or silver, etc., from the solutions.*

For lead the presence of carbonates seems necessary, and if the gangue minerals are of this nature, or the walls are limestone, the lead carbonate is decomposed, lime goes into solution, and the H_2S set free from pyrite at once forms galena, which is deposited.

The Solution and Precipitation of Gold.—The alteration of gold-deposits presents features differing very markedly from those accompanying the alteration of copper- or silver-ores. It is commonly assumed that the unaltered ore contains the gold in association with pyrite or quartz. The most frequent alteration of this is to a rusty brown mass of sesquioxide of iron, permeating the quartz and holding nugget-threads of free gold. As a result of further alteration by surface-waters, the iron is leached out, and a porous, spongy, white quartz remains, holding the gold. This kind of alteration is a very common feature of ore-deposits throughout the West. In many cases, however, different conditions prevail. Part of the gold, at least, is taken into solution by ferric sulphate, carried downward as the waters

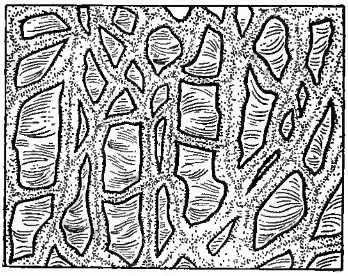
---

1 part ferrous sulphide, the latter only being herein considered. Moreover, we may have in oxidation zone: $Cu_2S + 4Fe_2(SO_4)_3 + 4H_2O = Cu_2SO_4 + 8FeSO_4 + 4H_2SO_4$. Then any sulphide would precipitate Cu_2S from the cuprous sulphate, providing the sulphide is soluble enough and the sulphate solution is strong enough to have enough cuprous ions and sulphide ions to exceed the constant of solubility. The formation of cuprous sulphate is theoretical, but its existence is indicated by recent experimental work, as yet unpublished, by C. F. Tolman, Jr.

* It must be understood that these equations are given in the simplest and most compact form possible. Thus $CuSO_4$ in water really holds $Cu(OH)_2$ and H_2SO_4.

seep below, and precipitated as native, leaf, wire or scale gold in minute cracks in sulphide ores, or, what is more commonly the case, the gold is deposited with silver in antimonial sulphides, especially ruby silver (pyrargyrite). This is the form in which it occurred at the Ruby mine, on Lowland creek (near Butte), where the surface of the quartz crystals lining the open spaces between boulders of decomposed rhyolite and coating these boulders is liberally sprinkled with ruby silver. This mine yielded $600,000 in less than a year, of which one-half the value was gold. The ore was a secondary concentration along a clay fault-fissure, and is now exhausted. The "indicators" of Australian ore-deposits afford a most interesting example of the reduction of gold by pyrite. These indicators are thin layers, sometimes but half an inch thick, of pyrite occurring in shale. In many cases the shales are, it is true, carbonaceous, and the organic matter may assist in the reduction. As shown by Don and by Rickard, the quartz veins are barren except where they intersect these pyritous layers.*

FIG. 2.



Alteration of Bornite to Chalcocite and Limonite, Blue Wing Ore, Virgilina District, N. C. The nucleal masses are bornite; the black borders represent chalcopyrite; the stippled area is iron oxide. Drawn from nature, twice the natural size.

The experiments of Liversidge† have shown that gold is precipitated from solution more readily by metallic sulphides than by organic matter.

---

* J. R. Don, *Trans.*, xxvii., p. 569. T. A. Rickard, *E. and M. Jour.*, 1895, lx., p. 561.

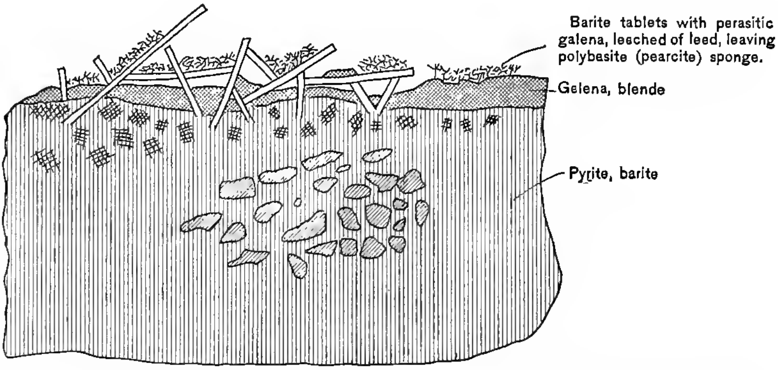
† *Proc. Roy. Soc. N. S. W.*, vol. xxvii., 1893, p. 287. See precipitation of gold by pyrite in the experiments of Daintree, quoted by Rickard in "Origin of the Gold-Bearing Quartz of Bendigo Reefs," *Trans.*, vol. xxii., p. 313.

Résumé.—It seems unnecessary to expand this section further, as the reactions given are sufficient to show that secondary sulphides are formed in depth. It is evident that a majority of the reactions depend upon the presence of iron sulphides, either as pyrite or in some other form. Pyrite is therefore the great precipitant of secondary sulphides.

EVIDENCE THAT CERTAIN MINERALS AND ORES HAVE THE GENESIS STATED ABOVE.

That chemical reactions similar to those given do take place in nature, and that the resulting precipitates are true minerals, is shown by abundant mineralogical proof. Thus the auriferous copper-ores of Gold Hill, North Carolina, show chalcopyrite altering about its borders to a spongy mass of black copper sulphide; the iron being largely carried off, but in part forming hematite nests near by. In other specimens, the copper sulphide has gone into solution, and has been carried a few inches and redeposited in crystalline masses. In a similar manner bornite alters to chalcocite and iron oxide, as shown in specimens from the Blue Wing mine at Virgilina, Person county, North Carolina. Fig. 2, drawn from nature, shows this alteration. In other specimens the iron is carried off and fills cavities with specular iron-ore.

FIG. 3.

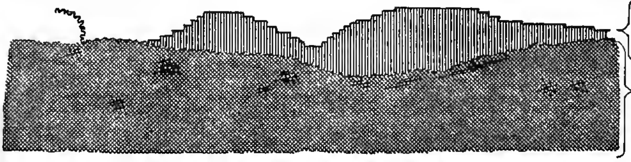


Specimen Showing Leached Galena and Residual Polybasite; Florence Mine, Neihart, Montana.

At Neihart, Montana, polybasite and pyrargyrite encrust barite, quartz, galena and pyrite, which are themselves later than and encrust fractured masses of impure galena, blende and pyrite that constitute the original vein-filling. These crusts are now forming in vugs and water-courses filled by sluggish descending water. Nucleal masses of impure galena are seen in thin section surrounded by a spongy mass of polybasite, just as chalcopyrite is seen surrounded by amorphous copper glance. Fig. 3 is a diagrammatic representation of a portion of the surface of a specimen of ore from the Florence mine. The main mass of the specimen consists of a breccia of pyrite fragments, held in a cement of barite and ankerite spar, with scattered grains of galena. The upper surface shows galena, blende and barite, the latter in projecting tablet-shaped crystals upon which there are parasitic masses of impure argentiferous galena. This galena is etched and leached so that, on part of the specimen, the surface shows a crust of about $\frac{1}{16}$ to $\frac{1}{8}$ inch thickness consisting of a spongy residue, or a skeleton of the galena. This spongy mass consists largely of polybasite left behind as the more soluble lead was leached out. That some of the antimonial sulphide of silver goes into solution, is shown by the presence nearby of minute newly-formed crystals of the latter. The crystalline polybasite occurs nearby coating fractures and showing characteristic triangular markings, or as loose aggregates of rough and mossy-surfaced crystals. It is also probably derived from blende, as it occurs very commonly coating that mineral under conditions which seem to preclude precipitation by that mineral. An examination of numerous specimens from the Florence and Big Seven mines shows that polybasite and pyrargyrite are secondary minerals filling cavities and cracks in the original ore. The material gathered from the lowest level of the Florence mines shows polybasite in the form of crystalline tablets upon barite and other minerals, and also as a moss-like mass of open skeleton-texture, which seems to represent arrested deposition. The latter form is believed to come from a place in the vein where mineral-bearing water is now depositing this mineral, together with spar, quartz, and probably galena. Studied under the microscope, the polybasite appears to be an alteration-product of galena, and itself to be mixed with, and to grade into, pyrargyrite, which is in some cases its undoubted alteration-product. It is certain that polybasite, as the important constituent of many of the ores, is of secondary origin. It occurs on all other minerals, and is itself not coated or dotted by them. Fig. 4 is a diagram of a specimen of the common ore of the district consisting of galena and carbonate "spar" with scattered pyrite and chalcopyrite. The specimen is from the wall of a fracture traversing the somewhat friable bands of galena. The surface of the fracture has been coated with a thin drusy covering of quartz upon which there rests massive polybasite whose upper surface shows the typical triangle striations of polybasite. The specimen is drawn nearly to natural scale.

Sphalerite also occurs in well-formed crystals in some of the vugs and is one of the most recently deposited minerals.

Fig. 4.



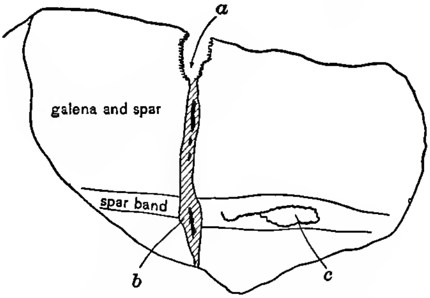
Secondary "triangle" ore; polybasite encrusting fractured surface of primary ore.

Primary ore; galena and carbonate minerals: no quartz, some pyrite and chalcopyrite.

Specimen from the Florence Mine, Neihart, Montana.

While polybasite and pyrargyrite are economically the most important of the secondary minerals formed by enrichment-fractures in the Neihart ore, yet other minerals, galena, pyrite, blende and quartz, are also formed. An excellent example is seen where quartz veinlets have filled fractures in the primary ore. Fig. 5 shows a piece of the common spar and galena ore in which the ore is fractured and the fissure filled by a veinlet of quartz in whose center pyrite is seen. At the top the fissure is open and the vug is lined with a drusy coating of quartz, on the surface of which occasional larger crystals of polybasite are seen. The druse (*c*), connected with the quartz veinlet by a fracture following a layer of spar, shows secondary quartz and pyrargyrite. Where such fractures traverse the ore, and its carbonate gangue is at a decided angle to the banding of the deposit, and the crusts or filling are notably different in composition, there is no doubt of their being of later origin. A veinlet of this kind is illustrated on a natural scale in the diagram, Fig. 6. In this case various secondary minerals were formed. The figure represents a cross-section of a little quartz "vein" of the Big Seven mine, which constitutes the high-grade ore-streak of the lode. It shows the relative abundance and association of the minerals, but does not represent the spongy texture of the polybasite and its intimate admixture with both galena and pyrites (chalcopyrite), as this growth is too mossy to be represented well, and the mineral is therefore indicated as polybasite alone. The specimen, seen in thin section, shows ruby silver and polybasite intimately associated and forming irregular, shreddy and ragged patches. No positive identification of galena as the nucleus of such masses was made, but the association with galena is such as to indicate a possible change to polybasite. The pyrite is broken and fractured, but the grains are always sharply defined, and no genetic relation to the silver sulphides is recognizable. A blende crystal, seen isolated in the central quartz-filling, shows in thin section a crust of polybasite, the latter holding minute inclusions of pyrite. The blende, seen in another section of rich ore, is invariably surrounded by a dark crust which is not iron oxide, nor does it appear to be an iron-rich blende. It is not definitely determinable, but resembles galena or a silver sulphide.

FIG. 5.



a = Druse forming part of secondary quartz veinlet - quartz encrusted with pyrite and polybasite.

b = Secondary quartz veinlet with pyrite center.

c = Vug in galena and carbonate ore. shows secondary leaching and deposition of quartz in cavity.

Specimen of Silver- and Lead-Ore from Neihart, Montana.

Posepny has described stalactitic deposits of sulphide, which, as urged by Dr. A. Schmidt,* form excellent proof of the formation of secondary sulphides by a leaching of ore in the zone of weathering and a redeposition of ore in the zone of enrichment. Posepny, it is true, denied such an origin for these deposits because they occurred below water-level. The

---

* *Die Zinkerzlagerstätten von Wiesloch, in Baden,* Heidelberg, 1881, p. 94. Posepny, *Genesis of Ore Deposits,* p. 63; and *Trans.,* xxiii., 259.

existence of open spaces below water-level is a phenomenon frequently encountered in ore-bodies exposed by mine-workings. I myself have seen such openings a foot or more across at 1000 feet below the water-level at Elkhorn, Montana, and at 200 feet below water-level at Neihart. The pipe-ore of Raibl described by Posepny is, I believe, an excellent example of the formation of secondary minerals by descending waters. Posepny's explanation that they are due to ascending waters which were denied access to the cavity except through the roof, seems to me to be an hypothesis opposed to both the facts of observation and physical laws. Moreover, as the geology of the mining regions is more carefully studied, it is certain that they have passed through various physiographic changes, with migration of water-level, so that air-filled spaces below what is now the water-level are not only possible but in some cases probable.*

Prof. Vogt also describes† the recent concentration of gold and silver in a zone beneath the "iron hat." He says that in the Rio Tinto region the "iron hat" is from 35 to 50 meters deep, and consists of iron oxide or hydrated oxide, with from 35 to 50 per cent. of iron, some silver in part as basic sulphate, and a few ten-thousandths per cent. of arsenic, while on the other hand the copper-contents are, as already remarked, entirely oxidized and dissolved out. In one mine, North vein No. 2, at Rio Tinto, there occurred between the iron hat and the underlying comparatively fresh pyrite, a layer of earthy, porous material, bearing gold and silver. This earthy ore, though a few decimeters in thickness, may be followed continuously over the entire ore body. This very marked layer follows closely the irregular plane between the iron hat and the underlying pyrite. It everywhere contains an average gold- and silver-contents of from 15 to 30 grammes gold and 1.025 silver, with a value of about 150 marks per ton. In stripping off the "iron hat," this earthy mass is carefully laid to one side, and has thus yielded fully a thousand tons of ore. It is clear that the formation of this gold- and silver-bearing zone is connected with the oxidizing process that formed the iron hat, and that the gold and silver comes from the very small percentage of such metals in the primary ore.

---

* This volume, p. 69; and *Trans.*, xxiii., 260. † *Zeitsch. Prak. Geol.*, July, 1899.

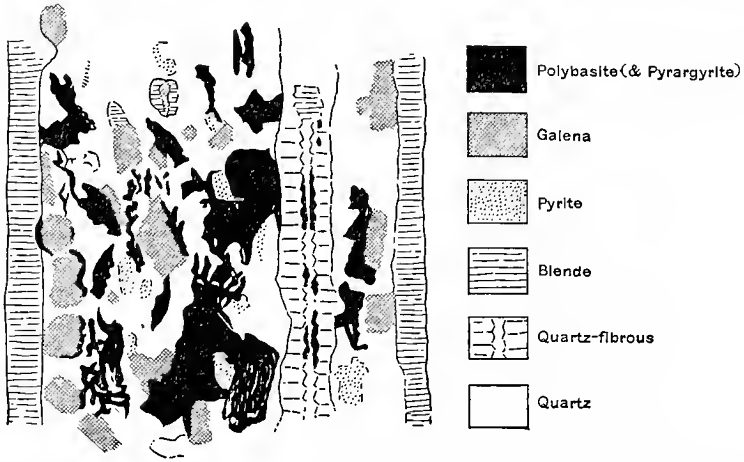
Deductions.

From the chemical reactions given, it is evident that enrichment is largely dependent upon the presence of marcasite, pyrite or some other form of iron sulphide in the primary ore, since lixiviation depends upon the presence of the iron sulphates, and precipitation is mainly effected by the unaltered sulphides. As a consequence of this, it follows that ore-bodies lacking in iron pyrites will not show enrichment, thus explaining the absence of any such phenomena in the pure silver-lead bodies of the Cœur d'Alene district and elsewhere. In this region, visited by the writer in 1895, the ore-bodies consist of galena with a siderite gangue and are replacement-deposits in quartzite and argillaceous schists. The veins are covered by great masses of barren limonite gossan, beneath which the ores are carbonates and sulphates of lead, which extend along fractures to a depth of 200–300 feet. The silver values, which carry about 10 ounces of silver to 1 per cent. of lead, do not show any enrichment. This is quite what would be expected, since, although the galena in decomposing would yield up silver as sulphate, there would be no reducing agent at hand to extract it from the waters as it seeped down into the unaltered ore. Also, at Barker, Montana, the ore-bodies show no enrichment, though a common feature of such deposits, viz., the change of galena to pyrite, in depth, would favor enrichment, if the silver-lead bodies were deeply enough weathered. The writer has also examined the Zosel mines in andesite porphyry near Deer Lodge, Montana, and those in similar rocks on Basin Creek, and near Elliston, as well as the Castle Mountain and Elkhorn ores in limestone, and the Bear Paw ores in basalt, all in Montana, as well as the McMakin in North Carolina. These deposits all consist essentially of galena without any notable amount of pyrite, and although favorable physical conditions for enrichment occur, no bonanzas or pay-streaks of rich secondary ores are found.

The Occurrence of Bonanzas and Pay-Streaks.

The location of bonanzas and pay-streaks of secondary sulphide-ores is dependant upon physical factors. From a consideration of the processes described in the preceding pages, it is evident that the localization of enrichments will depend wholly upon structural conditions. If the vein consists of a solid unshattered impermeable body, with no fractures by which the solutions can seep down into the underlying original sulphides, the zone of enrichment will be confined to the vicinity of the water-lines, and, if above water-level, will constitute the ore-bodies described by Penrose, De Launay and others as one of the results of superficial alterations. In fact, many such enrichments do occur at, or just below, the water-level. If the primary ore-body is shattered by cracks, sheeted by later movement or traversed by secondary fractures, faults running with or across the vein, such crevices and fractures will be the channels in which the descending solutions will travel, and along which the secondary ores will form deposits in the unaltered ore below.

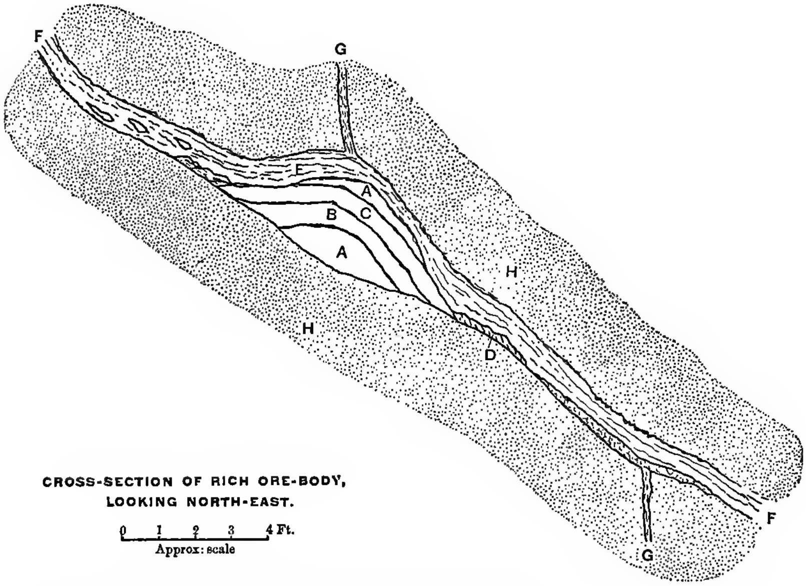
Fig. 6.



Secondary Veinlet of Quartz and Rich Sulphide Ore Filling Fracture in Primary Ore; Big Seven Mine, Neihart, Montana. Pyrite and galena are angular fragments of original ore.

Such secondary fractures may be now filled with quartz or other gangue-minerals holding ore, or they may be barren and open, or they may be marked by a soft mushy mass of clay or attrition breccia. Very often the so-called splits, feeders and stringers of a vein, when examined critically, will be found to be secondary fractures and not true offshoots of the vein itself, the latter phenomenon often being the cause of ore-shoots of primary origin. Where the later fracturing runs parallel to the vein, as is so often the case at Butte, and in the silver mines of Jefferson county, it may only be revealed by a clay selvage of a rare slickenside surface, though it is more frequently marked by a soft and mushy mass of mud and breccia, in which fragments of the wall-rock ore and gangue, one or all, may be seen. This is seen at the Comet mine, where secondary ores were abundant along recent fissures filled with clay and a breccia of leached ore and altered wall-rock.

Fig. 7.



Australian Broken Hill Consols Mine, New South Wales. (After George Smith, *Trans.*, xxvi., 73.)

A, dyscrasite; B, stromeyerite; C, decomposed amphibolite, etc., assaying under 7 oz. per ton; D, fahlerz; E, soft gossany material, containing nodules of silver chloride, stromeyerite, etc., and averaging about 750 ozs. per ton; F, limonite, practically free from silver; G, cross-vein; H, amphibolite.

An excellent example is afforded by the ore-body of the Australian Broken Hill Consols mine, New South Wales, described by Smith.* The occurrence of the largest bonanzas yet found in the mine were in association with the vertical vein G, shown in the diagram (Fig. 7). This cross-vein has been faulted by the lode, and is really a succession of joints along a line of

---

* *Trans.*, xxvi., 69.

weakness. Another bonanza occurs in the same mine, 500 feet to the east, under similar conditions.

Mr. Smith's statement is that the lode itself is only ore-bearing where it makes junction with cross-veins. The well-known occurrence in Australia of ore-bodies where veins cross "indicators," *i.e.*, pyritic bands a few inches wide, is readily understood, either as secondary enrichment or primary, since the reducing effect of pyrite upon gold held in solution has been established by Liversidge.

The part played by such secondary fractures at Butte can hardly be appreciated by those not familiar with the ground. In descriptions and diagrams of the veins of this district the occurrence of clay and breccia bands and walls has not been overlooked, though their true significance appears to have escaped notice since the fractures so often run parallel with and in the vein itself. Emmons first noted the significance of such fractures, and their genetic connection with glance and bornite veins. It is now known that these fractures are extensive laterally and vertically, and the enrichment probably due to them extends in some instances to a depth of 2000 feet below the present surface. Lest this statement prove misleading, it should be qualified by adding that not all such fractures have caused enrichment, and some of the largest fault-fractures are of relatively recent formation, later than the ore-bodies of glance and bornite, etc., which they cross.

FIG. 8.

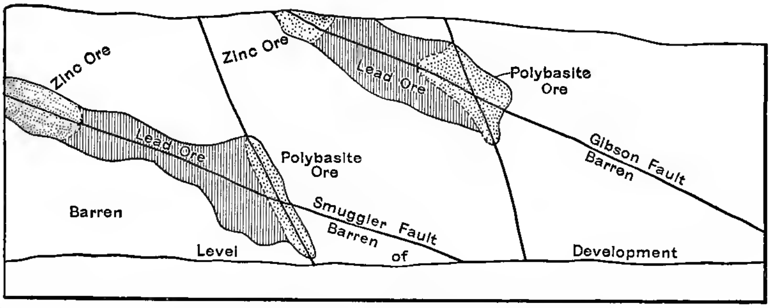


Diagram to Show Relation of Mollie Gibson and Smuggler Ore-Bodies and Bonanzas (of Polybasite) to Fault-Fissures. (From Spurr.)

In his monograph upon the Aspen district, Colorado,* Mr.

---

* J. E. Spurr, *U. S. Geol. Survey, Monograph No.* xxxi., *Geology of the Aspen Mining District.*

Spurr describes the occurrence of the famous ore-bodies of the Smuggler and Mollie Gibson mines at Aspen, Colorado. The ore consists of barite and polybasite, with tennantite. Although Mr. Spurr gives no definite statements as to the possible secondary origin of these ores, yet the sketch which he gives* (Fig. 8) and the descriptions all indicate that the original ore was a silver-bearing lead sulphide, with more or less iron and zinc sulphides, formed along inclined faults, and that subsequent to the formation of these ore-bodies, nearly vertical faults displaced the ore and formed the two bodies now worked at the mines mentioned. Although in these vertical or nearly vertical fissures rich polybasite ore is now found, it does not extend far in either direction from this fault; and the description of the ores given by Mr. Spurr indicates that it is derived by secondary alteration-processes from the lead and zinc ore-bodies. This is also indicated by the fact that the polybasite is in part altered to native silver at the extreme lower end of the ore-body.

In conversation with me, Mr. Spurr has admitted the possible secondary origin of these polybasite bodies, but had no new evidence upon the subject. He says:

> "This ore was of a rich character, having large amounts of polybasite and native silver. This polybasite body appears to lie in a sort of subordinate shoot, trending south of east and lying at the Gibson fault-plane. This shoot is marked by exceptionally large and rich bodies of a nature not found elsewhere in the mine. It is noteworthy that this rich shoot is practically the lower termination of the ore of the Gibson fault. Most of the ore below this is native silver, which, from the nature of its occurrence, is manifestly a secondary deposit leached from the rich ore above. Some of these secondary deposits are, however, of considerable size, and empty vugs are often found beautifully and elaborately festooned with delicate wires of silver. Above the polybasite ore, however, the ore appears to be pretty continuous, but the amount of silver becomes less."

It will be noticed that he recognizes the secondary nature of the silver, and that the polybasite lies between the native silver and the lead sulphide.

In a chapter upon the chemical geology of the region, where he discusses the alteration of the ore-deposits and of the limestones, he does not adduce any new facts concerning the formation of the polybasite ore; but he does say that iron pyrites carrying small amounts of arsenic, lead, copper, zinc, cadmium,

---

* *Op. cit.*, 183.

cobalt and nickel is found, and that tetrahedrite is also very common. The polybasite is said to be later than the barite.

The description given by Leggett* of the Rosario mine, San Juancito, Honduras, C. A., shows that the secondary enrichment may account for the peculiar features of the deposit. This fissure-vein splits into two distinct veins in more barren ground and unites into one consolidated vein where ore-bodies occur and where feeders enter from the hanging-wall—a condition paralleled in the Drum Lummon lode in Montana. The oxidized ore of upper levels includes frequent streaks of argentite and the rich silver sulphides. The lower levels show the unchanged sulphides of iron, copper, lead and zinc. The gangue is quartz, carrying in the ore-bodies occasional clay-streaks, heavily stained with the hydrated oxides of iron and manganese. Other accompanying minerals found less frequently are polybasite, embolite, etc. The vein-material is quartz pure and simple. The foot-wall is usually decomposed and broken, and a clay parting often runs a foot or two inside of the wall, necessitating close stulling till the stope can be filled with waste. The conditions noted here are the counterpart of those encountered in the copper-veins of Butte, where later fractures, marked by clay and attrition-breccia, have been the channels for enriching solutions.

The Secondary Enrichment of Veins at Neihart, Montana.

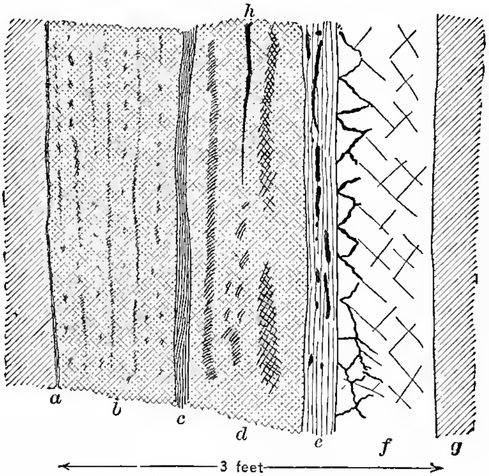
Secondary enrichment has played an unusually important part in the development of the ore-deposits of Neihart. The ores extracted in the earlier workings and those found to-day where new veins are opened, all show silver sulphides deposited by secondary enrichment as crusts or crystals lining cavities, or as films or thin coatings along fractures of the primary ore, or in the oxidized zone as the so-called "sooty sulphide" ores that occur with manganese oxides. It is from this zone of enrichment that the high-grade ores, running from 200 to 1000 ounces of silver to the ton, or even higher, were obtained in the early history of the camp. Although such ores gave out in depth and caused many disappointments and failures, their occurrence played a most beneficial part in the development of the veins.

---

* *Trans.*, xvii., 432.

The secondary minerals recognized are chiefly polybasite (really pearcite) and ruby-silver, the former being more abundant. There are also bright metallic coatings, presumably argentite, on crystals and along fracture-planes, and rarely in minutely crystalline masses. The superficial alteration of the Neihart veins is not a marked one, as there are no great zones of carbonates and oxidized ore. Such ores occur only in limited amounts, being most abundant in the Broadwater vein, where the partially oxidized ores extend down 170 feet below the outcrop, and, in pipes and along drainage fissures, reach even greater depths. Generally, however, there is another zone of alteration below the level of these altered or highly altered ores—the zone of enrichment. This secondary ore also occurs in the cracks of the shattered country-rock, forming the vein-matter where it is associated with secondary quartz (Fig. 9). Very commonly the polybasite occurs in crystalline masses showing no definite crystal outlines. In the open spaces and

FIG. 9.



a = Black "clay" ¼" seam: Colored by ground up galena etc.
b = White spar stippled with galena, pyrite and blende.
c = Secondary fault-fissure in primary ore. Filled by clay holding ore fragments.
d = Shattered "spar" ore, galena etc.
e = Secondary fault-fissure traversing vein: The clay filling is black and holds secondary antimonial sulphides of silver making good ore.
f = Shattered and altered gneiss holding films of rich sulphide ore and vugs of ⅛" across holding rich silver sulphides.
g = Gneiss
h = Vein of polybasite

Face of Broadwater Vein Exposed August, 1897, on Stope Below Third Level.

vugs of the vein, crystallized specimens have been found associated with barite. It is possible, of course, that this may be due to the meeting of surface- and of deep-seated waters. The zones of impoverishment, of enrichment, and of unaltered primary sulphides recognized in the case of the copper veins are clearly present here, though the uppermost is of limited extent, and the zones are not so sharply or definitely separated from one another as they are in copper deposits, owing to the later fissuring of the vein-filling allowing the secondary enrichment to be mixed with the unaltered sulphides. Polybasite is said by Dana to alter to stephanite and pyrite. In the Neihart ores the mineral seems to show an alteration to pyrargyrite and pyrite, and the former, in turn, changes to native silver in the upper zone.

An example of the economic necessity of carefully observing secondary fractures and accompanying enrichment is shown by the Eva May mine, on Cataract creek, near Boulder, Montana. In the early history of the mine much high-grade ore was found consisting of pyrite, together with more or less galena, blende and chalcopyrite, the whole impregnated with scattered bunches of rich antimonial sulphides of silver. The vein is a large one and shows thick ore-shoots of pyritic ore, but the bulk of this away from the enriching fracture is too poor to work. Concentrates made from it have, according to analysis in the Survey laboratory, the composition shown under I. in the following Table:

		I. Per cent.	II. Per cent.
Silica, Alumina, etc.	Insoluble,	19.81	10.31
	Part of ore,	.50	.56
Fe,		24.08	23.59
Pb,		9.83	23.93
Zn,		6.00	5.74
Cu,		4.56	1.29
Bi,		.33	.12
Ni,		.03	trace
Ca,		none	none
As,		2.01	.98
Sb,		.55	trace
S,		32.30	33.48
		100.00	100.00
Gold, ounces per ton,		.10	.75
Silver, " " "		1.85	7.25

This material, which looks so much like good ore, has caused the mine to shut down. It will be seen that it furnishes an admirable material for alteration and concentration of silver according to the process outlined in the first part of this paper. In point of fact the pay-streaks and pay ore-bodies of this property are of secondary origin, and it is only by confining mining operations to such places that the mine can be made to pay.

Another example is the Frohner mine, 10 miles south of Helena, at the head of Clancey creek. The main ore is a mixture of galena and pyrite, and occurs in sufficient abundance to warrant working, if it were not too low in grade. Yet the primary ore, where not enriched, will not pay for concentration. The composition of this ore is given in column II. of the table on the preceding page. The ore has been concentrated until it carries but 10.3 per cent. silica, with iron and lead present in nearly equal proportions. The sample was carefully collected, so as to represent a true average of the concentrates as shipped. The rich ore of the mine, carrying as high as 200 oz. of silver per ton, was found near secondary fractures, and consisted, I am told, of pyrite and galena with films and nests of antimonial sulphides of silver.

A considerable list of mines in Montana might be mentioned in which such phenomena have been observed by the writer. Of many others the past history shows rich surface-ores, becoming rapidly leaner in depth. This is true not only of silver mines, but of gold-silver properties, near Marysville, Montana, in California at the Mojave mines, etc.

Where telluride ores occur, the only enrichment observed has been due to superficial alteration, as has been observed in the Judith mountains, Little Rocky mountains, the Dolcoath mine near Elkhorn, and the Mayflower mine, all in Montana.

The Effect of Physiographic and Climatic Changes.

Active degradation favors the accumulation of enrichments, while prolonged degradation of a region, resulting from physiographic revolutions, may result in successive migrations of material and the accumulation in a relatively shallow zone of the metals derived from many hundreds, and possibly thousands, of feet of the vein worn away in the degradation of the land. Climatic conditions, rainfall or aridity, warmth and rapid alteration of vein fracture are agents affecting surface-weathering, and hence, also, enrichment.

Active degradation of a region, that is, rapid weathering, favors enrichment by the quickness with which it removes the upper already leached part of the vein, so that a larger amount of vein matter is lixiviated in a given time than would result from slower wasting of the land. Such enrichments are favored by high altitudes. Moreover, the mountainous regions are those in which secondary fractures are most apt to be found.

Changes of Water-Level.

Prolonged degradation is favorable for a similar reason, since time is a factor in enrichment, and changes in elevation, etc., affect the rate and progress of decay of the vein; while the crustal movements accompanying physiographic changes favor fractures of the earlier deposit, which give facilities for leaching and spaces for deposition. If a region passes through several cycles of erosion and elevation, it is evident that their result is likely to be a succession of enrichments in which not only the original ore is leached, but the earlier enrichment-deposits migrate downward. At Butte, Montana, the region has passed through several very pronounced changes in elevation since the formation of the veins in tertiary time. In early Tertiary time the present topography was blocked out, and the mountain ranges and deep intervening valleys were carved. This was succeeded by earth-movements by which the streams became clogged or the valleys dammed, forming lakes; while volcanoes broke out at numerous places and showered ashes and scoria over the region. The valleys were silted up or in part filled by volcanic débris, before crustal movements drained the valleys and altered the divides. More recent movement, possibly still continuing, is marked by faults and a reversing of stream-courses. The old valley at Butte is filled by hundreds of feet of débris, and a mountain wall 2500 feet high marks a north and south fault-line. These changes all caused a migration of water-level facilitating the processes of weathering and enrichment, and the great bodies of rich copper-ores of the region are believed to be in part due to this cause.

Metasomatic Processes in Fissure-Veins.*

BY WALDEMAR LINDGREN, WASHINGTON, D. C.

(Washington Meeting, February, 1900.)

CONTENTS.

PART I.—GENERAL FEATURES.

PART II.—MINERALS DEVELOPED BY METASOMATIC PROCESSES IN FISSURE-VEINS.

PART III.—THE FISSURE-VEINS CLASSIFIED ACCORDING TO METASOMATIC PROCESSES.

---

* Presented by permission of the Director of the U. S. Geological Survey.

PART I.

General Features.

Purpose and Extent of Inquiry.

A study of the changes in rocks contiguous to ore-bearing fissures is essential to a thorough understanding of the genesis of such deposits. Nevertheless, comparatively little work has been done in this direction, though many mining geologists (for instance, v. Groddeck) long ago emphatically declared the necessity of such investigations. Ores and structure have been dealt with in detail; but the important changes which adjacent rocks of known composition have suffered are too often briefly dismissed, or even incorrectly indicated. It is the purpose of this review to collect the scattered data relating to the alteration of rocks near or between fissures; to indicate the principal active processes; to classify the veins, if possible, according to the different phases of alteration accompanying them; and, finally, to draw some conclusions from the facts thus grouped. This first attempt to systematize the metasomatic data of fissure-veins is by no means complete: only such parts of the American and foreign literature are represented as were deemed to be of vital importance. The discussion principally involves the changes which the country-rock has undergone, whether they have resulted in the formation of *ores* or not; and, in the second place, some space is devoted to such alterations as fissure-veins already formed sometimes suffer through certain secondary agencies. I have excluded, however, all references to weathering, or to the decomposition of vein-materials near the surface by waters containing free oxygen. It is often difficult to draw the line between normal fissure-veins and deposits not to be regarded as such, strictly speaking, but clearly due to the same genetic causes; and some of the latter class have been included in this discussion.

Definitions.

Fissure-Veins.—For the present discussion, a fissure-vein may be regarded as a mineral mass, tabular in form, as a whole, though frequently irregular in detail, occupying or accompanying a fracture or set of fractures in the enclosing rock; this mineral mass has been formed later than the country-rock and the fracture, either through the filling of open spaces along the latter, or through chemical alteration of the adjoining rock. Such alteration does not ordinarily extend far from the fissure. Only in regions where the vein-forming agencies have acted with unusual intensity, a partial alteration may extend over larger areas. These zones of alteration being genetically connected with the veins proper, must necessarily also be considered in this discussion.

Metamorphism.—This term, meaning strictly a change of form, was proposed by Lyell in 1831, and has since been employed in a wider sense, so as to cover any change in the composition or structure of a rock, through whatever agency, and whether with or without gain or loss of substance.

Metasomatism.—This name, meaning a "change of body," is given to that variety of metamorphism which involves a change in the chemical composition of rocks, by the addition or subtraction of substance.* The terms "replacement," "substitution," "alteration," etc., have been employed in discussions of metasomatism with different shades of meaning. A review of the classification of pseudomorphs, which form the origin of our knowledge of metasomatism, will throw light upon the nomenclature of the subject.

The occurrence of organic remains, consisting of material of which they were certainly not originally composed, called attention to the remarkable transformations now known as metasomatic replacements. As instances, we may recall corals changed into quartz, belemnites converted into barite, and shells of bivalves or gasteropods transformed into pyrite, chalcocite,

---

* Dana (*Man. of Geol.*, 4th ed., p. 314) proposes for the same process the term "metachemic;" but this has not found general acceptance.

sphalerite or specularite. To the same order of phenomena belongs the silicified wood, in which the organic substance has been removed and replaced with silica so delicately as to preserve in minute detail the original organic structure. This replacement is probably due to the precipitation of silica from solution by the acids generated in the decay of organic matter. More rarely, wood and plant-remains may be replaced by pyrite, chalcocite, galenite, cinnabar, barite, limonite, malachite, etc.

But it is the study of pseudomorphs, showing one mineral appearing in the crystal-form of another, that has led to a more detailed knowledge of the chemical laws which govern these remarkable changes. Here was conclusive proof that one mineral, definitely crystallized, had changed into another, sometimes totally different, substance. Naumann says of pseudomorphs:

> "Their importance cannot be overestimated, because they enable us to study successfully the laws of the processes which are constantly acting in the rocks and constantly changing them; for the pseudomorphs represent only one special case of the grand process of chemical alteration going on in the mineral kingdom: namely, that in which the form remained in spite of the change. From these we may draw conclusions as to the chemical processes going on in rocks which may change each grain to another mineral."*

Blum, who made the first extensive examination of pseudomorphs, divided them into: (1) those produced by partial change in the composition of the original mineral (one or more elements being removed, added or introduced by substitution); and (2) those produced by a complete replacement of the original mineral with another. (This class includes both those produced by chemical replacement and by previous solution and subsequent filling.)

Naumann, in his well-known text-book of Mineralogy, divided the pseudomorphs into: (1) hypostatic pseudomorphs, formed by the mechanical deposition of substance outwards or inwards from the limiting planes, and again subdivided into pseudomorphs by covering, and pseudomorphs by filling; (2) metasomatic pseudomorphs, formed by the alteration of the substance by means of its molecular replacement with another mineral while the form has been preserved. The metasomatic

---

* *Mineralogie*, Naumann-Zirkel, 10th ed., Leipzig, p. 112.

pseudomorphs are also designated as "alteration" (*Umwandlung*) pseudomorphs. This, it will be noted, is the first introduction of the word *metasomatic* in technical literature. In nearly all cases, the metasomatic pseudomorphs involve chemical action.

Naumann further divides the metasomatic pseudomorphs into three classes, in which, respectively, (*a*) the original and the secondary substance are identical in chemical constituents ("paramorphic" pseudomorphs); or (*b*) chemical alteration has left one or more elements of the original in the secondary substance; or (*c*) the replacement of constituents has been complete, as in the substitution of galenite for calcite, or pyrite for quartz, but the process has been, nevertheless, a chemical one, since the removal and deposition have proceeded simultaneously, molecule for molecule. The second of these classes is again subdivided, according as the change involved simply the loss of original components (as in the formation of argentite from pyrargyrite), or the addition of components (*e.g.*, anglesite from galenite), or the exchange of components (*e.g.*, sericite from oligoclase).

The conceptions of Blum were introduced into English technical literature by James D. Dana,* who divided pseudomorphs into those formed: (1) by infiltration (mechanical deposition in a mould already formed); (2) by incrustation (mechanical covering of crystals); (3) by replacement, one mineral gradually replacing another, and assuming at the same time its form, without any interchange of elements (the process being in a certain sense chemical, and wholly different from simple deposition); (4) by alteration, some of the elements being removed or exchanged, or new ones being added; and (5) by allomorphism, without chemical alteration; the body changing to one of the same composition but of different crystallographic system (the paramorphic pseudomorphs of Naumann).

Somewhat extreme views, differing from the above, were advanced by T. Sterry Hunt,† who classed pseudomorphs as: (1) those produced by chemical alteration, meaning by this a partial exchange of constituents (*e.g.*, limonite after siderite); and (2) those produced by substitution or replacement (these

---

* *American Journal of Science*, vol. 48, 1845, p. 81.

† *Systematic Mineralogy*, New York, 1892, p. 111.

terms being evidently regarded as equivalent). The latter he believed to be produced by deposition in spaces left by the removal of some other matter. The form of the original substance is assumed by the material which displaces, or is substituted for it, *e.g.*, quartz after calcite, barite, etc. While thus admitting partial alterations, Hunt makes a special case of a complete replacement, refusing to consider it as a chemical process, and regarding it always as an instance of separate dissolving and refilling. To the theory of metasomatism, which maintains that all the chemical elements in a crystal may be removed, and by molecular processes replaced with foreign substances, Sterry Hunt was strongly opposed.

Pseudomorphs of the second group proposed by him are, as is well known, of frequent occurrence, and correspond to Naumann's hypostatic division or pseudomorphs formed by mechanical deposition. Spaces of dissolution, subsequently filled, are also common enough in rocks, and may usually be readily identified as such under the microscope. But that molecular replacement, as defined by Naumann and Dana, also exists, and, moreover, is of the highest importance, seems at present beyond doubt.

As the essential process of metasomatism applies as well to an irregular grain as to a perfectly developed crystal, we are justified in extending the conception to aggregates of grains of one or several minerals; in other words, to rocks and mineral aggregates in general. In this sense C. R. Van Hise* has defined metasomatism as "the process of metamorphism by which original minerals are partly or wholly altered into other minerals, or are replaced by other minerals, or are recrystallized without chemical changes, or one or all of these together." S. F. Emmons has defined metasomatism as follows:†

> "By metasomatic exchange is meant an interchange of substance without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced, or even of its original volume."

A second definition, based on the consideration that practically simultaneous solution and deposition could certainly be proved

---

* "Principles of Pre-Cambrian Geology," 16*th Ann. Rept., U. S. Geol. Sur.*, part i., p. 689.

† *U. S. Geol. Surv.*, Monogr. XII., p. 565.

for many cases, where the exact proof of chemical-molecular replacement could not be furnished, is given by Mr. Emmons as follows:*

> "By metasomatic interchange I understand an interchange of substances, but not necessarily molecule by molecule, in such a manner as to preserve the original structure, form or volume of the substance replaced."

The fundamental difficulty is that the final result does not always indicate the particular pseudomorphic process which has preceded. Mechanical deposition, for instance, may follow so closely after dissolution, that the two processes really appear as one. It may also be said that molecular replacement is difficult to prove, as molecular processes cannot be followed with the microscope; and this is, in a sense, true. We may assert, however, that, with the highest magnifying powers, we are able to follow the transformation of quartz, for instance, into sericite, or into calcite, or into siderite, without finding the slightest indication of an intermediate stage of open space. The fiber and blades of sericite project into the quartz without the slightest break in the contact; the rhombohedrons of siderite develop in quartzite, their crystal faces cutting across the grains without any interstices. Perfect tourmaline prisms develop in feldspar grains, and sharp cubes of pyrite in primary granitic quartz.

In cases of complete molecular replacement, such as galena after calcite, the replacing mineral was probably present in the solution, partly dissociated or ionized. The solution of a certain quantity of the original mineral caused the separation of a corresponding quantity of the ions of the replacing substance, according to physico-chemical laws. If carried out on these lines, the process is necessarily molecular and chemical. Where there were two solutions—one dissolving, the other depositing—and where a certain time intervened, the process is a mechanical one and should not, I think, be considered metasomatic. In many cases the distinction may be very difficult to draw.

In conclusion, metasomatism might be defined as the process by which a mineral has suffered, through chemical processes, a partial or complete change in its chemical constitution. Rocks or aggregates of minerals are "metasomatic," if any or

---

* "The Genesis of Certain Ore-Deposits," *Trans.*, xv., 128, 1886.

all of the constituent minerals have undergone such changes. This definition excludes the process of paramorphism which, as already emphasized by Naumann, is exceedingly rare.

In the use of the term *alteration* it would perhaps be best to follow Dana and let it mean a partial change of substance in a mineral or rock. *Decomposition*, it would seem advisable to restrict to the cases in which a mineral or rock is dissolved into its component parts; and a principal use for it would be found in the processes of weathering.

As has been shown, the words *replacement* and *substitution* have been used in very different ways. The majority of recent authors use them both as equivalent to metasomatism. Dana, however, applies *replacement* to a complete exchange of substance, reserving *alteration* for a partial loss, gain or interchange of elements; while Sterry Hunt gives the name of *replacement* or *substitution* to mechanical dissolution and the filling of the resultant cavities.

The chemist has, however, a distinct definition of *substitution* as "the replacing of one or more elements or radicals in a compound by other elements or compounds;" and it would probably be best to adhere to this, and discard *substitution* as a synonym for metasomatism or alteration.

Replacement is, in its general meaning, nearly identical with *substitution*, although it has no such distinct chemical use. It would seem advisable to regard it as a synonym of metasomatism, distinguishing, for the sake of convenience, between partial and complete replacement. This is contrary to Dana's distinction; but the word has been used so generally during late years in this wider sense that it seems best to retain this meaning for it.

Impregnation.—This term has been applied in so many different ways—to primary disseminations; to minerals formed by replacement; and to the filling of cavities or interstitial spaces in rocks—that it might well be rejected altogether as a genetic term, and used only in a structural sense, as descriptive of finely divided material disseminated in a differing mineral or rock-mass.

Cementation.—This term, proposed by Prof. C. R. Van Hise,*

---

* "Pre-Cambrian Geology." 16*th Ann. Report U. S. G. S.*, part i., p. 684.

is convenient and expressive for the purpose of indicating filling of interstices in porous or shattered rocks. Cementation assumes importance in proportion to the porosity of the rock, which, in sandstones and tuffs, may reach 10 or 20 per cent. In most intrusive igneous rocks the porosity is so small as to be a negligible quantity.

Weathering.—Under this name are included the changes of rocks near the surface in cohesion and composition, due to the decomposing and oxidizing action of percolating waters above the permanent water-level. The tendency of weathering is to destroy the rock as a geological unit. The final results of metasomatic action are a few resistant minerals, such as quartz, kaolin and limonite. The formation of serpentine, chlorite, epidote and (ordinarily) pyrite is not weathering, but is due to more deeply seated causes. The German usage of *Verwitterung*, to cover all secondary changes, due to weathering, thermal and other causes, seems highly objectionable, and especially apt to lead to many misconceptions.

In view of the difference of usage as to many of the above definitions, it is to be hoped that writers upon this subject will take pains to indicate the sense in which the various terms are employed by them.

Metasomatism in Connection with Mineral Deposits, Especially Fissure-Veins.

It was not long before the principles of metasomatic action, learned by the study of pseudomorphs, were applied to larger masses of rocks. This led, perhaps inevitably, to exaggerated notions, such as that of the formation of true granites from sediments and limestone,* etc.; and this undue extension was followed by a reaction, exemplified in Sterry Hunt's writings.

The observation that ores may be found, not only in the clearly defined vein-filling, but also in the rock adjacent to the fissure, is contemporaneous with almost the earliest scientific records of mining. Sandberger† mentions the occurrence of masses of native silver, found in 1786 in the altered granite of certain Schwarzwald veins, which greatly astonished the old miners. Vogelgesang,‡ in Cotta's "Gangstudien," describes

---

[*] G. Bischof, *Chem. Geol.*, Bonn, 1866, vol. iii., p. 34.

[†] *Erzgänge*, part ii., p 418.

[‡] Vol. ii., Freiberg, 1854, p. 78.

the dissemination of argentite, native silver, and various sulphides, in the gneiss adjoining certain veins near Freiberg.

But whether or not it contains ore, the rock adjoining a vein is very commonly softened, bleached and altered for some distance away from the fissure. This phenomenon has been explained in two radically different ways:

1. Bischof says:*

> "As we find ores in veins, proportionate in quantity to the alteration of the country-rock, what other relation can be thought to exist between the two facts than that the abundance of the ore is a result of this alteration?"

Sandberger says:†

> "The extent of the alteration on both sides of the vein corresponds with the area from which the products of leaching have been carried to the vein."

2. The opponents of these views say that the narrow zone of alteration, intense next to the fissure and gradually fading away within a short distance from it, most clearly indicates an agency within the fissure, acting with gradually diminishing energy on the adjoining strip of rock. They also point out that Bischof's premise, *i.e.*, the coincidence of richness of vein and extent of the altered zone, is not true as a universal proposition. And they show, further, that as the whole altered zone has, in many cases, received an addition of the same metals as are contained in the vein which may more than counterbalance its losses of other constituents, Sandberger's conclusion can certainly not have a general application; and finally, that, in those veins which have no gangue, but in which the ore has accumulated in the rock during the alteration, the incorrectness of that conclusion is particularly apparent.

Veins carrying cassiterite early attracted attention, as being almost always accompanied by ore impregnating the surrounding country-rock. The metasomatic character of the process was first shown by Daubrée‡ and later by Cotta,§ both of whom, in support of their views, call attention to the well-known occurrence of cassiterite as a pseudomorph after feldspar. Both explain the alteration as due to gradual replace-

---

* *Chem. Geologie*, Bonn, 1866, vol. iii., p. 666.

† *Erzgänge*, vol. i., p. 149.

‡ *Ann. d. Mines*, 1841, xx., pp. 65, 72, 83.

§ *Die Lehre von den Erzlagerstätten*, Freiberg, 1859.

ment by the agency of thermal waters. This explanation was substantiated by more recent and detailed investigations; for instance, by Richard Pearce (1864) and LeNeve Foster (1877) in regard to Cornwall; and by A. W. Stelzner (1864) for Geyer, Saxony.

The views of Cotta concerning the alteration of the wall-rocks or veins are well expressed in the following paragraph:*

> "When lodes are accompanied by ore-impregnations, it is to be assumed that generally the solutions from which the materials of the lode were precipitated—they may have been aqueous, igneous-fluid, or gaseous—also penetrated the wall-rock and there caused certain deposits in fine clefts or in the rock itself. In the last case, crystals have made room for themselves by their power of crystallization; or an ore took the place of the mineral dissolved; for example, tin-ore, that of feldspar."

This quotation shows plainly the clear conception which Cotta had of the alteration of rocks, as due, not only to filling of pores and cracks, but also to processes of replacement active within the rocks.

Although Cotta made no special division of replacement-veins, he was well aware of their occurrence and perfectly able to distinguish them from filled spaces. Describing the gold-veins of Tauern (Austria),† he says that they have not the character of clearly opened and filled fractures, but consist of several parallel tight fissures, between which lies more or less impregnated and altered country-rock. The gold penetrates into the country-rock from the fissure, and the tenor decreases gradually with increasing distance.

In 1873 Posepny published his famous examinations of the Raibl deposits.‡ These are not connected with fissures, but deserve mention, since entirely similar processes are active in fissure-veins. Posepny found that carbonate of zinc had replaced carbonate of lime "by metamorphic processes."

Von Groddeck, in his well known text-book (1879), includes "metamorphic" deposits in his system, but limits them to replacements of limestone by zinc-, iron- and manganese-minerals. At about the same time, Stelzner, in his lectures, introduced a corresponding division of "metasomatic deposits,"

---

* *A Treatise on Ore-Deposits.* (Prime's Translation.) New York, 1870, p. 90.

† *Die Lehre von den Erzlagerstätten,* Freiberg, 1859, part ii., p. 318.

‡ *Jahrbuch d. k. k. Geol. Reichsanstalt,* xxiii., 1873, p. 317.

though they were still limited to a relatively small number of the irregular masses in limestone.

Raphael Pumpelly was, I believe, the first who applied the principles of metasomatism to ore-deposits in this country, in describing the copper-deposits of Michigan (in part fissure-veins) in vol. i. of the Geological Survey of Michigan (1873), and in his noted paper on the "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior."* The copper, to a great extent, replaces other minerals.

In 1879 J. A. Church published a volume on the Comstock mines,† in which he maintained the origin of the quartz by replacement acting from a number of narrow fissures.

In 1882 S. F. Emmons first published the results of his examinations of the Leadville silver-lead deposits, in which it was shown that these were entirely formed by metasomatic replacement of the limestone by galena and other minerals. A little later, J. S. Curtis published his first results in regard to the silver-lead deposits of Eureka, Nevada, in which he arrived at substantially the same results as Mr. Emmons. Though these deposits, as well as those of Leadville, are not to be regarded as fissure-veins, it was evident that the same process might be considered as active along fissures, provided the waters circulating in them had the composition attributed to those of Leadville and Eureka. The results obtained were certainly of the greatest interest to students of fissure-veins, and threw a new light on many obscure facts. During the following years, Mr. Emmons, who had visited a great number of mining regions in the West containing fissure-veins, published several papers,‡ in which he maintained that, for a great number of the veins formerly considered as containing ore deposited in open spaces, another and much more plausible explanation could be advanced, namely, that, in many cases, the fissures had not been opened to any noteworthy extent, but only so much as to admit the passage of the mineral-bearing waters. The latter had attacked the rock on either side of the fissure, and, by a process of metasomatic replacement, had deposited ores in the place of

---

* *Proc. Am. Acad. Arts and Sci.*, vol. xiii. (new series, vol. v.), 1878, pp. 253–309.

† The Comstock Lode. New York, 1879.

‡ "The Genesis of Certain Ore-Deposits," *Trans.*, xv., 125, 1886; "Structural Relations of Ore-Deposits," *Trans.*, xvi., 804, 1887.

the simultaneously dissolved rock-constituents. Applying this process to composite veins, consisting of a number of narrow fissures, and considering that gradual replacement had taken place, extending into the rock on each side of each smaller fissure, Mr. Emmons succeeded in showing how, under certain circumstances, a banded structure such as had ordinarily been attributed to the filling of open spaces could to some extent result from the process of replacement.

During the following years the theory of the formation of fissure-veins by replacement rapidly gained ground; and for some time it seemed as if the old view of deposition in open spaces were doomed to complete extinction. Carried away with the importance and interest of the metasomatic theory, many geologists and mining engineers extended its teachings beyond proper bounds, and were prone to speak of any fissure-vein as unquestionably a product of replacement. Attempts were made to show that open fissures could not exist unsupported, at any rate below the most superficial depths; and facts and proofs were too often neglected for bare assertions that metasomatic replacement had taken place. Posepny, in the discussion of his paper,* protested against this unwarranted extension of a most excellent and well-founded theory, and stated with some force that the experience and observations of a hundred years were not to be thrown away without very careful scrutiny. The pendulum had now swung to its extreme position; and it was not unnatural that a reaction should follow. It gradually became clear on the one hand that open spaces can and do exist down to a depth of many thousand feet,† and that these open cavities may be filled by the action of mineral-bearing water. On the other hand, it is evident that there is ample room for processes of replacement in fissure-veins, which may either affect the surrounding country-rock without producing notable amounts of ore, or, on the other hand, may attack it in such a way as to convert it wholly or partially into valuable minerals.

Some kind of metasomatic action is usually noticeable in the rock adjoining the fissure. But it is not to be denied that in many cases this alteration is very slight; and in a few veins it may be entirely absent.

---

* This volume, p. 239.

† Van Hise and Hoskins. In "Principles of Pre-Cambrian Geology," 16*th Ann. Rept. U. S. Geol. Surv.*, part i.

Calculation of Analyses.

In order to trace the metasomatic changes by which one mineral has resulted from another, it is necessary to know the composition of each, and the change in volume during the alteration. Without the latter the problem is capable of many solutions, any one of which may be possible, though not true. Only when some definite data, such as the constancy of one constituent, are available, can the changes be determined without reference to relative volumes. For instance, the percentage-composition and specific gravity of argentite and pyrargyrite are as follows:

	S Per cent.	Ag Per cent.	Sb Per cent.	Sp. Gr.
Argentite (Ag_2S), . . .	13.0	87.0		7.0
Pyrargyrite (Ag_3SbS_3), . .	18.0	60.0	22	5.8

Pyrargyrite may be altered into argentite; but analyses alone give no complete clue to the character of the alteration. Supposing, however, that we have found that 1000 cub. centim. of pyrargyrite becomes 570 of argentite; then we may calculate that about 9 kilos of sulphur and 22 of antimony have been removed from 100 kilos of pyrargyrite during the process, while the silver has remained constant. Supposing, again, that we have found pyrargyrite altered into argentite without change of volume; then from the original 100 kilos, 2.24 of sulphur and 22 of antimony have been lost, and 44.8 of silver added.

To exemplify further the many ways in which even simple metasomatic problems can be solved, we may take the well-known change of olivine to serpentine, consisting, as ordinarily considered, in a simple hydration of the original mineral. And, in order to simplify the matter still further, we may substitute for olivine the pure magnesium orthosilicate, occurring as a mineral under the name of forsterite, and assume the resulting serpentine to contain no iron. The formulas show that serpentine cannot be derived from olivine or forsterite by means of a simple addition of water. It may, however, be derived from enstatite (which is a magnesium metasilicate) and forsterite, as follows:

$$Mg_2\,SiO_4 + Mg\,SiO_3 + 2H_2O = H_4\,Mg_3\,Si_2\,O_9.$$

Translated into kilograms, this means that 50.8 kilos of forsterite + 36.2 of enstatite + 13 of water is equal to 100 kilos of serpentine. This again translated into volumes by aid of the specific gravities, means that 15.8 cb. cm. forsterite + 11.7 cb. cm. enstatite + 13 cb. cm. water is equal to 40 cb. cm. serpentine, or that 27.5 cb. cm. anhydrous silicates are needed to produce 40 cb.cm. serpentine. In other words, the increase of volume during the process of serpentinization amounts to nearly one-half;—the specific gravity of forsterite being 3.24, that of enstatite, 3.1; and that of serpentine, 2.5.

Serpentine may also be obtained by adding silica and water to forsterite. Thus, $3Mg_2SiO_4 + 4H_2O + SiO_2 = 2H_4Mg_3Si_2O_9$. Calculating in the same manner as above, we find that 131 cb. cm. of forsterite results in 221 of serpentine, which represents an increase in volume of somewhat more than two-thirds.

Still another way of derivation is by subtracting MgO and adding water, as shown by the following formula:

$$2Mg_2SiO_4 + 2H_2O = H_4Mg_3Si_2O_9 + MgO.$$

This again is equivalent to the formation of 110.4 cb. cm. of serpentine from 86.3 of forsterite, or an increase of volume of only a little more than one-fourth.

Many other formulas could be put forward, which would explain the formation of serpentine, each showing a difference in the relation of volume of the secondary mineral to that of the fresh. Even in this simple case it might be, in any given problem occurring in nature, extremely difficult to decide with confidence which particular formula should be applied. The problem only becomes definite when we positively know the relation of volume of original substance to that of secondary substance. It is perhaps superfluous to add that the mere knowledge of specific gravities does not give this relation of volumes.

When we have to consider metasomatic processes affecting rock-masses, aggregates of from two to six or more minerals, the complexity of the problem becomes immensely greater; for each of these constituent minerals may have suffered different metasomatic changes. Some may have remained unaltered, while others have been completely replaced; and others, again, may have lost, or gained, or exchanged one or more elements. To calculate the sum total of these changes is often an extremely puzzling task.

The mineral composition of the altered, as well as the fresh, rock may be accurately calculated by methods known to petrography, if its analysis, as well as those of the constituent minerals, be available. Even where the latter are only approximately known, a fairly accurate calculation may be made. Thus, for instance, from an analysis of an altered granite containing pyrite, calcite, magnesite, siderite, sericite and quartz, the percentages of these minerals may be obtained with fair accuracy.

The chemical changes suffered during any alteration of a rock may be considered by unit-weight of original substance or by unit-volume of the same. The results will be identical if both rocks are non-porous, or if both have the same porosity. If the actual additions and subtractions should happen to balance, then the percentage-analyses offer, by comparison, direct evidence as to the quantitative alteration. If, besides, during the alteration, the porosity of the two rocks remain the same, then the changes measured by unit-weight will be identical with those measured by unit-volume. This exact balancing of gains and losses, however, is, of course, exceedingly rare. If we do not know the relation of volumes between the two rocks, other ways must be sought for, at least, a partial solution of the problem. If we know that one or more new constituents have been added, we may subtract these, recalculate on 100, and then compare the analyses. This method in many cases leads to fairly correct results; but it must be applied with the understanding that, ordinarily, it will only give approximate results; and that, if there be many partial additions and subtractions, the inaccuracies may be very great, and actual losses and gains may appear reversed.

If we know that one constituent has remained constant, with neither gain nor loss (as the silver in the example cited above), then correct results may be obtained by recalculation on this assumption, as has been shown. This mode of calculation has been used by Scheerer, J. Roth, and lately also by Prof. G. P. Merrill, in his book on "Rocks and Rock-Weathering." It is only rarely, however, that we are able to recognize this constancy; for nearly all constituents undergo some change in the alterations of wall-rocks. Even alumina, often considered to be nearly insoluble, shows great changes in some altered rocks. Besides, if we base recalculation on some compound of which but a small percentage is present, the multiplication of errors may play havoc with the result. Altogether, this mode of ascertaining gains and losses must be applied with the greatest caution.

Any given analysis of fresh and altered rock may correspond to several very different mineral compositions. For any given mineral composition, the constancy of one constituent during the change to another (also known) mineral composition, determines the change in volume involved (not considering porosity). When the change in volume can be directly ascertained, we are definitely able to obtain the absolute gains and losses suffered by unit-volume of the rock; and this comparison is ordinarily the one which throws most light on the processes involved. But relations of volume are difficult to obtain with certainty, especially in regard to a rock made up of a number of minerals which have suffered different changes. As a rule, in fissure-veins, the replacing minerals are denser than those replaced; so that, if the rock remained compact, there would be a decrease in volume. But as there usually are no indications of compressive stress in the altered rock, the result of this replacement of lighter by heavier minerals will be a porosity expressed by a notable difference in the experimentally determined specific gravity of the rock and that calculated from its known mineralogical composition. This may, in some cases at least, justify the assumption that the rock has not changed its volume as a whole; and if this be true, a direct comparison between equal volumes of fresh and porous altered rock is practicable. Should it appear probable that an actual change of volume has taken place, either by expansion or contraction, it will ordinarily be a difficult matter in each case to ascertain the exact amount of this change, without which knowledge the calculations cannot be carried out. If there is porosity, the changes by unit-weight of original substance may differ greatly from those obtained by unit-volume; hence porosity is a factor which must not be overlooked. One method may indeed indicate the very opposite of the other. For instance, by the first way, it may be ascertained that a rock has gained several per cent. of its weight; while the other method may show that an actual loss per unit-volume of original rock has taken place.

In the considerations outlined above, it is assumed that the rocks to be compared have undergone no change of volume since their removal from the surrounding mass. In regard to the fresh rocks, there is, as a rule, little fear of this. Certain altered rocks, however, easily soften or crumble when exposed to the air, probably indicating that an increase in volume is taking place. An exceedingly slight action of this kind would evidently be sufficient to break up the rock if it were not confined. There is, therefore, little reason to fear that such change of volume has taken place, if the specimens of altered rock remain firm and solid.

Criteria of Metasomatism.

Considerable space was devoted to this subject in the discussion of Posepny's paper in the Transactions of the Institute,* and it may therefore be passed with brief notice.

It is not always easy to be sure whether metasomatic action really has taken place, and in deciding this question the greatest caution must be observed. The mere occurrence of two minerals together by no means proves that one has been derived from the other. The chief difficulty is to draw the distinction between molecular processes involving simultaneous dissolution and precipitation, on the one hand, and previous dissolution and subsequent precipitation on the other.

The only decisive criterion is that of metasomatic pseudomorphism, involving the proof (generally to be furnished by microscopic study) as to whether simultaneous dissolution and deposition have actually taken place. The most satisfactory proof is the distinct alteration of well-defined crystals (or, at least, well-defined grains) of the original mineral into the secondary mineral, in such a way that the latter projects into the former in prisms or fibers, having crystalline outlines. Another proof is afforded by sharply defined crystals of the secondary, embedded in the primary mineral, without any break between their surfaces; but in this case it must be clear that the replacing mineral is really secondary, and was not formed before the primary. Another satisfactory proof is given when, for instance, in a sandstone, the newly formed mineral has in part

---

* This volume, p. 188.

a crystalline form, and its surfaces squarely intersect the grains of clastic material which it partly replaces.

There are many other available criteria such as the enlargement of fissures in the replaced mass. An instance is shown in Fig. 30, representing a veinlet of quartz formed by filling a small open fissure, and adjoined on one side by galena, which extends most irregularly into the adjoining quartzite. (See also Fig. 28*.) The retention of the structure of the original mass by the secondary replacing minerals is also an excellent criterion, provided it be identified beyond doubt. Thus, for example, certain porphyritic rocks have suffered nearly complete silicification, but preserve almost entirely the outlines of phenocrysts and the structure of the ground-mass. The occurrence of remaining *nuclei* of unaltered rock is sometimes an available criterion; but it must be used with caution, and probably has given rise to misinterpretations, on account of its similarity to actual inclusions of country-rock in vein-filling. In cases of replacement by sulphides, the unaltered residual rock may be sharply defined, and may closely simulate inclusion. In cases of replacement by calcite or quartz, there is less of this danger, as the action is usually more gradual. If the alteration or replacement proceeds normally from the outside of a crystal or angular mass of rock, the tendency will be towards rounded residual portions in the interior of the mass, as may often be seen in altered crystals of olivine. This criterion for replacement, suggested by G. F. Becker, may under circumstances prove useful. Generally, however, the replacement proceeds very irregularly, owing to the effect of little cracks and fissures. Slight clay-seams may often interpose an absolute barrier, so that sharp contacts of replaced and fresh rocks result. The replacement of crystals or angular fragments may occur without changing in the least, even by the rounding of corners, the form of the masses.

In conclusion, I would repeat and adopt the statement of Mr. Becker,† that "the theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement."

---

* A somewhat similar and excellent illustration is given in Rickard's "Vein-Walls," *Trans.*, xxvi., 195, from the Hillside mine, Arizona.

† Discussion of Posepny's paper, this volume, p. 204.

In many fissure-veins, practically all of the economically important ore has been formed by replacement; and for these deposits the term *replacement-veins* is especially used. But if we do not confine ourselves to the fluctuating definition of "pay-ore," practically all fissure-veins are, to some extent at least, replacement-veins.

Mr. Emmons* has suggested the following criteria for "*replacement-veins*" in the narrower sense of the word: (1) absence of symmetrical banding or comb-structure in the vein-material, and of breccias of country-rock, cemented by vein-material; (2) great irregularity in the width of the ore-bodies, which may reach very great dimensions; (3) general lack of definition between ore-body and wall-rock.

Crystallization of Secondary Minerals in Other Bodies.

It has been known for a long time that perfect crystals of minerals, such as quartz, for instance, may be formed in soft rocks such as shale, limestone, clay, etc.; but concerning their exact mode of formation there has been considerable difference of opinion. Probably the prevailing view, some 20 years ago, was that the growing crystal had, by means of its force of crystallization, pushed apart the surrounding mass. This was indeed the opinion of von Groddeck, who declares† that the formation of a completely developed crystal in a solid, rigid mass is not possible. Apparent exceptions, such as magnetite in chloritic schists, he considers as caused by development, while the rock was soft, under the influence of metamorphic agencies. There is no doubt good foundation for this view; for in magmas and solutions crystals may grow to perfect development, and if, for instance, a saturated solution of ferrous sulphate is mixed with some neutral fine powder to a soft pulp, extremely clear and sharply developed crystals of this salt will separate out.

But it has gradually become apparent that it is not necessary to assume complete permeation and softening of a rock by concentrated solutions, in order to account for secondarily-developed crystals. It is now well known that the secondary development of crystals in solid material is not only a possible

---

* *U. S. Geol. Surv.*, Folio 38, on Butte, Montana.

† *Die Lehre von den Lagerstätten der Erze*, Leipzig, 1879, p. 68.

but an exceedingly common phenomenon, and that it may be caused by simple metasomatic replacement of the surrounding material.

The mechanical force of crystallization probably co-operates, to some extent, with the chemical agencies of replacement; and when the surrounding mass is thoroughly softened and saturated by the depositing solutions, the former force may be alone active. The growing crystal may include parts of the surrounding rock, as is seen in Figs. 3 and 4, representing calcite in quartz, and in Fig. 27, showing inclusions of sericite in pyrite. This is analogous to, but not identical with, the occurrence of inclusions of fluid and glass in crystals separating out from solutions or magmas. It is not uncommon to find new crystals of perfect development generated in a grain of another substance, such as quartz or feldspar, without any disturbance of the optical orientation of the older minerals, such as unfailingly would occur were the process simply one of mechanical force. No doubt the exchange of substance takes place through the medium of a film of water, but this is generally so exceedingly thin that the strongest powers of the microscope fail to reveal it. In many cases, however, the new mineral begins to grow on the planes of small fractures, traversing the original mineral. Fluid inclusions accumulate on this plane; and the first separation of the new mineral appears as little dots, closely connected with the inclusions. No doubt the line between metasomatism and cavities of dissolution subsequently filled is a very fine one, and difficult to draw in many cases; but when intermediate cavities or subsequent fillings cannot be traced with the microscope, the process may be classed as metasomatic; and in the great majority of cases this interpretation will be correct.

Secondary Alteration of Veins.

Under any given conditions, minerals tend to assume the forms most stable under those conditions. Since the conditions prevailing during vein-formation are very different from those prevailing afterwards, it may be inferred that the products of the first process might easily be changed. Such is indeed the case. We find many altered rocks which have evidently undergone more than one change. Especially near the surface, under the influence of oxidizing waters, the minerals formed in the rocks along veins are apt to suffer great changes. Examples are frequent, showing that the minerals which filled the open spaces along a vein have been completely dissolved and partly or wholly replaced by others. This is particularly true of fillings of calcite or barite. Many instances are known in which large masses of these minerals have been completely dissolved and replaced by quartz. Such are the well-known deposits of Schneeberg in Saxony, and those of the De Lamar mine in Owyhee county, Idaho.

Structure and Composition of Metasomatic Vein-Rocks and their Relation to General Metamorphism.

The aggregates replacing the original wall-rocks of veins show great variety of structure. It is most common, perhaps, that the structure of the resulting rock is much finer than that of the primary. As examples may be cited silicification, which nearly always results in microcrystalline and cryptocrystalline aggregates, and sericitization, which generally results in a mass of very fine tufted fibers. This is not, however, a general rule; because certain easily soluble minerals, when replacing others, produce a much coarser aggregate than that of the original rock. Of such character, for instance, are the carbonates. (See Fig. 27.) Fluorite replacing limestone (see Fig. 14) is another instance of coarser grain shown by the secondary rock.

As a general rule, the resulting minerals have, on the whole, a greater aggregate specific gravity than the original minerals. Muscovite, sericite, fluorite, the different carbonates, pyrite and other sulphides (as well as topaz and tourmaline, so abundantly formed in tin-deposits) are instances. On the other hand, there are exceptions, such as the development of jasperoids and other quartzose rocks from limestone, in which case the resulting material has less specific gravity than the original.

A banded structure of the altered rock may possibly, as mentioned above (p. 504 590), result from replacement by sulphides in a sheared rock, in which the shear-planes are closely spaced; but this banding is not likely to be as well marked as the crustification often caused by the gradual filling of open spaces. From these two sorts of banding a third must be differentiated, namely, the typical "ribbon-structure" caused by shearing of the already-formed vein, in connection with which a secondary concentration of gold and sulphides may have taken place on the shear-planes—whence the richness of vein-material often associated with this structure.

In no case, thus far, has any law of progressive alteration of the country-rock of a vein been detected, which would enable us to say that the intensity of the process either increases or decreases from the surface down. Nor has any instance been shown in which the processes of alteration permanently change with increasing depth. This does not exclude the fact that occasionally a different subordinate process of alteration may be introduced. It is known, for instance, that certain parts of the rock near the vein may be locally silicified, although the principal and prevailing process in depth, as well as near the surface, is of a totally different character. Thus, silicification and the formation of greisen may occur side by side in cassiterite veins, and silicification and carbonatization in cinnabar veins.

The metasomatic processes in wall-rocks of fissure-veins differ generally from those of regional (static and dynamic) metamorphism. In most cases oxides of iron and manganese such as magnetite, hematite, ilmenite and pyrolusite, are absent as a primary development; and many silicates, exceedingly common in static and dynamic metamorphism are, as a rule, missing in veins. Among these are amphibole, biotite, garnet, cordierite, serpentine, ottrelite, and zoisite. Chlorite and epidote are confined to the vicinity of only one or two classes of veins. Albite, exceedingly common in regional metamorphism, is not known as a metasomatic development in veins, though, like orthoclase, it may occur in the filling of open cavities. Muscovite, calcite, quartz and pyrite are common to both kinds of metamorphism. As compared with the products of contact-metamorphism, we note in metasomatic vein-phenomena a total absence of the pyroxenes, wollastonite, staurolite, cyanite, andalusite, vesuvianite and garnet. Only two classes of veins are characterized by tourmaline, which is a frequently occurring contact-mineral. Again, as compared with the results of ordinary hydro-metamorphism, we note in the results of metasomatic vein-action the scarcity of amphibole as well as of zeolites, except in one or two classes of veins, and also the relatively slight importance of chlorite and epidote.

The degree of hydration in altered vein-rocks is very moderate; and in some cases, as, for instance, in the change of serpentine to magnesite, there is a distinct dehydration. Strongly hydrous minerals are not common on fissure-veins.

I have emphasized these differences, to show that the metasomatic processes in veins cannot simply be identified with those that were active in the other phases of metasomatism mentioned. In the majority of cases, the vein-processes have a distinctive character of their own.

PART II.

MINERALS DEVELOPED BY METASOMATIC PROCESSES IN FISSURE-VEINS.

Quartz (including Chalcedonite and Opal).—Though silicic acid is weak, and cannot under ordinary circumstances expel even carbonic acid from its compounds, it is easily deposited instead of other minerals, which are dissolved by more active reagents contained in the same waters. Hence the frequency of quartz in the forms of other minerals. It would be erroneous to say, however, that silicification is a very common metasomatic process, even in veins containing quartz as a filling; and very rarely is it the exclusive process in any given vein. It is most common in limestone and other easily soluble rocks; also in such porous rocks as sandstones, though here it is usually to be regarded rather as cementation. In rocks rich in silica, such as rhyolite or quartzite, the tendency to silicification (probably by reason of mass-action) is greater than in more basic rocks in the same district.

Quartz replacing limestone along fissures is a common occurrence. The process usually results in a microcrystalline or cryptocrystalline aggregate of interlocking grains, preserving the original structure, as shown in Fig. 1,* which represents a silicified limestone from the Diadem lode, Plumas county, Cal., and shows the remaining outline of a foraminiferal test. The development of the quartz is shown in Figs. 3 and 4,† represent-

---

* After H. W. Turner, *Journal of Geology*, vol. vii., No. 4.

† The accompanying figures, with some exceptions noted in the list, were drawn by myself under the microscope, with camera lucida.

ing rocks from Aspen, Colorado.* Small secondary grains or well-developed crystals appear in the limestones and, gradually extending, finally produce an aggregate which, in this case, is somewhat coarser than in the rock from California. Quartz crystals with double terminals may occur in metasomatic rocks, but are foreign to quartz, filling open cavities. Opal and chalcedonite may occasionally also be present. The resulting fine-grained rocks, often stained brown or red, may, according to Mr. Spurr's proposal, be called jasperoids.

Daubrée describes heavy quartz veins, cutting through granite and overlying sedimentary rocks, in the Central Plateau of France.† Besides quartz, these veins carry fluorite, barite, calcite and galena. Agate and jasper in banded form are also frequently present. From the same description,‡ it appears that in some places, where these veins traverse limestone (*Muschelkalk*), there has been a very strong silicification of the enclosing rock, as is proved by means of the occurrence of crinoids in the compact quartz now forming part of the lode. Another locality, also in the Vosges, is mentioned as showing a large deposit of fine-grained hornstone-like quartz, also containing barite and fluor-spar, and full of little geodes with projecting crystals of quartz. In this siliceous rock, silicified shells of *avicula* and *pecten* have been found, showing its derivation from the surrounding limestone. The chemistry of the process is apparently simple: waters containing carbon dioxide and silica deposit the latter, while simultaneously dissolving a corresponding proportion of calcite.

In contrast to the fine-grained structure of jasperoids, quartz deposited in open spaces is usually characterized by coarse grains, the majority of which show partly developed crystal-faces. Crystals developed at both terminals do not appear, though earlier-developed individuals, growing from some deposit, are surrounded by later-developed grains. Fig. 2, which shows the normal structure of the quartz in the California gold-veins, illustrates this occurrence.

---

* The thin sections from which these figures were made were kindly loaned to me by Mr. J. E. Spurr.

† Daubrée, *Les Eaux Souterraines aux Époques Anciennes*, p. 124.

‡ *Loc. cit.*, p. 151.

Quartz may further replace orthoclase, as shown in Fig. 5, with preservation of the crystal-form. The ordinary course of alteration of the latter mineral is to quartz, sericite, or kaolinite, and potassic carbonate. In complete replacement by quartz, the alumina and potassa have been carried away, and the quartz has received a considerable addition. The process may also be explained as a complete replacement, by means of which the orthoclase, as such, has been removed, and quartz has been deposited. In the same manner, soda-lime feldspars may be replaced by quartz, as well in phenocrysts as in the ground-mass. Even the ferromagnesian silicates may suffer a similar change. A partial replacement of hornblende by quartz and chlorite (Fig. 6) is common. The ground-mass surrounding crystals of quartz in certain rhyolites (Silver City and De Lamar, Idaho) may be replaced by quartz, forming a secondary aureole around the primary crystal.

Under favorable and very exceptional circumstances, veinlets containing coarser quartz, simulating comb-quartz in structure, may be formed by replacement. Fig. 7 represents a contact between chloritic basalt and silicified rhyolite, on which a small quartz vein is developing, the crystals replacing the ground-mass of the silicified rhyolite.* Replacement of minerals by chalcedonite and opal instead of by quartz is less common. Near cinnabar veins, in California and elsewhere, serpentine, transformed into opal, with retention of the primary structure, has been observed.

Rutile and Anatase.—These minerals are common in metasomatic vein-rocks, as secondary products after ilmenite, titanite, titaniferous magnetite, biotite, etc. Rutile occurs in nearly every altered titaniferous rock; anatase (octahedrite) has been found in the altered rocks of Freiberg (Stelzner), Nagyag (Kollbeck), Schwarzwald (Sandberger), and Silver Cliff (Cross). Neither titanite nor ilmenite appear to be stable under the influence of vein-forming solutions. In several publications† I have assumed that the milky white flocculent mass (leucoxene) which often results in vein-rocks from the alteration of titaniferous minerals is titanite; but this assumption now appears to

---

* 20*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 186.

† 14*th Ann. Rept. U. S. Geol. Surv.*, part ii., p. 276, *et seq.* 17*th Ann. Rept. U. S. Geol. Surv.*, part ii., p. 149, *et seq.*

be incorrect. The substance is certainly free titanic acid, as shown by the fact that no titanium is extracted by hydrochloric acid, while the mineral is attacked by boiling sulphuric acid.

Fluorite.—This mineral may replace many others. It has generally a purplish, unevenly distributed color, and shows under all circumstances a strong tendency to crystal-development. Its formation from limestone is illustrated in Fig. 14, which represents the contact of one of the many small nodules of fluorite scattered in a limestone breccia from a mine in the Judith mountains, in Montana.* The sharp angles of the cube will be seen projecting into the limestone; the latter contains many imperfect fossil shells, and some crystals of secondary quartz.

While the reaction involved in this process is not clearly established, it is probably a complete replacement, the more soluble calcite being taken up by the waters and the less soluble fluorite simultaneously deposited.

Fluorite, together with quartz and pyrite, is further formed as a replacement-product of orthoclase, as shown in Fig. 10, representing a feldspar grain from a breccia in the Independence mine, Cripple Creek, Colo. The replacement of some of the phonolite and fine-grained granite-andesite breccia from Cripple Creek has resulted in a large quantity of crystalline fluorite and quartz (Fig. 9). Wherever calcium silicates are present, and the waters contain sodic fluoride, the result will be sodic silicate and calcic fluoride. In this way the mineral may be formed by interchange of constituents.† Alkaline fluorides and calcic fluorides may exist together in the same solution; but alkaline carbonates decompose fluorite, yielding alkaline fluorides and calcic carbonate; hence fluorite cannot exist as such in waters containing alkaline carbonates.

Calcite.—This mineral and the allied magnesian and ferrous carbonates are exceedingly common in metasomatic vein-rocks, and their occurrence gives testimony of the energetic altering action of carbon dioxide and alkaline carbonates on nearly all silicates. The metasomatic calcite is of fine or coarse grain—the latter especially when replacing easily soluble minerals. It

---

* This section was prepared for Mr. W. H. Weed, who kindly allowed me to use it.

† Bischof, *Chem. Geol.*, Bonn, 1864, ii., p. 95.

has very little tendency to crystallize, nearly always occurring in irregular grains.

Calcite replaces quartz to a greater or less extent, though in rocks containing also silicates like feldspars and hornblende, these minerals are first attacked, and the replacement of the quartz is usually only partial. The quartz is evidently dissolved by waters containing alkaline carbonates, and a corresponding quantity of calcic carbonate, also dissolved in the water, is deposited in its place. Under ordinary pressure and temperature, water does not dissolve quartz; but increase of either results in solution to some extent. The presence of carbon dioxide alone does not promote the solubility. No pseudomorphs of calcite after quartz are known—an evidence of the resistance of the latter mineral to solution.

The replacement of quartz by calcite in granitic rocks is shown in Figs. 13 and 15. The calcite, developed along cracks and fissures, spreads and corrodes the original substance. Small masses of sometimes rhombohedral calcite project into the quartz. Rounded and isolated bodies of calcite may also form on inclined fracture-planes; by extension they finally join and form larger masses.

Orthoclase is likewise replaced by calcite in many granitic rocks adjoining veins. The process is similar to the replacement of quartz; but the feldspars are much more easily soluble than quartz. Chemically, the process, as already pointed out by Bischof,* may be considered as simply due to the attack of waters containing calcic bicarbonate. The carbon dioxide of the latter alters the orthoclase; the resulting alkaline carbonates and silica are carried away; just in what form the alumina is removed is not certain. In the majority of cases a simultaneous formation of sericite occurs; so that the actual loss of Al_2O_3 may be very small. Even more easily effected is the replacement of soda-lime feldspars by calcite; for here the original mineral contains one of the constituents of the result. As is well known, andesine, labradorite and anorthite may be partly converted into calcite under the influence of ordinary cold waters containing carbon dioxide.

In the same manner, it is common to find pyroxene, amphi-

---

* *Chem. Geol.,* ii., p. 428.

bole and biotite partly converted into calcite. In vein-forming processes, these are usually the first minerals to suffer from the attack. The magnesia, alumina and ferrous oxide usually remain in the form of chlorite or other secondary silicates, though some of the magnesia and iron may also form carbonates.

Magnesite and Dolomite.—Small quantities of magnesian and ferrous carbonates nearly always combine with the newly formed calcite, but in many cases are of no special importance.

A change of limestone to magnesite is not known as a vein-forming process. Dolomitization commonly occurs, however, in limestones adjoining fissure-veins, as, for instance, described by Spurr* at Aspen, Colorado. At this place, as the dolomitization proceeds irregularly from the fissures, the coarse calcite grains are broken up into smaller rhombohedral crystals, of the yellowish tinge characteristic of dolomite. The process is clearly one of metasomatic replacement, carried on by waters containing magnesic bicarbonate, or even chloride. The correctness of this view has been shown by synthetical experiments.†

Mr. Spurr shows convincingly that ordinary circulating surface-waters do not dolomitize the limestone which they traverse. The reagents which produced this dolomitization must have been more potent. Several hot springs in the vicinity of Aspen, Colorado, carry carbonates of lime and magnesia, and also a large amount of sodium chloride and magnesium chloride. These waters, as shown by analyses, have a distinct dolomitizing influence on the adjoining limestone. The change is also accompanied by silicification and ferration.

Dolomitic carbonates may also partly replace albite, as shown by Mr. H. W. Turner‡ in the case of a mineralized dike of albite rock from Tuolumne county, Cal. An accompanying almost pure magnesite may possibly have resulted from the alteration of the adjoining serpentine.

Magnesite and dolomitic carbonates are very apt to form from serpentine, as illustrated in the country-rock adjoining the Idaho vein, Grass Valley, Cal.§ The fine-grained serpentine is trans-

---

* Monograph XXXI., *U. S. Geol. Surv.*, p. 210.

† Doelter, *Allgemeine Chemische Geologie,* Leipzig, 1900, p. 158.

‡ *Journal of Geology*, vol. vii., No. 4, p. 393.

§ W. Lindgren, 17*th Ann. Rept. U. S. Geol. Surv.*, part ii., p. 153.

formed into a coarse-grained magnesite, mixed with quartz and some residual serpentine (Fig. 26). The composition of the altered rock is

	Per cent.
Magnesic carbonate,	34.78
Calcic carbonate,	8.22
Quartz,	26.00
Serpentine (with chlorite),	31.00
	100.00

The chemical action involves a substitution of CO_2 for SiO_2; the latter being deposited in the rock.

Siderite.—This mineral is less common in altered rocks than the other carbonates. At Aspen, Colorado, Spurr mentions it as forming small rhombohedrons in silicified limestone. In the lead-silver veins of Wood River, Idaho, it replaces calcareous shales. In the lead-silver veins of Cœur d'Alene, Idaho, it replaces the clastic quartz of quartzite in the most energetic manner and abundant quantity (Figs. 16 and 17). The siderite has strong tendency to crystal development; and the rhombohedral crystals often cut squarely across the quartz grains which they partly replace (Fig. 18). To explain the chemistry of this process, we must suppose waters exceedingly rich in alkaline and ferrous carbonates and poor in silica. SiO_2 must be dissolved and $FeCO_3$ simultaneously deposited.

Muscovite and Sericite.—These two names practically signify the same mineral, though sericite is employed for the fine-grained or fibrous and tufted modifications, resulting from the replacement of other minerals. Sericite is probably the most universal and abundant of all minerals forming in altered rocks near fissures. Only a few classes of ore-deposits, namely, those in limestone and those in recent volcanic rocks, involving propylitic alteration, are comparatively free from it. A vast proportion of so-called "talc," "clay" and "kaolin" is really sericite.

Sericite forms from quartz in many rocks, though this action is less intense than in the case of the silicates. Foils and fibers of the secondary mineral may develop along cracks, or may intrude, sharply defined, into the quartz, from the outside of the grain. Complete pseudomorphs after quartz are rare. A complex chemical action is probably involved, as sericite is practically insoluble. A transportation of potash and alumina must be assumed, though in what form the latter oxide was in solution is not clear. The dissolved quartz may be directly combined with these two constituents. It is often observed that the replacement of the quartz is most active when, together with the sericite, calcite is formed (Fig. 15).

As is well known, sericite forms easily and abundantly from orthoclase and microcline, the foils and fibers developing on cleavage-planes and cracks, until they invade the whole crystal. The reaction may be chemically expressed as follows, water containing carbon dioxide being the only reagent necessary:

$$3K\,Al\,Si_3\,O_8 + H_2O + CO_2 = KH_2\,Al_3\,(SiO_4)^3 + K_2CO_3 + 6SiO_2.$$

This reaction is accompanied by a considerable reduction of volume, the sericite occupying less than one-half of the original volume of the orthoclase. If SiO_2 separates as quartz, the aggregate volume of the two secondary minerals shows a reduction of 13 per cent. from the volume of the orthoclase. Very often, however, the quartz is carried away in solution, to be deposited in neighboring open spaces. Calcite is frequently deposited together with sericite in the feldspar (Fig. 12). Though it is usually fine-grained, large foils may sometimes be formed. Fig. 19 shows radial muscovite forming, together with kaolinite from orthoclase, in the orthoclase of granite adjoining a fissure, in which thermal waters at the present time are depositing a vein.*

Sericite forms with equal ease from oligoclase, andesine and labradorite, as from orthoclase, and calcite usually also accompanies it. This interesting fact was first described, I believe, by Bischof,† who also furnished the chemical explanation. The potassic carbonate contained in the water changes the sodic silicate into potassic silicate, which unites with the aluminum silicate to sericite. This will result in a progressive elimination of soda and introduction of potash. In the same manner potassic carbonate decomposes calcic silicate, replacing lime with potash. Bischof gives an excellent illustration of this by describing the surface alteration of a knife of the "stone age," originally made from some flinty rock.

---

* Kindly furnished by Mr. W. H. Weed.

† Bischof, *Chem. Geol.*, i., p. 31, *et seq.*; also p. 44.

Even pyroxene and amphibole may alter to sericite, as is frequently shown in the metasomatic vein-rocks of California gold-quartz veins. The explanation is on the lines of the reactions just described. The resulting sericite is often coarsely fibrous.

Biotite alters very easily to coarse muscovite, with loss of magnesia and iron, and separation of rutile (Fig. 27).

An instance of replacement of andalusite by muscovite is shown in Fig. 20. Few analyses are available, indicating the exact composition of the sericite contained in metasomatic vein-rocks; but the satisfactory results obtained from the calculation of many rock-analyses on the basis of molecular ratio, closely corresponding to the composition given below, leave little room for doubt that the sericite is practically identical in composition with a normal muscovite.

Prof. Beck, of Freiberg, has had the kindness to give me an unpublished analysis, made by Dr. H. Schulze, of a white mica, separated by Prof. Stelzner by heavy solutions from the altered country-rock adjoining the Dietrich Stehenden, Morgenstern Erbstolln, Himmelfahrt mine, Freiberg. This analysis is as follows:

	Per cent.
SiO_2,	47.48
TiO_2,	trace
SnO_2,	0.02
Al_2O_3,	35.16
Fe_2O_3,	1.92
CaO,	0.48
MgO,	1.11
K_2O,	10.08
Na_2O,	0.41
H_2O,	4.02
	100.68

As minerals most closely related to muscovite, we may mention zinnwaldite, containing much fluor and lithia, which replaces feldspar in granite near cassiterite-veins; also mariposite (fuchsite), containing chromium, which, with magnesite, apparently replaces serpentine and allied rocks at Nevada City, and on a much larger scale at many places along the Mother Lode of California.

Biotite.—Exceedingly common in the form of metamorphism, biotite appears but rarely in fissure-veins. Replacing hornblende and feldspars, it is found as small scales in veins carrying tourmaline (Meadow Lake, Cal.); replacing the same minerals, it appears abundantly in the gold-copper veins of Rossland, B. C. A greenish mica, probably biotite, occurs, replacing quartz, in small veinlets, associated with quartz, garnet, tourmaline, actinolite and zinc-blende, in the Bunker Hill and Sullivan mine, Idaho. Prof. Penrose reports secondary biotite forming in the Ocean Wave mine, Cripple Creek, Col. Under the influence of waters containing carbon dioxide or alkaline carbonates, biotite is not stable.

Chlorite.—This mineral, replacing amphibole, pyroxene and biotite, is commonly found in altered vein-rocks, but ordinarily it is only a transition-form, often abnormally rich in iron, which these minerals assume, under the influence of waters slightly charged with carbon-dioxide, before their final conversion into sericite and carbonates. The chlorite has the ordinary fine fibrous character and shows a strong tendency to migrate into adjoining minerals. In the case of biotite, the conversion should normally result in chlorite, ferrous carbonate, potassic carbonate and silica; in that of amphibole or pyroxene, calcic carbonate may form beside chlorite. Pseudomorphs of chlorite and quartz after hornblende are, in fact, very common (Fig. 6). The chloritic alteration is most important in the group of the propylitic veins. Possibly, under the influence of strong alkaline carbonates and carbon dioxide, chlorite cannot exist. G. F. Becker mentions chlorite as enclosed in vein-quartz from some localities in the Southern Appalachians, and also in gold-quartz veins from Funter's Bay and Admiralty Island, Alaska. I have described a similar occurrence in an abnormal vein, from Crown Point mine, Grass Valley, Cal. But, on the whole, it is not a common mineral in vein-fillings.

Pyroxene and Amphibole.—These minerals are, as a rule, foreign to fissure-veins, and entirely absent from gold- and silver-veins characterized by sericitic alteration. Amphibole has been noted in the filling of certain copper-veins. Some of these are more or less intimately connected with contact-metamorphism; others, like the copper-veins of Rossland, B. C., have probably been formed under dynamic-metamorphic conditions. It occurs also in small veinlets of abnormal character, containing garnets, in the Bunker Hill and Sullivan lead-silver mine, Idaho. Rhodonite, a bisilicate of manganese allied to pyroxene, does, however, occur in many veins as part of the filling (Butte, Montana; Real del Monte, Mexico; Kapnik, Hungary; Broken Hill, Australia).

Garnet.—This mineral is very rare in fissure-veins, though common in dynamic and contact-metamorphism. Mr. S. F. Emmons* states that it replaces limestone at Clifton, Arizona, apparently as a part of the phenomena of mineralization. As part of the filling of gold-quartz veins, it is reported by G. F. Becker† from several localities in the Southern Appalachians. The remarkable occurrences of Broken Hill, N. S. W., should be mentioned here. From the extensive literature‡ it is apparent that opinions differ somewhat widely with regard to these interesting deposits.

The deposits of the Barrier ranges near Broken Hill are probably fissure-veins, occurring in crystalline schists of various kinds, perhaps chiefly a garnet-gneiss. Broken Hill Proprietary lies parallel to the schistosity, and may, according to some, be considered as a saddle-reef. Other veins, such as the Broken Hill Consols, cut the schistosity in strike and dip. The ores are galena, zinc-blende and rich silver-ores. The gangue in the Proprietary mine is chiefly garnet, with quartz, opal and rhodonite. In the Consols and other veins, siderite and calcite also appear, besides quartz and garnet. If veins, as seems most probable, they represent a decidedly novel type. The sulphides, to some extent, replace other minerals. (See under *Galena*, below.)

Epidote.—This mineral, so common in regions of static and dynamic metamorphism, is not abundant in the altered rocks of fissure-veins, or in the filling of open spaces. When it occurs, it has a deep yellow color, contains much iron and develops in irregular grains, or into radial bunches of imperfect crystals. It occurs chiefly in basic rocks containing labradorite and similar soda-lime feldspars, and may form pseudomorphs after orthoclase, plagioclase, hornblende or augite. In altered vein-rocks, epidote and muscovite rarely occur together. Epidote contains much ferric oxide, and can hardly be formed

---

* Unpublished observations.

† *16th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 276.

‡ J. B. Jaquet, *Mem.* 5, *Geol. Surv. of N. S. Wales*, Sydney, 1894; George Smith, *Trans.*, xxvi., 69, 1896; R. Beck, *Zeitschr. f. prakt. Geol.*, March, 1899, etc.

under strong reducing influences. It does, however, not follow that it must have been formed under oxidizing conditions; for rocks ordinarily contain much ferric oxide, and pyrite has often been observed embedded in epidote. Epidote is found in the veins of Lake Superior which carry native copper; in some veins characterized by tourmaline (Fig. 21); and, finally, in the metasomatic rocks accompanying the propylitic Tertiary gold-silver veins.

Orthoclase.—As a product of thermal alteration, orthoclase does not commonly appear, and has not been recognized until lately. Closer search will probably reveal it in many altered rocks and vein-fillings of the propylitic type. When forming, it has always a strong tendency to crystallize, and in thin sections usually appears with rhombic, sharply defined outlines. The crystal form is similar to that of adular, though the basal plane is small or entirely wanting; the prisms and dome being the only prominent faces. For this variety, occurring in fissure-veins, the revival of the name of valencianite is suggested, proposed by Breithaupt for the mineral as occurring in the Valenciana silver-mine, Guanajuato, Mex. In certain propylitic gold-silver veins (Silver City, Idaho; La Valenciana, Mex.) valencianite is prominent as part of the filling of open spaces. In the copper-bearing veins of Lake Superior, orthoclase replaces prehnite, and is deposited on datolite, calcite, analcite and quartz. In connection with the occurrence of adular at St. Gothard, this mineral is found on calcite. At Bergen Hill, N. J., the Mesozoic diabases are traversed by veins (1 to 4 inches thick) of quartz and orthoclase, associated with various zeolites, galena, chalcopyrite and pyrite. At Cripple Creek, Colo., orthoclase is an important vein-mineral, occurring partly as a coating of cavities of dissolution in granite (Fig. 11), partly in metasomatic development after many minerals in granite-andesite breccia and phonolite. Orthoclase and calcite have apparently been formed together in certain metasomatic rocks from Cripple Creek, Colo.

Orthoclase has been reproduced artificially by the action of potassic silicate on muscovite at 500° C., but it is evident from many occurrences that a much lower temperature is sufficient for its formation in fissure-veins. In the Silver City, Idaho, veins, for instance, the temperature cannot have been much higher than 100° C. during the deposition of the mineral.

Albite.—Though known as a vein-filling, together with quartz, at many places, for instance, in many California gold-quartz veins, this mineral has not been observed hitherto replacing other substances. In metasomatic rocks resulting from other metamorphic processes it is, as is well known, very abundant.

Tourmaline.—This very complex silicate of aluminum, magnesium, ferric iron and sodium contains also about 10 per cent. of boric acid, as well as a little combined water and fluorine. In metasomatic development, it forms irregularly massed crystals, or single crystals impregnating the mother-mineral. Its tendency to crystallization is very strongly marked. It replaces orthoclase and plagioclase, as well as quartz, but is not known to be formed from ferromagnesian minerals. As shown in Fig. 21, small almost perfect crystals may develop in the feldspathic substance, without disturbing its optical orientations. Similar development in quartz is illustrated in Fig. 23. In fine-grained clastic rocks like slate, tourmaline may also form. The only occurring variety is black, usually showing dark brown and dirty bluish or greenish colors in thin section. Tourmaline often occurs in large masses of small felted individuals, together with quartz, entirely replacing the original rock.

The mineral is confined to cassiterite-veins and to the allied group of the gold-copper-tourmaline veins. It is not usually associated with carbonates; and the occurrence of siderite with tourmaline, described by von Fircks from Tasmania,* is therefore of special interest.

Topaz.—This fluosilicate of aluminum, containing besides, according to the latest investigations, some chemically combined water, is confined to the cassiterite-veins. It usually appears abundantly in the altered rock next to these veins, replacing the feldspar and even the quartz,† as well as the groundmass of porphyritic rocks. The new-formed topaz may appear in irregular grains, but is often partly crystallized, and then appears in radial masses. The formation of topaz from orthoclase is analogous to kaolinization, silica and potassa being set free. But fluorine is also introduced, which points to another agent than carbon dioxide as active in this reaction. It has been artificially reproduced by the action of hydro-

---

* *Zeitsch. d. d. geol. Ges.*, Bd. li., p. 443, 1899.

† *Loc. cit.*, p. 444.

fluosilicic acid on silica and alumina. Topaz is not very stable. It is easily altered to kaolinite or sericitic minerals.

Kaolinite.—The hydrous silicate of aluminum was formerly supposed to occur very extensively in altered vein-rocks; but it has been shown that the larger part of the minerals considered as kaolinite or as "talc" are really sericite in finely divided form. Kaolinite forms from orthoclase, albite or soda-lime feldspars, with liberation of silica, the reaction in the first case being expressed as follows:

$$6\,(K\,Al\,Si_3\,O_8) + 6H_2O + 3CO_2 = 3\,(H_4\,Al_2\,Si_2\,O_9) + 3K_2CO_3 + 12SiO_2.$$

Ferromagnesian silicates, and even quartz, may be converted into kaolinite, as is shown by the altered rock adjoining a recent vein near Boulder, Montana. The mineral is nearly always in an extremely fine state of distribution; the aggregates have a very low bi-refracting power. Kaolinite and sericite may form together (Fig. 19), as is also shown by the calculated composition of many altered rocks. Wherever abundant carbonates form, metasomatically, together with sericite, kaolinite seems to be absent. It often occurs on cassiterite-veins (though it is possible that the kaolinite may here be simply a secondary alteration of topaz); further, together with sericite, in veins of the pyritic galena-formation of Freiberg; in some veins of propylitic character, as at Cripple Creek, and in veins where the action of stronger reagents, such as sulphuric acid, seems probable (Summit District, Colo.,* De Lamar, Idaho†). Kaolinite is formed most abundantly in the upper, oxidized zones of many ore-deposits.

Zeolites.—These hydrated minerals are almost completely absent from fissure-veins. Exceptions are the silver veins of Andreasberg in the Hartz, and Kongsberg in Norway, where many zeolites occur as vein-filling with quartz and calcite. As metasomatic minerals, they occur in the Lake Superior copper-veins replacing feldspars and other minerals. Daubrée has described zeolites forming in old bricks at Plombières, by the action of thermal waters ascending on a vein which does not contain any

---

* R. C. Hills, *Proc. Colorado Sci. Soc.*, vol. i., pp. 20–36.

† W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 171, 172.

of these minerals. W. H. Weed finds stilbite with quartz as the filling of a recent vein by ascending hot waters at Boulder, Montana. The absence of the zeolites from veins is somewhat difficult to explain, as it is well known that many of them may be formed at very widely differing pressures and temperatures. Very slight modifications of condition may result in the formation of hydrous or anhydrous minerals. Thus, for instance, Friedel and Sarasin* found that when a solution of silicate of sodium mixed with silicate of aluminum, in proportions required to form albite, was heated to 500° C. in a closed tube, analcite was formed. When excess of the alkaline silicate was used, albite resulted.

Pyrite.—Of all the sulphides occurring as metasomatic minerals pyrite is naturally the most common. In most fissure-veins, it impregnates the adjoining rock in varying amounts, even if the alteration in other respects has not progressed far. The mineral has a remarkable tendency to crystallization when developing in the rock, as contrasted with its often massive texture when occurring as a filling of open spaces. The forms assumed are either cubes or pentagonal dodecahedrons, or a combination of both.

Pyrite develops in nearly every one of the ordinary constituents of rocks. By preference, it forms in the new aggregates of sericite, carbonates and chlorite so common in altered rocks; but it also occurs in the fresh original minerals of the rocks, as in quartz, feldspar, hornblende and pyroxene. It is also abundant in calcareous shales adjoining veins. It is common to find small, sharp crystals embedded, for instance, in perfectly clear quartz grains, which show no break in their optical orientation around the secondary crystal, proving that the genesis is by purely metasomatic processes, and not, as may be advocated in the case of crystallization in soft aggregates, by the mechanical pressure of the growing crystal. On the other hand, the development of a larger crystal in quartz or feldspar will often produce a breaking-up of the grains as an optical unity, and the substitution for it of an interlocking aggregate of smaller grains. To what force this is due is not certain; there are usually no indications of direct pressure from the growing crystal.

---

* *Comptes rendus, Acad. des Sci.*, Paris, July, 1883, vol. xcvii., p. 291.

The pyrite crystals are often bordered by a small rim of calcite or quartz; and little bunches of sericitic fibers may adhere to them, when forming in quartz. On the whole, the pyrite seems to obtain some, if not all, of its iron from the ferro-magnesian minerals, rather than from the magnetite and titaniferous ores, which appear to alter to carbonates and rutile.

Marcasite.—In metasomatic development, this mineral is rare, though it has been observed accompanied with kaolin, at De Lamar, Idaho, as the result of the hydrothermal alteration of rhyolite.* It is always crystallized, and the individuals combine to arborescent forms.

Chalcopyrite.—This mineral is not common in the metasomatic rocks of gold- and silver-veins, but it forms abundantly in certain replacement-veins, such as those of Butte, Mont., and Rossland, B. C. In such cases, it may replace any of the ordinary rock-forming minerals. It forms in irregular masses, is rarely crystallized, and is frequently accompanied by a narrow lining of chlorite.

Arsenopyrite.—Like pyrite, arsenopyrite nearly always forms in crystals; these show the simple combination of rhombic prisms and striated dome, and may also replace any of the rock-forming minerals. Next to pyrite it is the most common sulphide in the altered rocks adjoining veins.

Pyrrhotite.—This mineral is not abundant either in vein-filling or in metasomatic rocks. Indeed, in many classes of veins it is entirely absent; and if it happens to be present in the rock close to the vein, it may suffer alteration to pyrite under the influence of the vein-forming agencies.† As a product of replacement of feldspar and ferro-magnesian silicates, it occurs in the Rossland veins of British Columbia, associated with chalcopyrite. The conditions governing the formation of pyrrhotite are not fully known. It has been artificially reproduced, but not under conditions which seem analogous to those of nature. At any rate, the mineral can only be formed under very strongly reducing influences.

Galena.—By preference, galena replaces calcite and dolomite. Hence the great abundance of metasomatic galena-deposits in

---

* *20th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 169.

† *17th Ann. Rept. U. S. Geol. Surv.*, part ii., p. 147.

limestone, calcareous shale and similar rocks. In crystalline igneous or metamorphic rocks, it is not abundant as a metasomatic product. But it may replace other minerals, especially quartz. Metasomatic galena scarcely ever appears in crystalline form, but often forms wiry, extremely irregular masses. Fig. 25 shows its appearance in primary quartz of a quartz-diorite. It only occurs in quartz which is completely filled with fluid inclusions; and its growth begins as little knots and particles, dotted over any given plane of fluid inclusions. These dots, of which some are shown in the figure, finally appear to have united to larger masses. The quartz grain in which the galena occurs is partly broken up into new quartz aggregates. Galena replacing quartz in quartzite from Northern Idaho is shown in Fig. 16. Gradually extending, the galena unites to larger masses, as illustrated in Fig. 17.

The replacement of calcite by galena is illustrated by Fig. 29, representing part of a section from the Elkhorn mine, Montana, which Mr. W. H. Weed kindly put at my disposal. The rock, a crystalline limestone, apparently free from organic matter, contains small, partly idiomorphic quartz grains, scattered among the larger grains, and also many small veinlets of secondary quartz. There is thus at least an incipient silicification accompanying the formation of the galena. In the little quartz veins and throughout the rock are small, sharply defined pentagonal dodecahedrons of pyrite, nearly always connected with small quartz grains. The galena appears in several smaller grains closely intergrown with pyrite; also in larger masses surrounded by a narrow rim of pyrite, and by clusters of small secondary grains and crystals of quartz. The galena is not clearly crystallized, but appears in small, solid masses, developing along the cleavage planes of calcite so that rhombohedral grains of the latter may be almost surrounded by galena.

Concerning the chemical reactions involved in the replacement by galena opinions differ. Some think that the slightly soluble sulphate of lead is reduced from solutions by organic matter—and adduce as confirmation the universal occurrence of galena in limestone or other sedimentary rocks, presumably containing organic matter. Another view is that, the sulphide of lead being soluble to a considerable extent in water containing sodic sulphide (Doelter), a simple precipitation from solution has taken place, dependent on the simultáneous solution of limestone and separation of silica.

For most cases I would be inclined to the latter view, since the small quantity of organic matter available, for instance in the Elkhorn limestone or in the Cœur d'Alene quartzite, seems utterly insufficient to reduce such large masses of galena as are found at these localities. Besides, silver-lead veins may occur in the same districts in very different rocks. Thus, for instance, in the Wood River region, Idaho, they are found not only in the limestone but also in granite, which certainly does not contain organic substances.

In this connection should be mentioned the replacement of rhodonite by galena and zinc-blende, described and figured from Broken Hill, Australia, by Prof. R. Beck. From the same locality Mr. Jaquet described and figured galena replacing orthoclase; and a silver mineral, probably argentite, replacing garnet, and perhaps quartz, in a garnet schist.

Zinc-blende and Other Sulphides.—In metasomatic occurrence zinc-blende is extremely similar to galena. It is usually found as irregular grains, replacing limestone, quartzite (Fig. 17), and many minerals in igneous rocks.

Much additional material might be quoted regarding the replacement of rocks by other sulphides; the literature on the subject should be used, however, with care, since critical studies of the modes of replacement are very few, and some statements are simply based on casual inspection with the naked eye.

Many other sulphides are undoubtedly formed by metasomatic replacement. Enargite, for instance, is noted by Emmons* as replacement thus present in the altered vein-rock of Butte, Mont.

Tellurides.—Tellurides of gold and silver are found at Cripple Creek and elsewhere, under circumstances indicating metasomatic deposition.

Native Copper.—This metal replaces many minerals. According to Pumpelly,† it replaces feldspar and various zeolites in the Lake Superior amygdaloids; and most of the large masses of copper there found are believed to be metasomatic.

---

* *U. S. Geol. Surv.*, Folio 38.

† *Geol. Surv. Mich.*, vol. i., part ii., p. 19, *et seq.*

Gold and Silver.—Native gold and silver are likewise important results of replacement in many veins. It is well known that masses of these metals are occasionally found in the country-rock away from the fissure; and these occurrences are probably to be interpreted as metasomatic, though the process has not been followed in its details.

Gold is also often contained in the replacing pyrite and other sulphides; and free gold can be obtained by panning from certain kinds of altered vein-rock. But caution should always be observed in stating such observations. I have known instances of supposed replacement where, in fact, all the value was derived from the filling of minute fissures and cracks.

Resistant Minerals.

Among the minerals which yield not at all or only with difficulty to metasomatic influences are apatite, muscovite, zircon and chromite. The resistance of apatite is very remarkable; for according to R. Müller* apatite is soluble with comparative ease in water containing carbon-dioxide.

PART III.

THE FISSURE-VEINS CLASSIFIED ACCORDING TO METASOMATIC PROCESSES.

Under this head, I suggest fourteen classes of fissure-veins, each usually characterized by its own distinctive metasomatic process. These fourteen divisions are not offered as a permanent classification, though most of them are sharply defined. The principle is not unqualifiedly good for a genetic classification, for the reason that the same waters may cause a different metasomatic development in different rocks.

The list, in each title of which the first word indicates the predominant metasomatic mineral or process, is as follows: 1. Topaz-cassiterite veins; 2. Scapolite-apatite veins; 3. Tourmalinic gold-copper veins; 4. Biotitic gold-copper veins; 5. Propylitic gold- and silver-veins; 6. Fluoritic gold-tellurium veins; 7. Sericitic and kaolinic gold- and silver-veins; 8. Sericitic and calcitic gold- and silver-veins; 9. Silicic and calcitic quicksilver-veins; 10. Sericitic copper-silver veins; 11. Silicic

---

* *Tsch. Min. Mitt.*, p. 25, 1877.

and dolomitic silver-lead veins; 12. Sideritic silver-lead veins; 13. Sericitic silver-lead veins; 14. Zeolitic copper- and silver-veins.

1. *Topaz-Cassiterite Veins.*

This sharply defined class is characterized by exceedingly strong metasomatic action, with fluorine as mineralizing agent, resulting in often coarse-grained, altered rocks, containing topaz and sometimes tourmaline, besides an often considerable percentage of cassiterite.

The cassiterite-veins are characterized by their occurrence in connection with intrusive igneous rocks, and by the pneumatolytic change of the country-rock to *greisen*, a granular rock consisting chiefly of quartz, topaz and white mica, usually containing fluor and lithia. Tourmaline and cassiterite are usually accessory constituents of this rock. The feldspar and the brown mica of the original rock are destroyed, and the minerals mentioned above are added. Topaz often forms pseudomorphs after quartz; cassiterite, tourmaline and topaz, after feldspar. The alteration of the country-rock varies somewhat in chemical aspects, but is distinguished by strongly marked transportation of substance.

In the granular greisen, the new minerals appear as individuals of considerable extent and optical continuity, perhaps indicating that the processes by which it was formed were more active and energetic than those producing the aggregate structure commonly found in altered vein-rocks. The minerals found in the metasomatic wall-rock appear also in the fissures themselves; hence the same chemical process must have been active in both. Other rocks, such as gneiss, quartz-porphyry and rhyolite, show similar alteration, though tin-deposits do not so commonly occur in them. A notable feature of the cassiterite-veins is the occurrence of apatite, a mineral generally unknown in fissure-veins. Under ordinary circumstances, in altered vein-rocks, apatite is the last mineral to remain fresh, after all other primary minerals have been destroyed.

Vogt's explanation* of the genesis of cassiterite-veins and the alteration of their wall-rocks follows closely the previously expressed views of Elie de Beaumont, Daubrée, Le Neve Fos-

---

* J. H. L. Vogt, *Zeitschr. f. prakt. Geologie,* 1895, p. 145.

ter and Dalmer. He assumes that they were formed immediately after, or even during, the granitic eruptions, and, further, that the mineral solutions originated by the action of hydrofluoric acid and hydrochloric acid on the magma, still entirely or partly in igneous fusion. By means of these, fluorides of silicon, tin, boron and lithium were extracted, as well as phosphoric acid. These solutions took place under pneumatolytic conditions, that is, the "critical point"* had been passed and the substances were present in a gaseous state in spite of the high pressure. These extracts in gaseous state ascended on the previously formed fissures and strongly attacked the adjoining country-rock, changing it to greisen by means of replacement by minerals containing fluorine and other mineralizing agents. Different rocks were, perhaps, not affected exactly in the same way. For instance, the altered product resulting from schists is not quite similar to that resulting from granite, this being possibly due to the fact that the schists were not heated to such a degree as was the granite. While the formation of the greisen took place after the consolidation of the rock, as is evidenced by the fact that fissures could form in it, still it is believed that the temperature must have been very high, and, in fact, that the lower masses of the granite were not yet consolidated.

Altenberg and Zinnwald, Saxony.—The tin-deposits of Altenberg and Zinnwald, in Saxony, have been lately investigated by K. Dalmer.† The cassiterite-deposits of Altenberg consist, as is well known, of a number of ore-fissures which sometimes carry a notable amount of quartz, mica and topaz, as well as cassiterite. Over a considerable area traversed by these veinlets appears a greisen, locally called *zwitter*, which Mr. Dalmer shows to have resulted unquestionably from the metasomatic alteration of the granite. The process consisted of a replacement of feldspar, principally orthoclase, by topaz containing lithium and fluorine. The beginning of the process is often

---

[*] The critical temperature for water is + 365° C. at a pressure of 200 atmospheres. For most other substances the critical point is passed below this temperature and pressure. It is, perhaps, not needless to state that the passing of the critical temperature does not mean that the substances are dissociated.

[†] *Erläuterungen zur Geologischen Specialkarte des Königreichs Sachsen*, Section "Altenberg-Zinnwald," Leipzig, 1890.

visible, small strings of aggregates of mica and topaz pervading the feldspar. These strings repeatedly cross each other, and by extension of the mineral individuals complete replacement is attained. The greisen consists of: quartz, 50.28; topaz, 12.14; mica, 36.80; and cassiterite, 0.43; total, 99.65 per cent.

Dr. Dalmer has calculated the composition of the rock from these percentages, and obtained a result which closely agrees with the old analysis of the same rock by Rube, quoted in Cotta's *Gangstudien.* The following table shows the result, I being the fresh granite and II the altered product:

	I. Per Cent.	II. Per Cent.
SiO_2,	74.68	70.41
TiO_2,	0.71	0.49
SnO_2,	0.09	0.49*
Al_2O_3,	12.73	14.86
Fe_2O_3,	......	1.42
FeO,	3.00	5.09
CuO,	0.50	......
MnO,	......	0.29
CaO,	0.09	0.21
MgO,	0.35	0.09
K_2O,	4.64	3.01
$Na_2O + Li_2O$,	1.54	0.98
Fl,	......	3.10
H_2O,	1.17	......
	99.50	100.44

From these two analyses it is clear that the formation of greisen does not by any means involve silicification. Dalmer concludes that the principal changes consisted in the addition of FeO, Fl, SnO_2, and possibly Al_2O_3, while K_2O, Na_2O and SiO_2 have been subtracted. In the absence of further knowledge of the relations of volume during the alteration, it is scarcely possible to conclude from the comparison of these analyses alone what the actual changes have been. The determination of specific gravities of the rocks would probably help to obtain a clearer insight in regard to this matter. This much is evident, that the mineral aggregate of the granite has changed to a new aggregate of greater density.

It will be observed that the second analysis contains no water. This has probably been unintentionally omitted, as it must

---

* As cassiterite, 0.43; in mica, chemically combined, 0.06.

surely be present, being contained, chemically combined, both in topaz and in the lithium-mica.

In view of the fact that in this alteration not only the potassium-aluminum silicate, muscovite, but also the pure aluminum fluo-silicate or topaz appears, it is interesting to note that metasomatic kaolin is undoubtedly present in cassiterite-veins. Pseudomorphs of it after topaz have been frequently observed, and it is often stated that "steinmark" is present in the veins; this being really only a synonym for kaolin. Daubrée long ago called attention to the connection of kaolin with cassiterite-veins.

In several places the alteration of the granite and the adjoining porphyry is of a radically different character, and consists in a complete silicification. While this is not the normal process, yet it appears fairly common, and must be taken into consideration in attempting to explain the genesis of these veins.

Mt. Bischoff, Tasmania: The rocks of the tin-deposits of Mt. Bischoff, in Tasmania, have lately been described by W. von Fircks,* who devotes considerable space to the alteration which they have suffered. The tin-deposits appear in an area of quartzites and clay-slates with dikes of quartz-porphyry. Granite is present some distance from the mines. The deposits are in part fissure-veins carrying cassiterite, pyrite, arsenopyrite, fluorite, wolframite, tourmaline and siderite. The latter mineral is notable, because not usually present in veins of this character. Another part of the deposits is formed by replacement, chiefly of porphyry dikes. All rocks in the vicinity of the mines are much altered. The schists and slates contain much tourmaline, and are in part changed to typical *tourmalin-fels* by complete replacement, only a few grains of the original rock remaining. Besides the tourmaline, some siderite also appears, while topaz is present in but small quantity. These altered schists contain cassiterite (rare), and also pyrite, arsenopyrite, pyrrhotite, fluorite, calcite, siderite and pyrophyllite as metasomatic products. The tourmalinization begins with the appearance of needles and bunches of crystals of tourmaline traversing fresh quartz grains, as shown in Fig. 23. These tourmaline crystals, by further growth, finally replace the

---

* *Zeitschr. d. d. geol. Ges.*, Bd. li., p. 433, 1899.

quartz altogether. According to the description, the fissure-veins must have been produced partly, at least, by processes of filling. Where they traverse the schists, their walls show impregnation of ores and the development of a great quantity of sericite. Sometimes, it should be added, the wall-rocks are completely silicified. Of greatest interest are the quartz-porphyry dikes and their alteration-products. The principal secondary mineral in these dikes is topaz, while tourmaline is only of subordinate importance. The groundmass of the porphyry is changed to aggregates of topaz and quartz. The quartz phenocrysts are usually intact, while the feldspars are often completely replaced with cassiterite, pyrite, pyrrhotite, arsenopyrite and fluorite, as shown in Fig. 22. In the final product, the feldspar and mica have disappeared completely, the zircon being, besides quartz, the only mineral which has withstood the metasomatic influences. Here again siderite appears occasionally, seemingly of simultaneous formation with the other metasomatic constituents. There is, as shown by the author, a great similarity between the metasomatic action in these deposits and that described from the vicinity of Schneckenstein, in Saxony, by Mr. M. Schroeder.*

None of the rocks from Tasmania can well be designated as "greisen"—a name which ought to be reserved for the granular alteration-products of granite consisting of quartz, lithion-mica, topaz and cassiterite. Here again, as at Altenberg, we find occasionally, seemingly as an exception, a change in the metasomatic processes resulting in complete silicification of the wall-rock.

Prof. R. Beck† has discussed the tin-ore deposits from Banca and Billiton, in referring to the work of Mr. Verbeek on the same subject. It has been shown by Prof. Cl. Winkler that many granites and rocks allied to *hornfels* contain a small amount (from 0.01 to 0.07 per cent.) of oxide of tin. This is not cassiterite, but appears to be chemically combined with silicates, partially replacing SiO_2. Sandberger had, indeed, also shown long ago the presence of tin in certain muscovites from different places in Europe. Another very interesting fact shown by Mr.

---

* *Erlaeut. z. Geol. Sp. Karte des Königr. Sachsen,* Leipzig, 1885, Section "Schneckenstein."

† *Zeitschr. f. prakt. Geologie,* 1898, p. 121.

Verbeek is a stanniferous siliceous sinter, deposited at a hot spring in Malacca. This sinter contains, according to an analysis by St. Meunier, SiO_2, 91.8; SnO_2, 0.5; Fe_2O_3, 0.2, and H_2O, 7.5 per cent.

This observation possesses the greatest importance for our knowledge of tin-deposits, as it shows that the metal may be held in solution and deposited at ordinary pressure by thermal waters. Prof. Beck shows the presence of primary cassiterite in some granites from the same locality, and also points out that the veins are practically identical with tin-deposits from other parts of the world, being characterized by an often strong alteration of the adjoining country-rock, converting it into typical greisen. The feldspar is replaced by topaz, cassiterite and muscovite. The typical greisen is illustrated in Fig. 24, copied from Prof. Beck's article.

2. *Scapolite-Apatite Veins.*

This interesting group of veins has lately been described in detail by Prof. Vogt.* It is characterized by some most remarkable features, closely relating it on one hand to the group of the cassiterite-veins, but showing, on the other hand, strong relationships with the pegmatite-veins, formed under pneumatolytic conditions and exceedingly high temperature and pressure. The structural features of scapolite-apatite veins are not those of fissure-veins, as they chiefly follow contraction-joints (in gabbro). Indeed, this may be said to some extent of cassiterite-veins; but the latter often also follow strong, well-defined fissures. At any rate, it seems probable that the apatite-veins were formed almost simultaneously with, or very closely following, the solidification of the magma.

The characteristic minerals are apatite, phosphates, rutile, pyrrhotite, specularite, enstatite, scapolite, hornblende and malacolite, many of which are absolutely foreign to ordinary fissure-veins. A most characteristic feature is the presence of chlorine (in apatite and scapolite), just as fluorine persistently appears in cassiterite-veins. In the gabbro adjoining the vein-filling, the labradorite is usually altered to scapolite, and the diallage to hornblende. This alteration is explained (*loc. cit.*, p. 456) as a saturation of the country-rock under high pressure

---

* J. H. L. Vogt, *Zeitschr. f. prakt. Geol.*, 1895, p. 367.

by the sodium chloride which acted as a mineralizing agent during the formation of the veins.

3. *Tourmalinic Gold-Copper Veins.*

In the type of veins distinguished by a gangue of tourmaline and quartz the country-rock is generally subject to strong metasomatic changes. The vein-forming agents, which contained boron and some fluorine, appear to have attacked the adjoining rock strongly, and caused a more or less complete metasomatic conversion into tourmaline. Von Groddeck* has described an occurrence of this kind from Tamaya, Chile, in which veins containing copper-ores cut gabbro and porphyrites. The tourmaline is here not only present in the filling of the fissure but is also distributed through the adjoining country-rock. A further contribution to the knowledge of veins carrying tourmaline was given by A. W. Stelzner† in his description of occurrences of this kind from Chile. The rocks examined, from the mining district of Las Condes, 90 miles east of Santiago, consist of granite and greenish porphyritic rocks, which the author is inclined to consider as altered andesites. The vein-filling is pyrite, chalcopyrite, quartz and a loose porous mass of tourmaline needles. By a specific-gravity separation of the latter, Stelzner obtained, as a residue, zircon in well-developed crystals, as well as specularite and anatase. The zircon is probably developed under the influence of the vein-forming solutions, the anatase and specularite quite certainly so. Again the fact is emphasized that the adjoining country-rock is bleached and filled with pyrite and tourmaline.

Dr. E. Hussak‡ has recently described the auriferous quartz-vein of Passagem, in Minas Geraes, Brazil. This vein, which lies, parallel to the stratification, between mica schist and itabirite (hematite-mica-schist), shows a filling of quartz, tourmaline, and arsenopyrite, with smaller quantities of pyrite and pyrrhotite. The arsenopyrite is strongly auriferous. A very interesting feature is the occurrence of zircon and monazite in the ore, formed apparently simultaneously with it. Here, too, the tourmaline is present in the adjoining country-rock. Musco-

---

* *Zeitschr. d. d. geol. Ges.*, 39, 1887, p. 237.

† Posthumously published in *Zeitschr. f. prakt. Geologie*, 1897, p. 41.

‡ *Zeitschr. f. prakt. Geologie*, 1898, p. 345.

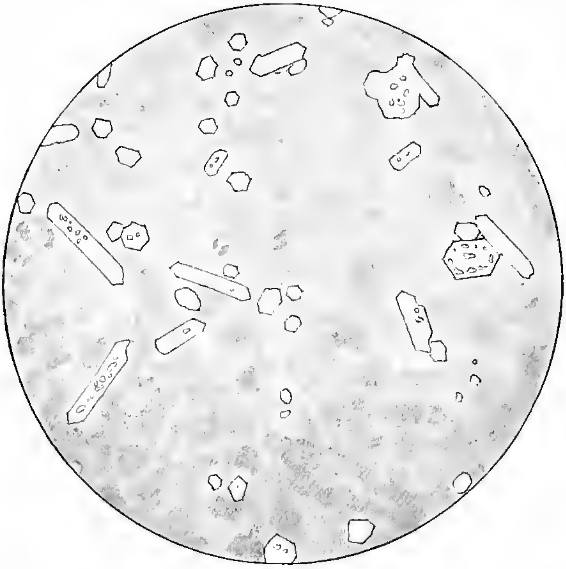
FIG. 1.

Silicified Calcareous Shale with Outline of Foraminiferal Test. Diadem lode, Plumas county, Cal. (After H. W. Turner.) Crossed nicols. All quartz. Magnified 29 diameters.

FIG. 2.

Primary Vein Quartz from Filling. Federal Loan mine, Nevada county, Cal. Crossed nicols. All Quartz. Magnified 14 diameters.

FIG. 3.

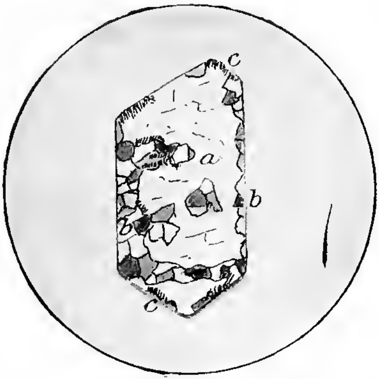


Incipient Silicification of Limestone. Aspen, Colo. White areas represent quartz crystals with small inclusions of limestone. Magnified 30 diameters.

FIG. 4.

Silicified Limestone ("Jasperoid"). Aspen, Colo. Crossed nicols. All quartz. Small inclusions of calcite in some of the grains. Magnified 30 diameters.

FIG. 5.

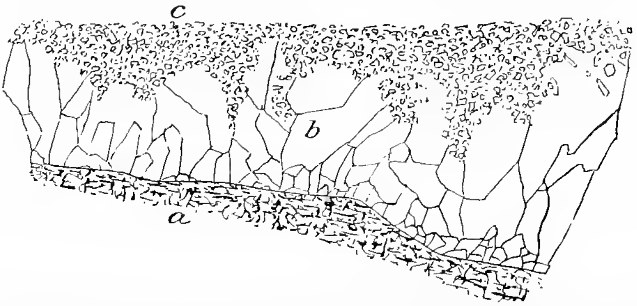


Incipient Silicification of Orthoclase Crystal in Rhyolite. Silver City, Idaho. Crossed nicols. *a*, Orthoclase ; *b*, secondary quartz ; *c*, sericite. Magnified 34 diameters.

FIG. 6.

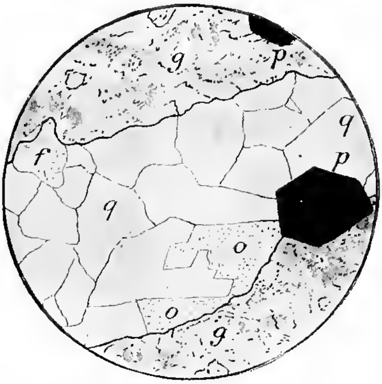
Hornblende Crystal with Partial Chloritization and Silicification ; in Propylitic Andesite. Virginia City, Nevada. (After G. F. Becker.) White, quartz and calcite ; grey, chlorite ; dark grey, hornblende. Magnified 70 diameters.

FIG. 7.



Veinlet of Quartz (*b*) on Chloritized Basalt (*a*), Replacing Silicified Rhyolite (*c*). Bishop vein, Silver City, Idaho. Magnified 11 diameters.

FIG. 8.

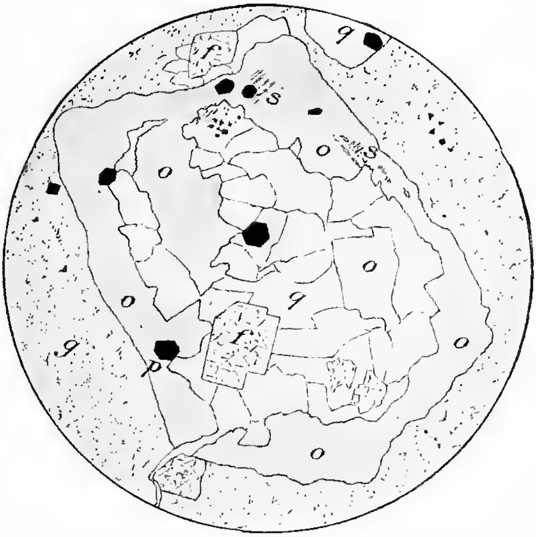


Filled Veinlet in Andesite Breccia. Independence mine, Cripple Creek, Colo. *q*, Quartz ; *o*, valencianite (orthoclase) ; *p*, pyrite ; *f*, fluorite ; *g*, ground-mass of breccia. Fluorite and pyrite partly replacing ground-mass. Magnified 11 diameters.

FIG. 9.

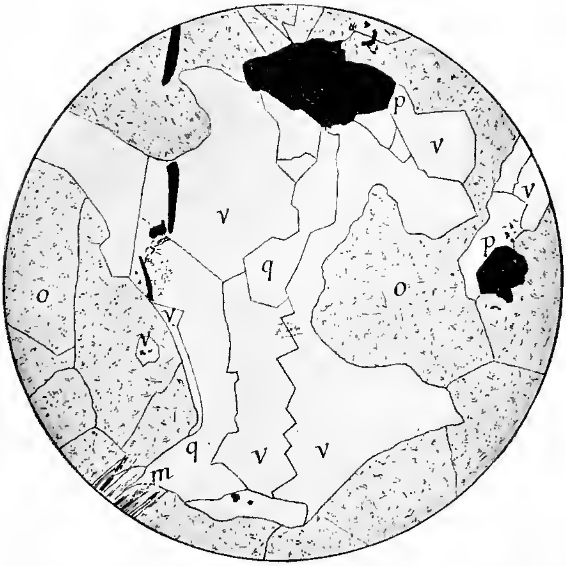
Fluorite Ore, Replacing Phonolite. Portland mine, Cripple Creek, Colo. *p*, Pyrite ; *q*, quartz, coarser and finer grains ; *f*, fluorite. Magnified 50 diameters.

Fig. 10.



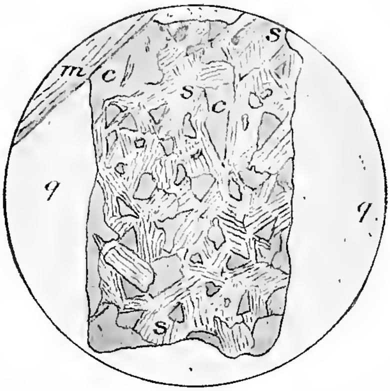
Orthoclase Grain (*o*) in Granite Andesite Breccia, Partly Replaced by Quartz (*q*); Fluorite (*f*); Pyrite (*p*); Sericite (*s*); Ground-Mass of Breccia (*g*). Independence mine, Cripple Creek, Colo. Magnified 60 diameters.

Fig. 11.



Filled Space of Dissolution in Granite. "Granite Ore," Independence mine, Cripple Creek, Colo. *o*, Orthoclase of granite; *m*, biotite, converted into valencianite and pyrite; *v*, valencianite (secondary orthoclase), showing crustification; *q*, quartz. Magnified 20 diameters.

Fig. 12.



Andesine Crystal in Granodiorite, Replaced by Sericite and Calcite. Pinetree vein, Ophir, Placer county, Cal. *q*, Quartz ; *m*, muscovite ; *c*, calcite ; *s*, sericite. Magnified 80 diameters.

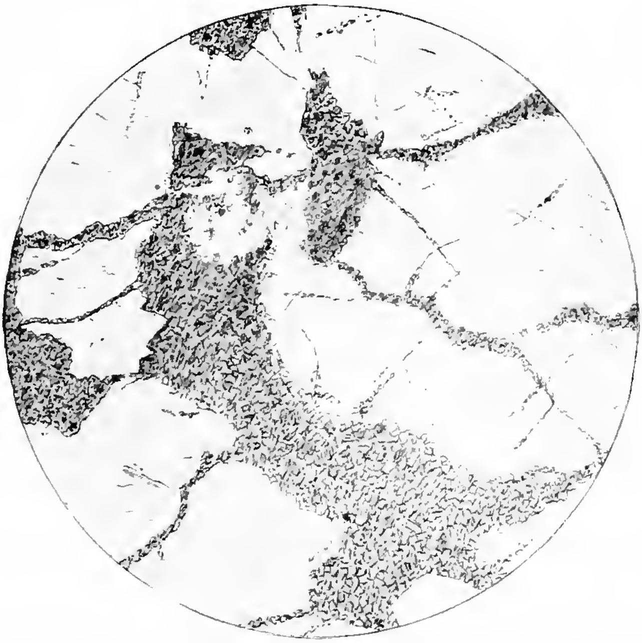
Fig. 13.

Quartz Grain in Same Section, Partly Replaced by Calcite. *q*, Quartz ; *c*, calcite with some sericite replacing from outside ; also, secondary calcite grains forming on inclined fissure-plane in quartz. Magnified 80 diameters.

Fig. 14.

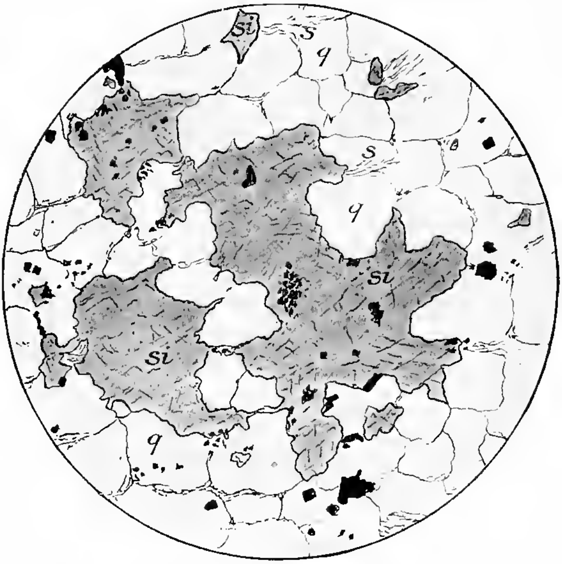
Fluorite Replacing Limestone. Florence mine, Judith Mountains, Mont. *f*, Fluorite; *l*, limestone; *q*, secondary quartz. Magnified 7 diameters.

Fig. 15.



Metasomatic Replacement of Quartz in Granodiorite by Calcite and Sericite. Providence mine, Nevada City, Cal. White areas quartz. Shaded areas fine-grained calcite with some sericite. Magnified 52 diameters.

FIG. 16.



Siderite with Pyrite and Galena, Replacing Quartzite. Helena and Frisco mine, Cœur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *si*, siderite; black, galena and pyrite. Magnified 100 diameters.

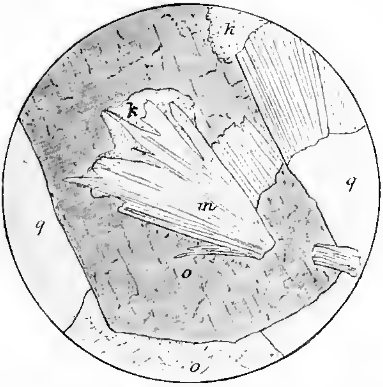
FIG. 17.

Replaced Quartzite, Same Locality as Fig. 16. Black, galena; *z*, zinc-blende; *q*, quartz; *s*, sericite; *si*, granular siderite. Quartzite in same section gradually changing to this ore. Magnified 35 diameters.

Fig. 18.

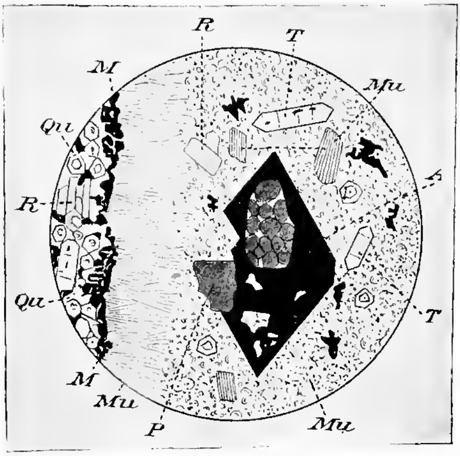
Quartzite Partly Replaced by Siderite and Pyrite. Helena and Frisco mine, Cœur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *si*, siderite with partly rhombohedral form; black, pyrite. Magnified 100 diameters.

Fig. 19.



Orthoclase Partially Replaced by Muscovite and Kaolinite. From quartz-monzonite adjoining recent vein, Boulder, Mont. *o*, Orthoclase; *q*, quartz; *m*, muscovite; *k*, kaolinite. Magnified 22 diameters.

FIG. 20.



Part of Andalusite Crystal Altered into Muscovite, Arsenopyrite, etc. Passagem gold-quartz vein, Brazil. (After E. Hussak.) *M*, Pyrrhotite ; *A*, arsenopyrite; *P*, pyrite ; *Qu*, quartz ; *R*, rutile ; *Mu*, muscovite ; *T*, tourmaline.

FIG. 21.

Replacement-Veinlet of Tourmaline in Fresh Andesine Grain. Keystone mine, Meadow Lake, Nevada county, Cal. *t*, Tourmaline ; *f*, andesine ; *e*, epidote; *s*, sericite. Magnified 50 diameters.

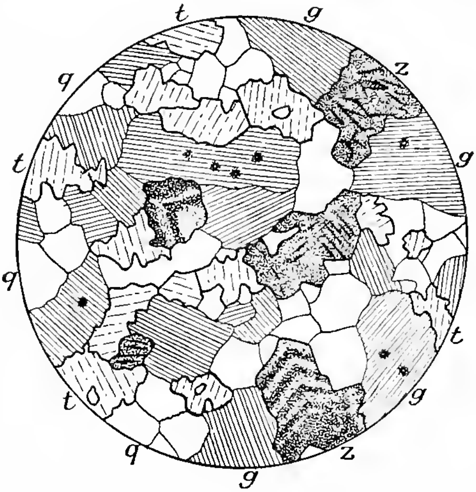
Fig. 22.

Feldspar Crystal Replaced by Topaz, Quartz, Fluorite and Cassiterite, in Ground-Mass Converted to Partly Radial Aggregates of Topaz. Mount Bischoff, Tasmania. (After W. von Fircks.)

Fig. 23.

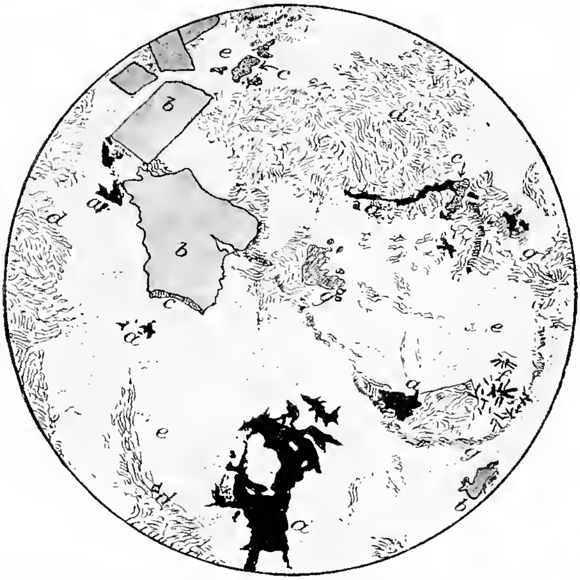
Incipient Tourmalinization of Quartzite. Three quartz grains shown. Needles single and in bunches, of tourmaline. Mount Bischoff, Tasmania. (After W. von Fircks.)

Fig. 24.



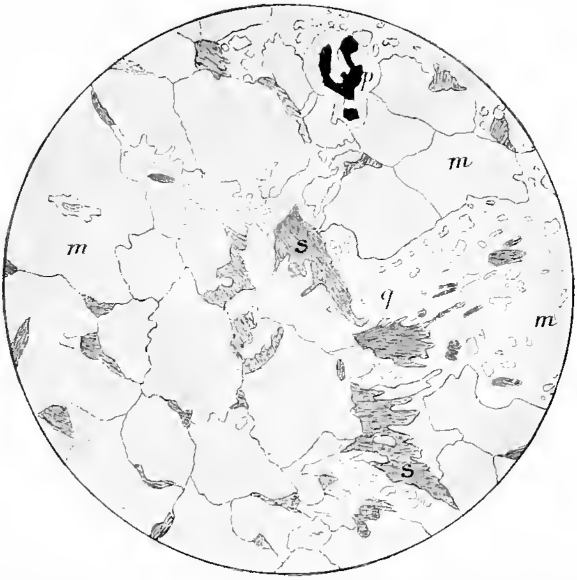
"Greisen" from Tin-Deposits of Banca, Malay Peninsula. Derived from granite. (After R. Beck.) *g*, Lithion-mica; *q*, quartz; *z*, cassiterite; *t*, topaz. Stippled spots in mica consist of zircons and rutiles, surrounded by polychroic ring. Slightly magnified.

Fig. 25.



Altered Quartz-Mica-Diorite. Crœsus mine, Wood River, Idaho. *a*, Galena; *b*, arsenopyrite; *c*, chalcopyrite; *d*, sericite; *e*, quartz with secondary fluid inclusions; *f*, rutile; *g*, chlorite. Magnified 19½ diameters.

Fig. 26.

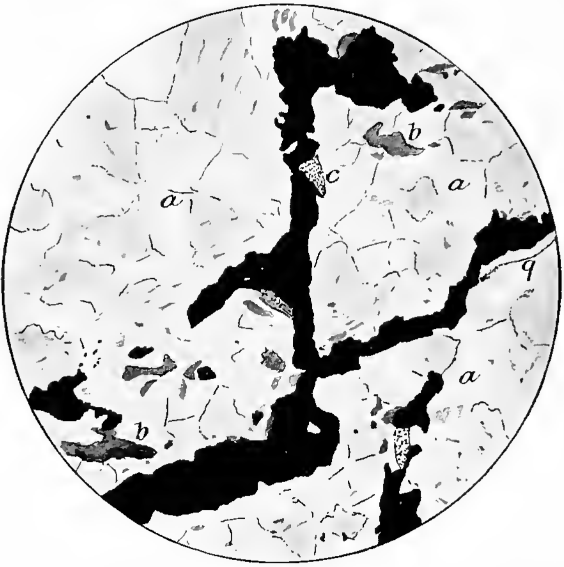


Altered Serpentine. Idaho mine, Grass Valley, Cal. *m*, Magnesite ; *s*, serpentine ; *p*, pyrite ; *q*, fine granular quartz. Magnified 15 diameters.

Fig. 27.

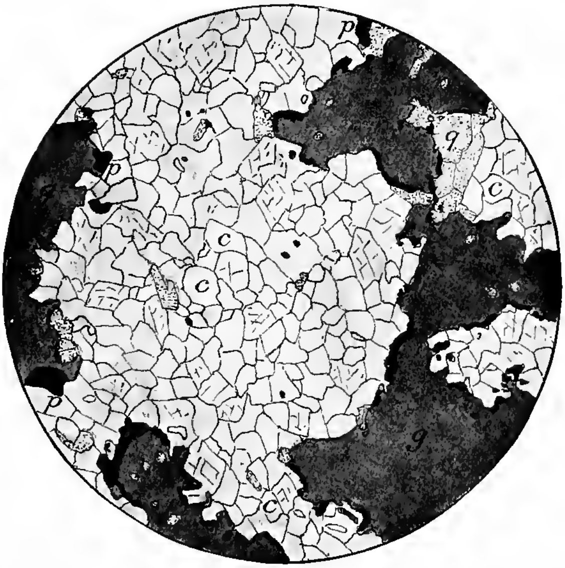
Altered Granodiorite. Bellefountain mine, Nevada City, Cal. *m*, Fine aggregate of sericite, with a little calcite and secondary quartz, replacing orthoclase and andesine ; *b*, original biotite altered to sericite ; *q*, original quartz ; black, pyrite with included sericite. Magnified 15 diameters.

FIG. 28.



Replacement-Vein in Syenite Rock. War Eagle mine, Rossland, British Columbia. *a*, Granular aggregate of orthoclase with very little sericite; black, secondary pyrrhotite; *b*, secondary biotite; *q*, secondary quartz; *c*, chlorite. Magnified 60 diameters.

FIG. 29.



Galena, Replacing Crystalline Limestone. Elkhorn mine, Montana. *g*, Galena; *p*, pyrite; *c*, calcite grains of limestone; *q*, secondary quartz. Magnified 15 diameters.

FIG. 30.

Quartzite Showing Filled Quartz Veinlet and Accompanying Galena, Replacing the Quartzite on One Side of the Filled Fissure. The quartzite contains some replacing siderite. Bunker Hill and Sullivan mine, Cœur d'Alene, Idaho. Black, galena; white, quartz; grey, quartzite. Natural size. Reproduced from photograph.

vite or sericite is also described as very plentiful in the schistose rock adjoining the vein. Certain crystals of andalusite, occurring (as inclusions ?) in the vein, are completely altered into sericite, rutile, arsenopyrite and pyrite, as is well shown in Fig. 20 (reproduced from Dr. Hussak's paper). The author concludes from his study that the deposit is a product of igneous injection, and should be considered a dike rather than a fissure-vein, basing this conclusion largely on the occurrence of zircon, monazite, tourmaline and staurolite in the adjoining rock. It is a question whether this argument will carry conviction. From Dr. Hussak's excellent descriptions I should be inclined to consider this interesting occurrence as a fissure-vein deposited by aqueous agencies, though, perhaps, at a higher temperature than ordinary veins. The contact-minerals cited by the author do not appear to be confined to the adjoining rock, but are present in the whole series of schists. The very schistose and sericitic quartzite forming the wall of the vein, and the presence of pseudomorphic sericite after andalusite, as well as the apparently simultaneous forming of arsenopyrite and sericite, appear to me evidence that the deposit of Passagem is really a normal vein. The tourmaline is here also present in the country-rock, apparently replacing it to a greater or lesser degree.

Again, similar deposits have been described from Meadow Lake, Nevada county, Cal.,* where granitic and dioritic rocks contain fissure-veins with pyrite, arsenopyrite, pyrrhotite, zincblende, and various secondary copper-ores, indicating primary chalcopyrite in a gangue of quartz and tourmaline, with which some yellow epidote is usually associated. Chlorite is also common in the gangue as well as a brown mica, probably biotite. A colorless mica and a little calcite were also observed. In contrast to the usually clearly defined fissure-veins of the gold-belt of California, in which the quartz-filling is the predominant ore, these veins show very irregular and undefined walls, and it is clear that the mineral-forming solutions rose along very narrow fissures, from which they penetrated more or less deeply into the adjoining country-rock, and there, by metasomatic replacement deposited the auriferous ores. One of these occurrences

---

* Waldemar Lindgren, *Am. Jour. of Sci.*, 3d series, vol. xlvi., Sept., 1893, p. 201.

is illustrated in Fig. 21. The specimen is from the Keystone mine, and shows a granitic rock traversed by a narrow fissure, from which an intense alteration has proceeded, converting the immediate rock into an aggregate of quartz and tourmaline. The metasomatic process is well shown in the figure.

Prof. Vogt describes* certain veins in Telemarken, Norway, which he considers as related to the cassiterite-veins proper. These contain chalcopyrite, bornite, and chalcocite, also a little native silver and gold, all associated with a gangue of fluorite, tourmaline, apatite, muscovite and calcite. They are considered to be genetically connected with the granite in which they appear, and the presence of tourmaline and apatite certainly suggests their close relationship to normal cassiterite-veins. The country-rock is a normal biotite-granite, with orthoclase, microcline and oligoclase, and no muscovite. The alteration extends for several feet on both sides of the veins, and all transitions are plainly visible. The first part of the process consists in a peripheric change of biotite to muscovite and a little epidote; then the feldspars are attacked, muscovite and quartz together with a little calcite forming on the cleavage-planes; and finally the feldspars and biotite are entirely decomposed. The result is muscovite, quartz, calcite, rutile, zircon and apatite,—the latter two not altered, but constituting the only material remaining fresh from the unaltered rock. A little fluorite, chalcopyrite or bornite is also occasionally present in the product of alteration. Regarded from a chemical standpoint the process is not always the same. Sometimes, according to Vogt, substance is added; sometimes taken away. Quartz may occasionally prevail; at other places muscovite predominates. Prof. Vogt calls this altered rock a greisen; but the process of alteration as described by him is so nearly that of ordinary sericitic replacement that it may be questionable whether it would not be better to reserve the term greisen for the characteristic rock accompanying the cassiterite-veins. The process of formation in the case of the Telemarken veins was probably not carried on under the extreme conditions attending the normal cassiterite-veins.

The three classes of veins described above are undoubtedly

---

* *Zeitschr. f. prakt. Geol.*, 1895, p. 147.

closely related and form a group, which, however, is connected by transitions from the following classes. In their whole development a distinct genetic connection with intrusive rocks is recognizable, and they seem to have been formed under exceptionally high pressure and temperature—in fact, partly under pneumatolytic conditions. The metasomatic action on the country-rock is very strong, and the presence of fluorine, chlorine or boron is characteristic. It is well to emphasize, however, that fluorine and boron appear in many other veins which certainly have not originated under pneumatolytic conditions, or even under high temperature or pressure. The three foregoing classes appear to form a transition from pegmatite-veins to ordinary-fissure veins.

4. *Biotitic Gold-Copper Veins.*

This class, of which few representatives are thus far known, are exemplified in the veins of Rossland, British Columbia. They are well-marked fissure-veins, contained in granular, intrusive rocks of great variety, ranging from diorites to monzonites and even syenites. The ore-minerals are pyrrhotite, chalcopyrite and a little arsenopyrite, all containing gold, but usually not in a free state, amenable to amalgamation; the principal gangue-mineral is biotite, with a little quartz, calcite, muscovite, amphibole, chlorite, tourmaline and garnet.

The veins are excellent examples of replacement-deposits, as there is but little material which can be identified as the filling of open cavities, while most of the ore has been formed by replacement of the rock-forming minerals on both sides of narrow fissures. The original hornblende of the rock is altered to aggregates of biotite foils, which also invade the feldspars; and simultaneously the feldspar substance is replaced from small cracks by pyrrhotite and chalcopyrite, forming a characteristic network which, by gradual extension, finally replaces the whole rock. One of these replacement-veinlets is illustrated in Fig. 28. The sulphides do not as a whole have crystalline outlines, though in some places the grains show crystal-faces. The secondary character of the sulphides is further shown by narrow linings of quartz, chlorite or biotite. The feldspar substance, generally clouded by interpositions of biotite, muscovite, etc., usually presents a narrow, clear rim adjoining the sulphides. Extensive biotitization results in fine-grained siliceous rocks, consisting of brown mica and quartz, possibly also secondary feldspars. Green secondary amphibole was noted in places, embedded in calcite. The whole process is more characteristic of dynamic metamorphism than of ordinary fissure-veins, and it is probable that the veins were formed under actual unrelaxing compression. Strongly reducing conditions are indicated (otherwise pyrrhotite would not form so exclusively), and the absence of notable quantities of carbon-dioxide. Along secondary slips, below the water-level, the pyrrhotite may be transformed to pyrite. Epidote appears to be absent. The veins are earlier than an extensive system of lamprophyric dikes which cut across them. These dikes were no doubt closely connected with the principal intrusion of igneous rock; and the conclusion may be drawn that the mineralization followed pretty closely upon the consolidation of the rock.

5. *Propylitic Gold- and Silver-Veins.*

General Features.—As the cassiterite-veins are closely connected genetically with certain intrusive rocks, so another group of veins shows a dependence on tertiary effusive rocks, such as andesites, dacites and basalts, in part also rhyolites and trachytes. In the vicinity of these veins there is a very extensive metasomatic action resulting in so-called propylite (named by v. Richthofen) which was regarded formerly as a primary rock-type, just as greisen has sometimes been regarded as a primary rock forming a variety of granite. But all fissure-veins in tertiary effusive rocks do not belong to this class; a considerable number belong under the head of sericitic veins. Rosenbusch expresses the process in the following apt words:*

> "The characteristic features of the propylitic *facies* consists in the loss of the glassy habit of the feldspars; in the chloritic alteration of the hornblende, biotite and pyroxene (often with an intermediate stage of uralite), with simultaneous development of epidote; further, in alteration of the normal ground-mass into holocrystalline granular aggregates of feldspar, quartz, chlorite, epidote and calcite, and in a considerable development of sulphides" [usually pyrite].†

---

* *Elemente der Gesteinslehre*, Stuttgart, 1898, p. 303.

† Rosenbusch adds (*loc. cit.* and *Mikr. Phys. d. Mass. Gest.*, Stuttgart, 1896, p. 91) that similar rocks (excepting the pyrite) may result from atmospheric weathering. Against this statement I would protest, referring to page 586 of this paper.

Chemically, the change is not considerable; the principal additions consist of water and sulphur; some substance is often subtracted, usually lime or magnesia, while the alkalies show slight change. The following analysis, taken from Mr. Clarence King's monograph on the Comstock Lode, shows the composition of a propylitic andesite:

	Per cent.
SiO_2,	64.62
Al_2O_3,	11.70
FeO,	8.39
MgO,	1.18
CaO,	8.96
Na_2O,	3.13
K_2O,	1.95
H_2O,	1.02
	100.95

Propylitic rocks occur in the vicinity of large fissure-veins and vein-systems in Tertiary effusive rocks—for instance, at the Comstock, Nevada; Pachuca and Real del Monte, Mexico; in the South American Andes; and in Hungary and Transylvania. Although the propylite indicates the general metasomatic process in these veins, it is not uncommon to find rocks and soft clays containing sericite as a product of the extreme metasomatic action very close to the vein. The waters principally active during the formation of the propylitic veins probably contained only a small amount of carbon dioxide and very little lime, but may have been rich in sulphuretted hydrogen.

The filling of open spaces is a very important process in these veins, as may be expected from their formation comparatively near the surface; and this filling usually constitutes the principal ore, though altered rock, containing enough gold and silver to be classed as ore, occurs extensively in many places.

The primary character of propylite as a separate eruption is to some extent still upheld by Zirkel,* but his arguments are not convincing.

The Comstock Lode.—The relations at the Comstock lode, described by G. F. Becker,† are exceedingly interesting, because the deposit, besides being celebrated for its immense

---

* *Lehrbuch der Petrographie*, ii., p. 485.

† G. F. Becker, "Geology of the Comstock Lode," *Monograph III.*, *U. S. Geol. Surv.*

production, is a representative type. The vein, which carries both silver and gold, is surrounded by an area of extreme alteration, occupying a space of about 5 by 2 miles, affecting alike the diorite, diabase and andesite.* In the course of this alteration the hornblende and augite are changed to chlorite, which also infiltrates the feldspars. Pyrite is present in the rock in proportion to its alteration, and is probably developed from the ferro-magnesian silicates; to a lesser degree, from the magnetite. The feldspars are decidedly less easily altered than the silicates mentioned. Beginning alteration is made apparent by specks of calcite. Later on, quartz grains and an opaque white, doubtful substance appears. No kaolinite was recognized, and if present, it occurs in very subordinate quantities only. Epidote is more abundant near the surface than in depth, and appears to result from the further alteration of chlorite, under the influence of calcic solutions derived from the feldspars. Muscovite as a product of alteration of the feldspars is absent.

The extreme alteration is represented by the so-called clays, which were formerly supposed to consist largely of kaolin. Becker shows this assumption to be erroneous, and gives analyses to show that the clays are simply derived from the normal rocks by a partial alteration. An examination of the analyses quoted from the monograph of Clarence King,† in Table I., following page 152 of Becker's monograph, will show that in the diorites, andesites and diabases the Na_2O decidedly exceeds the K_2O. In two of the three analyses of "propylites," which are simply rocks subjected to incipient thermal alteration, the K_2O is present in decidedly larger quantity than the Na_2O. In the remaining "propylite" analysis, the reverse is true. The four analyses of the "clays," or the extremely altered, crushed and bleached material adjoining the veins, run as shown in table on the following page.

The quantitative relations of the alkalies clearly show a concentration of potash and a leaching of soda. There can scarcely be any doubt that these clays really consist of 30 to 40 per cent. of finely divided sericite, mixed with some quartz and residual rock.

---

* Without wishing to reopen the Comstock question, I would state my strong belief that these three rocks are separate and independent eruptive bodies.

† "Survey of the 40th Parallel," vols. i., iii., vi., *passim*.

Analyses of Comstock Clays.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	60.02	59.71	65.69	39.52
TiO_2	......	......	......	......
Al_2O_3	12.15	17.59	15.39	15.97
Fe_2O_3	4.38	5.04	2.11	4.47
FeO	......	......	......	......
MnO	......	......	......	......
CaO	6.00	0.73	1.66	9.20
MgO	1.40	4.41	2.85	3.40
Na_2O	0.45	1.01	2.36	......
K_2O	1.23	3.98	4.64	3.11
CO_2	3.17	......	......	6.20
FeS_2	1.84	3.58	2.84	9.18
P_2O_5	0.34	trace	trace	trace
H_2O	8.09	4.19*	2.80*	9.95
Total	99.07	100.24	100.34	101.00

	Locality.	Analyst.
I.	Yellow Jacket east clay,	S. W. Johnson.
II.	Chollar west clay,	W. G. Mixter.
III.	Hale and Norcross east clay,	W. G. Mixter.
IV.	Savage second station,	S. W. Johnson.

The Veins of Nagyág, Hungary.—In 1885, Béla von Inkey published an interesting report on the ore-deposits at Nagyág.[†] These consist, in brief, of a complicated system of not very persistent veins, cutting an eruptive mass of trachytic rocks breaking through Tertiary sediments, which in turn rest on older argillites. The deposits are famous as containing gold accompanied by various interesting tellurides. The whole occurrence bears in its geological relation some similarity to the deposits at Cripple Creek, Colo. The principal gangue is quartz, accompanied by galena, zinc-blende, pyrite, chalcopyrite, etc., besides gold and rich tellurides. In addition to the quartz, various carbonates are present. The fissures are small, but contain the (generally rich) ore as the filling of open spaces. The sedimentary rocks do not in general contain much valuable ore, although such occurrences are known. The ore-shoots are chiefly confined to the eruptive mass of trachyte. In the vicinity of the mineral deposits the trachytes are quite generally changed to so-called propylitic rocks, the change

---

* By ignition.

[†] *Nagyág und seine Erzlagerstätten*, by Béla von Inkey, Budapest, 1885.

consisting in the development of chlorite in the ferro-magnesian minerals. It is, in fact, difficult to obtain fresh rocks anywhere in the vicinity. In the immediate vicinity of the veins, and in the whole zone in which the veins are closely massed, the rock has suffered another alteration, which v. Inkey refers to as a kaolinization, in consequence of which the rock loses its normal hardness and greyish or greenish color, and is transformed into a soft brownish yellow to white mass, resembling kaolin. The last traces of hornblende and augite are lost, and only carbonates replace them. The biotite is transformed to a soft talcose substance. The magnetite is often replaced by pyrite. Only the quartz remains unaltered, and, in connection with the pseudomorphs of biotite, affords the best criterion for recognizing the trachytic nature of this highly altered rock. This modification is so clearly connected with the veins that its origin from the fissures cannot be doubted. Where the rock is not altered, rich shoots are rarely found. Von Inkey thinks that this alteration clearly indicates, not superficial waters, but thermal waters ascending on the fissures. Both kinds of alteration, the chloritic as well as the "kaolinitic," are regarded as closely related to the genesis of the veins. The chloritic modification is supposed to have resulted from a sort of hydrometamorphic action preceding the immediate formation of the veins. This so-called kaolinized rock has been examined in more detail by Dr. Kollbeck,* who showed it consists partly of sericite. Dr. Kollbeck separated the rock by means of heavy solutions, finding that, besides the sericite, it contained some pyrite (with a little arsenic, gold and silver), zircon and anatase, as well as a little apatite. The chief constituent fell between specific gravity 2.918 and 2.649, though most of it came down at 2.788. The analysis of the micaceous mineral gave the following composition: SiO_2, 48.67; Al_2O_3, 39.30; Fe_2O_3, 0.30; MnO, 0.25; CaO, 0.38; MgO, 1.42; K_2O, 3.73; Na_2O, 0.13; H_2O, 5.83; CO_2, 0.23; FeS_2, 0.43; total, 100.67 per cent.

As may be inferred from the variability of the specific gravity, the mineral is clearly not pure muscovite, but probably a mixture of sericite and kaolinite, as is shown by the high

---

* *Oesterr. Zeitschr. f. B. & H.-Wesen*, 1888, pp. 25–27.

percentage of alumina and water and the low percentage of potassa.

Pachuca, Mexico.—Another type of this class of veins is described by Messrs. J. Aguilera and E. Ordoñez.* The well-known and very productive veins of Pachuca cut a series of Tertiary effusive rocks, principal among which is a pyroxene-andesite. Rhyolite and basalt are also present, but contain, near Pachuca, no mineral veins. The deposits are typical fissure-veins, filled with a gangue of quartz carrying in fine dissemination argentite, pyrite, galena, zinc-blende, stephanite and polybasite. The value is almost exclusively in silver, very little gold occurring. There is no ruby-silver; and in depth the veins are said to be impoverished by the appearance of large quantities of barren zinc-blende. The pyrite and galena contain a little silver, but no gold. Calcite appears in subordinate and varying quantities, as the latest gangue, filling interstices between quartz crusts. Inclusions of country-rock in sharp fragments are common in the quartz. On the whole, there can be no doubt that the ore in these veins is chiefly the filling of open cavities by quartz, as in the gold-quartz veins of California.

Over a large area in the vicinity of the veins the rocks contain much chlorite and quartz, with a little calcite. Close to the veins, the alteration is most intense. The country-rock is filled with small, perfect crystals of pyrite, which is always practically barren. Its sharply developed crystal-form contrasts with the generally anhedral form of the pyrite in the vein. Black sulphides occasionally, but rarely, appear in the country-rock next to the veins. These are, of course, rich. The rocks immediately adjoining the veins contain, besides pyrite, much chlorite, also some calcite and a considerable amount of secondary quartz. The latter is so abundant that the chief alteration near the vein is often a silicification, the quartz sometimes appearing in the ground-mass; in other cases the whole rock is silicified by substitution of quartz. Chalcedony, and more rarely opal, is also found in the altered rock. In many cases, in the deeper parts of the veins, the only difference between the rocks adjoining and those more distant from the vein is in

---

* *Boletin del Instit. Geol. de Mexico*, Nos. 7, 8, 9. "El Mineral de Pachuca."

the quantity of impregnating silica. The pyroxene alters to chlorite and epidote. The feldspars (oligoclase and labradorite) are often converted to calcite, epidote and quartz. Mr. Ordoñez says further that the feldspars have a marked tendency to become transformed into kaolinite (*arcilla*). As he gives no analyses of the altered rocks, it is difficult to judge whether finely divided sericite is present or not. On the whole, the similarity of this district to the Comstock, so far as the alteration is concerned, is very striking; and there is little doubt that the two deposits owe their origin to extremely similar solutions.

New Zealand.—The auriferous veins of Thames, New Zealand, are contained in andesitic rocks, which, near the fissures, have suffered considerable alteration. The character of this alteration has been described by F. W. Hutton* in a report on the rocks of the Hauraki gold-fields, which include, among others, the Thames district, and are situated near Auckland on the northern island. Triassic or pre-Triassic sediments are unconformably overlain by younger volcanic formations which contain the gold-deposits. The rocks consist largely of andesite, both augitic and hornblendic, which is accompanied by masses of tuffs and breccias. Rhyolite and dacite also occur. The alteration, chiefly of propylitic character, is distinguished by the appearance of much secondary chlorite, not only in the bisilicates but also in the ground-mass and in the feldspars, the latter, besides, altering to calcite and "kaolin." The chlorite alters again, in places, to a mineral which, from the description of the author, probably is sericite. Another common secondary product is quartz in fine aggregates. The pyrite frequently, though not always, present, is sometimes derived from magnetite. In other cases it is associated with the product of decomposition of titanic iron-ore, usually referred to as leucoxene. The color of the rocks subjected to the propylitic alteration is greenish grey, which, on further alteration, changes into lighter tints. The process is illustrated by several analyses by Skey, but they only throw an imperfect light upon the subject, as the alkalies are not separated, nor CO_2 and H_2O individually determined.

Prof. Hutton is a pronounced advocate of lateral secretion, and believes that the gold was derived from the surrounding volcanic rock. This conclusion is disputed by Dr. Don.†

---

* *Austral. Ass. Adv. Sci.*, vol. i., 1887, pp. 245–274.

† "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 586.

Alaska.—The Apollo mine on Unga Island, described by G. F. Becker,* is an interesting deposit in andesitic rocks. The ores consist of pyrite, galena, zinc-blende, chalcopyrite, with a little calcite. Native gold and copper occur with these ores, and the presence of a small quantity of orthoclase has also been proved. According to Becker, the ore is present exclusively as the filling of cavities, and shows beautiful comb-structure. In the vicinity of this deposit, the andesites are highly chloritic and contain abundant pyrite. Neither sericite nor carbonates are mentioned. The course of the alteration is very clearly propylitic. The pyrite in the altered rock is largely derived from the ferro-magnesian silicates.

Silver Cliff, Colorado.—The deposits of Silver Cliff should probably be referred to the propylitic class, although sericitization here also appears as a very important metasomatic characteristic. The districts of Silver Cliff and the Rosita Hills, as described by Messrs. Emmons and Cross,† are characterized by a complex of andesites, rhyolites and trachytes, resting on old Archean rocks and erupted through them. The igneous rocks and, to some extent, the old gneisses are traversed by a system of veins and irregular deposits carrying chiefly silver-ores, consisting of tetrahedrite, stephanite, pyrite, chalcopyrite and galena, in a gangue of barite with a little calcite. The ore consists chiefly of altered country-rock in which the different sulphides and gangue-minerals have been developed by metasomatic replacement. Mr. Emmons considers that the solutions first filled narrow fissures between sheeted rocks, and from these fissures gradually worked into the rock itself. The whole occurrence at Silver Cliff appears to show strong analogy with that of Cripple Creek and Nagyág; for in all of these places a relatively small complex of Tertiary eruptive rocks, at or near the point of eruption, has been traversed by a complicated system of fractures along which the ore has been deposited by solutions penetrating the fissures, as a later manifestation of the eruptive activity.

Over large areas the rock, especially the andesite, is much decomposed and bleached, and also contains a considerable

---

* 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 83.

† 17*th Ann. Rept. U. S. Geol. Surv.*, part ii., pp. 269–472.

amount of pyrite. The greenish color first appearing is due to the development of chlorite, the pyroxene being replaced by chlorite, calcite and quartz. Further alteration results in a strong sericitization, and in removal of iron and lime. The biotite always changes into muscovite, which sometimes contains crystals of anatase. The lime-soda feldspars are also replaced by aggregates of muscovites, but the potash-feldspars are rarely altered until all the other minerals have been almost completely decomposed. The magnetite disappears with the silicates. Pyrite is common, and in certain cases seems to be a direct replacement of magnetite. Calcite is frequently associated with muscovite, and may replace plagioclase or augite. Mr. Cross recognized no kaolin in noteworthy amount among the products of alteration. In some instances the bleaching extends through large rock-masses, but it clearly proceeds from fissures. Near the veins, the bleached rock adjoining the small fissures may gradually shade off into fresh rock within a few feet.

A silicification is noted in some cases, especially in the case of a dike of rhyolite,* which has suffered so great alteration as to be almost completely changed to quartzose fine-grained material. The andesite may also occasionally show silicification. The rhyolite is altered in some places to soft, whitish material, and in other places to hard cavernous quartzose material. The contacts of rhyolite and andesite are sometimes changed to such a degree as to make rock-determination very difficult.

Silver City, Idaho.—The fissure-vein of the Trade Dollar and Black Jack mines, Florida mountain, near Silver City, Idaho, presents some unusual features.† The sharply defined vein cuts across granite, basalt and rhyolite. The ores consist of argentite and chalcopyrite in a gangue of quartz and valencianite (orthoclase), forming typical fillings of open spaces. The alteration affects the various rocks somewhat differently; but the vein is undoubtedly of the propylitic class, in the formation of which alkaline carbonates and carbon-dioxide were present only in small amounts.

In the granite the adjoining rock is very slightly altered, though spaces of dissolution and crushed portions in it may be filled with quartz and valencianite.

---

* *Loc. cit.*, p. 358.

† W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, pt. iii., pp. 134–144, 174–187.

The rhyolite is extensively altered and somewhat silicified, the quartz crystals having received aureoles of the same mineral in secondary deposition. The feldspars are often converted into fine-grained quartz and sericite, the ground-mass being changed to the same minerals, and the quartz predominating. A little kaolinite is probably also present, and pyrite in small cubes is scattered through the rock. Near the underlying basalt, epidote and chlorite have been introduced into the rhyolite, indicating an upward movement of the solution.

The basalt is also considerably altered, and the character is typically propylitic, with abundant chlorite and pyrite, and slight changes otherwise in the chemical constitution.

6. *Fluoritic Gold-Tellurium Veins.*

This peculiar and interesting class of deposits, the discovery and study of which date only a few years back, is characterized by the appearance of tellurides of gold and silver, besides a little native gold; by the universal presence of (usually purple) fluorite; and by an intense metasomatic action—so that the larger proportion of the ores consists of altered country-rock. The gangue is quartz, fluorite and barite; ore-minerals, except tellurides, are not very abundantly present.

The age of these deposits, as thus far known, is probably Tertiary, following the outbreaks of phonolitic magmas, with which all of the occurrences show a remarkable connection. The depositing waters must have been poor in carbon-dioxide, alkaline and earthy carbonates, but contained more or less fluorine as hydrofluoric acid, which is possibly indicated by the abundant spaces of dissolution in the granite of Cripple Creek. Or else (and this was probably the more common case) they contained alkaline fluorides. Though the veins are closely connected with the eruption of phonolitic magma referred to, it is not believed that the conditions of deposition were of pneumatolytic character, but rather that they were normally hydrothermal.

Cripple Creek.—The geology and mineral deposits of the Cripple Creek district, Colo., have been examined by Whitman Cross and R. A. F. Penrose.* The general occurrence of the veins is somewhat analogous to that of Nagyág, Hungary, and

---

* 16*th Annual Report U. S. Geol. Surv.*, part ii.

Silver Cliff, Colorado, inasmuch as they cut igneous masses, here consisting of andesite and phonolite, and occur in close proximity to the original *locus* of eruption of these rocks. The veins, of which there are a great number, contain native gold, tellurides and pyrite, together with a little galena and zinc-blende. Silver is present in very small amounts only. The gangue consists of quartz, fluorite and barite. Prof. Penrose designates the veins as very largely replacement veins, formed by metasomatic action of the solutions ascending in narrow fissures on the surrounding country-rock. Filling of open fissures exists to a subordinate extent. Large masses of the volcanic rocks, especially the porous tuffs, were subjected to thermal action prior to the formation of some of the fissures. The alteration results in silicification, kaolinization and some sericitization. In the breccia and tuff, the process consists in the total destruction of the dark silicates, and the substitution of a white mica for them. The feldspar changes to muscovite or kaolin; the only fresh remaining crystals consist of apatite; and the rocks are greatly impregnated with pyrite. In some places the alteration consists in a silicification, but more commonly muscovite or kaolin are the minerals formed. Penrose says also that kaolin occurs in the veins in irregular masses, mixed with quartz. Three analyses of this product show that it is a normal kaolin. While it is conceded that the kaolin is to some extent the result of surface alteration, its formation was chiefly earlier than the development of this superficial alteration. The quantity of kaolin, he says, does not diminish in depth, where it still occurs associated with unaltered sulphides.

An opaline silica is also found in the veins, often appearing like red, brilliant, conchoidal jasper. An analysis of it shows: SiO_2, 72.46; Al_2O_3, 2.52; Fe_2O_3, 17.88; CaO, 0.14; MgO, trace; K_2O, 1.08; Na_2O, 0.06; H_2O, 5.70; total, 99.84 per cent.

The origin of this product is not stated, but it is not improbably the result of extreme alteration of a volcanic rock. It is interesting to note that among the alkalies K_2O strongly predominates, and, to judge from the analysis, the rock must contain about 10 per cent. of sericite.

During the last year I had opportunity to examine a suite of specimens collected by Mr. S. F. Emmons from the Independence and Portland mines; and some of the results are here published with his permission. At these mines, the narrow fissure along which the replacement took place cuts both the granite and the andesite-granite breccia, and in places follows a dike of phonolite. The specimens clearly bear out previous statements as to replacement. In addition to the fluorite, secondary orthoclase, or valencianite, was recognized as a universally present gangue-mineral. The granite-ore from both mines consists of a coarsely granular rock, largely of microcline and quartz, made cellular and porous by spaces of dissolution. The cavities are coated with abundant small and clear crystals of valencianite showing the usual combination of prism and dome; also with a little pyrite, gold, and small cubes of fluorite.* The crystals of valencianite were isolated and conclusively identified by qualitative analysis and tests. Microscopic analysis reveals but little alteration in the granite, though the biotite foils are replaced by a substance which appears to be valencianite. The feldspars contain a few shreds of sericite, and pentagonal crystals of pyrite are scattered through feldspar and altered biotite. In places, small replacement-veinlets of fluorite and quartz traverse the feldspar. The cavities of dissolution apparently result from the removal of both quartz and microcline. Some of them are filled with quartz, valencianite and pyrite; the secondary feldspar often being deposited with orientation parallel to that of older grains. A few grains of secondary feldspar show microcline structure, but most of them are simple individuals. These filled spaces, characterized by crustification, are illustrated in Fig. 11.

The processes of replacement are remarkably variable. In some of the granite-andesite breccias the result is quartz, valencianite, fluorite and pyrite. Fig. 10 shows how the replacement progresses in a grain of orthoclase. Fig. 8 shows a filled veinlet in the same breccia, which by means of a narrow crack connects with the feldspar grains just mentioned. The valencianite shows crustification, while the fluorite and pyrite, by corroding the walls, indicate partial metasomatic action.

Some of the phonolites of the Independence mine are porous siliceous rocks, completely replaced with quartz, valencianite crystals, pyrite, and a few grains of a telluride of gold and

---

* Confer: W. Lindgren, "The Gold and Silver Veins of Silver City," *20th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 167.

silver. Other specimens show only incipient alteration, being impregnated with pyrite crystals and containing a few per cent. of sericite; they contain, besides, spaces of dissolution filled with quartz, fluorite and valencianite. Certain fine-grained granitic breccias from the Annie Lee shoot, in the Portland mine, show a most peculiar alteration, the quartz and orthoclase being both replaced by calcite, pyrite and secondary orthoclase. The final result of the alteration of phonolite is, in many cases, a purple fine-grained rock consisting of quartz, fluorite and pyrite; as usual, the fluorite is crystallized; and the quartz also shows, to some extent, idiomorphic outlines (Fig. 9).

Other Occurrences.—To this class belong also the so-called Potsdam tellurium-ores of the Black Hills, Dakota, described by Devereux, Carpenter, F. Clemes Smith, and lately by J. D. Irving.* According to Mr. Irving, the irregular deposits are connected with fissures, and consist in a replacement of limestone by silica, with fluorite, and gold, partly in the form of tellurides. While the age of these deposits is not fully known, they are believed to be genetically connected with phonolitic and tinguaitic dikes of Tertiary age.

Mr. W. H. Weed† has described interesting occurrences of the same type from the Judith mountains in northern Montana. The deposits, though, strictly speaking, not fissure-veins, are still more or less clearly connected with fractures, and are found in the brecciated contact-zone between limestone and intrusive masses of acidic porphyry. The principal gangue-minerals are quartz and purple fluorite, the ore-minerals being native gold and tellurides of gold and silver. The mode of ore-deposition is certainly a replacement of limestone, the fluorite occurring in more or less sharply defined patches in the limestone breccia. From a specimen which Mr. Weed kindly selected for me a section was cut, which is partly illustrated in Fig. 14. The invasion of the normal limestone, still carrying organic remains, by the crystallizing fluorite, is well shown, as well as the incipient silicification which accompanied the metasomatic action. Much secondary silica, replacing limestone,

---

* "A Contribution to the Geology of the Northern Black Hills," *Ann. N. Y. Acad. Sci.*, vol. xii., No. 9, pp. 297–314.

† 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 588.

also occurs in jaspery or cherty form. Small cubes of fluorite, found in the fresh limestone, represent places of incipient fluoritization. Dikes and sheets of phonolitic rocks are found in the vicinity of the deposits. A deposit occurring in rhyolite porphyry not far from the limestone shows strong alteration of the country-rock. The feldspar is here changed to sericite, the ferro-magnesian minerals are transformed to calcite, and abundant small crystals of pyrite appear in the rock. Fluorite is also present on some of the veins in rhyolite porphyries. Mr. Weed regards the deposits as possibly of pneumatolytic origin. It is scarcely necessary, however, to assume the fluorine to have been present in the form of free hydrofluoric acid (compare pp. 521 and 524).

Similar deposits, with purple fluorite and tellurides, are also described by Mr. Weed from the Little Rocky Mountains, in Montana.*

7. *Sericitic and Kaolinitic Gold- and Silver-Veins.*

General Remarks.—This class has not been studied as much as some of the other subdivisions, but many deposits will probably be found to belong to it. Apparently the pure aluminic silicate cannot be formed when the generating waters contain much carbon dioxide or alkaline carbonates. But it does form under the influence of some waters containing a small amount of these reagents, and also in the presence of sulphuric acid, which, as is well known, rapidly attacks the feldspars. Even under the latter two conditions, some sericite is ordinarily also formed; and I am not aware of any veins in which kaolinite forms without sericite. The class may be subdivided according to the absence or presence of silicification.

The Freiberg Veins.—As is well known, several very different kinds of veins appear in the Freiberg district, practically all, however, being sharply defined fissure-veins in gneiss, in which the filling of open spaces constitutes the only ore; extensive zones of alteration are absent. It is a peculiar fact that very little is known of the metasomatic processes affecting the country-rock at this celebrated locality, no chemical examinations having been made to determine how the various classes of

---

* *Journal of Geol.*, vol. iv., pp. 399–428 (1896).

veins may differ in their metasomatic products. A letter from Prof. Beck, of Freiberg, informs me that Prof. A. W. Stelzner devoted much time during the last years of his life to the examination of the changes in the country-rock adjoining the veins, but that his manuscript notes have never been published.

W. Vogelgesang,* in describing the veins south and southeast of Freiberg containing carbonates and rich silver-ores, describes the impregnation of the adjoining rock with ores. He mentions the occasional introduction of argentite and native silver into the gneiss, also, in places, of arsenopyrite, pyrite, chalcopyrite, zinc-blende and galena. The impregnation with silver-ores appears only in especially rich places along the vein. In one case, however, the impregnated rock appears as an irregular, limited mass, almost entirely independent of the direction of the vein. In another locality, chalcopyrite and bornite were found in the wall-rock, while the filling of the vein contained neither. In the same paper, the author describes the alteration of the so-called normal gneiss of Freiberg near the veins of the *Kiesige Bleiformation*. The mica is the first mineral attacked; the second is the feldspar. The former acquires a silvery-white color, often connected with a chloritic appearance. The feldspar is changed to a white "kaolin," and the whole rock is bleached white. By extreme alteration, the quartz disappears, and the rock forms a white or yellowish-white talc-like mass. The altered rock is frequently, in fact usually, filled with arsenopyrite. Some of the crystals are large; others microscopic; and their amount may so increase as to form a connected, compact mass of arsenopyrite. All these crystals are twins, excellently developed, with perfect faces. This description refers especially to the *Dietrich Stehender* vein.† In the foot-wall, and partly also in the hanging-wall, of this altered mass appears a rock, recognizable as the ordinary grey gneiss of Freiberg. It contains no aresenopyrite but is strongly impregnated with galena, arranged in curved streaks parallel to the schistosity, and replacing one constituent of the rock, namely, the feldspar. The altered rocks have been analyzed; but the determination of alkalies being omitted, the analyses have no special value.

---

* Bernard Cotta, *Gangstudien*, vol. ii., Freiberg, 1854, p. 78.

† The sericite from this vein has been analyzed by H. Schulze; see page 609.

The rock adjoining the Gotthold-Stehender vein is likewise strongly impregnated; but here, besides arsenopyrite, galena, chalcopyrite, pyrite and zinc-blende are also found.

As early as 1883 and 1884 Stelzner* devoted considerable attention to the examination of the soft and altered rock adjoining the veins of Freiberg. These altered rocks are also usually impregnated with small crystals of arsenopyrite, or pyrite, or (more rarely) zinc-blende and galena. In the normal gneiss of Freiberg, which Prof. Stelzner subjected to separation by heavy solutions, he found much zircon, as well as a little tourmaline and a large quantity of apatite. All three of these minerals were also separated from the altered wall-rocks in the crystalline shape which they had had in the fresh rock; hence none of them had been attacked. He observes further that the quartz, feldspar and biotite of the fresh gneiss is completely or almost completely changed into white potassium mica, forming, in small hexagonal or irregular foils, the chief mass of the rock. This secondary mica contains, according to analysis by Dr. Schulze, as much as 0.41 per cent. of TiO_2 and 0.54 per cent. of SnO_2. As newly-formed minerals in the altered rock, appear small crystals of quartz, rutile and anatase. In certain of the examined rocks only rutile was found, in others only anatase (octahedrite), but both were present as sharply defined small crystals. These two minerals are considered as resulting from a decomposition of the biotite, which is rich in titanic acid. In analyzing the heaviest part obtained by the Thoulet solution from the altered rock close to one of the veins, it was found that cassiterite was present in notable quantity. Whether this tin-ore resulted from the decomposition of the biotite, or whether, like the arsenopyrite, it had been introduced from the vein-fissure, is not certain. The latter hypothesis is probable; for the black zinc-blende of the same vein (the Carl Stehender) contains small, but numerous, crystals of cassiterite.

Examination of the fresh gneisses of Freiberg discloses the presence of pyrrhotite, pyrite, and probably also a little arsenopyrite. These are presumably primary; at least the statement of Prof. Stelzner is probably to be interpreted in this sense.

The first attempt to examine the altered wall-rocks in a sci-

---

* A. W. Stelzner, "Studies of the Gneiss of Freiberg and its Products of Alteration." *Neues Jahrbuch*, 1884, vol. i., p. 271.

entific manner was made by Prof. Th. Scheerer,* in connection with his classic paper on the gneissic rocks from the vicinity of Freiberg. According to Scheerer, the normal character of the grey gneiss is always more or less changed in the vicinity of mineral veins, the extension of this alteration being, in general, dependent upon the width of the vein. The mica has turned into a light greenish-grey or white talcose mass; and the whole rock is softened and easily crushed. The width of this alteration ranges from a few inches up to 6 feet. In the porous gneiss, small bodies of pyrite, zinc-blende and galena have been formed; partly as separate crystals, and partly in little veinlets. Prof. Scheerer examined especially a gneiss closely adjoining the Erzengel vein belonging to the *Kiesige Bleiformation*, in the Himmelfahrt mine. The specimen was taken from one of the deep levels, thus eliminating the action of surface-water. The analysis gave: SiO_2, 61.69; TiO_2, 0.73; Al_2O_3, 21.74; Fe_2O_3, 0.43; CaO, 1.07; MgO, 1.15; K_2O, 2.69; Na_2O, 0.30; H_2O, 3.96; fluorite, 1.20; pyrite, 4.26; chalcopyrite, 0.23; galena, 0.09; argentite, trace; total, 99.54 per cent.

Scheerer recalculated this analysis on the basis of constant alumina and, combining the result with the analyses of the fresh rock, obtained the table on the following page. The assumed constancy of the alumina is probably not quite correct, but offers an easy and fairly accurate way of approximately judging the changes that have taken place.

This result is remarkable in many respects. First, we note that a very decided removal of substance has taken place. Counting by equal weights, only 5 parts in 100 have been added (even less, if we consider that the Fe of FeS is derived from Fe_2O_3 and FeO in the fresh rock) while no less than 42.45 parts have been carried away. This contrasts strongly with the results obtained from gold-quartz veins in California and Idaho. Of the silica, 26.62 parts or 40 per cent. is removed. The total bases, except alumina, have been diminished to the extent of 81.01 per cent. Both K_2O and Na_2O have been removed; the former, however, in much smaller proportion than the latter. Lime, magnesia and iron have also been very greatly reduced. A large part of the iron, however, appears to

---

* *Zeitschr. d. d. geol. Ges.*, vol. xiv., p. 87 (1862).

	Normal Grey Gneiss.		Altered Grey Gneiss.		Additions and Subtractions Suffered by the Altered Rock.	
	Per cent.		Per cent.		Per cent.	
SiO_2	65.42		38.80		-26.62	
TiO_2	1.05		0.46		-0.59	
Al_2O_3	13.68		13.68		...	
Fe_2O_3	4.26	18.80	0.27	3.56	-3.99	-15.24
FeO	2.88		...		-2.88	
CaO	1.44		0.67		-0.77	
MgO	2.66		0.73		-1.93	
K_2O	6.18		1.70		-4.48	
Na_2O	1.38		0.19		-1.19	
H_2O	1.05		2.49		+1.44	
Fluorite	...		0.76		+0.76	
Pyrite	trace		2.68		+2.68	
Chalcopyrite	trace		0.15		+0.15	
Galena	trace		0.06		+0.06	
Argentite	...		trace		trace	
	100.00		62.64		-42.45 +5.09 37.36	
			100.00			

have been transformed into pyrite. There are no carbonates at all, while a little fluorite has formed.

Of course, no microscopic diagnosis of Scheerer's specimens is now available. But from Stelzner's later separations and Schulze's analysis it is clear that considerable sericite is present. An attempt to calculate Scheerer's analysis shows at once that kaolinite is also present. A rough calculation gives the following result: Quartz, 40; sericite, 32; chlorite, 3.20; kaolinite, 17.70; titanite, 1.90; fluorite, 1.20; pyrite, 4.26; chalcopyrite, 0.23; galena, 0.09; total, 100.58 per cent.

In this calculation $K_2O + Na_2O$ are taken as a basis for sericite, according to Schulze's analysis; MgO is calculated as chlorite; the remaining H_2O is calculated, with proper quantities of Al_2O_3 and SiO_2, as kaolinite; and there is a small excess of CaO, possibly belonging to apatite. P_2O_5 is not determined in the analysis. But there remains also an excess of 4 per cent. of Al_2O_3, which is inexplicable on the basis of this assumed mineral composition; and it is difficult to see how this should be treated. Possibly the determination of H_2O is a little too low. At any rate, a considerable amount of kaolinite is surely present. This result is of great interest. The strong leaching of SiO_2 and bases, as well as the presence of kaolinite together with sericite, points to a process and to water very different from those by which sericite alone is produced. It is not out of place in this connection to call attention to the presence of fluorite and to the close relationship which, as indicated by Dalmer, exists between the cassiterite-veins and those of the *Kiesige Bleiformation* of the Erzgebirge, a relationship still further emphasized by the occurrence of cassiterite in the Freiberg veins. Scheerer believed that the grey gneiss, by reason of its easily-attacked biotite, had a precipitating influence on the mineral waters. The red gneiss, containing muscovite in general, carries no large bodies of ore.

De Lamar, Idaho.—The quartz veins of De Lamar, Idaho, belong to that class in which the alteration of the country-rock results in sericite, kaolinite and quartz.[*] These ores, which carry finely-divided gold, together with some rich silver minerals, are peculiar, because the quartz now constituting the filling is pseudomorphic after a former vein-filling of calcite. The country-rock has undergone two corresponding changes: the first consisting in a normal sericitization; the second in a silicification, probably under the influence of waters containing sulphuric acid. The final result is that the rhyolite is converted to a silicified rock, in which the structure is plainly preserved. The phenocrysts of quartz have received aureoles of secondary silica; and the feldspars are fully converted into fine-grained aggregates of quartz. The composition is as follows: Sericite, 15.43; kaolinite, 3.81; quartz, 78.73; pyrite, 0.90, and water (hygroscopic), 0.51; total, 99.38 per cent.

Expressed quantitatively, the process appears to consist in the loss of nearly all of the soda, half of the alumina and much of the ferrous and ferric oxide; and finally, in the addition of several per cent. of silica. The pseudomorphic filling consists of crossing laminæ of quartz, each consisting of a thin plate of microcrystalline silica, coated on both sides with small quartz crystals.

The character of the process involved in this change from calcite to quartz is probably as follows: Calcite-filling in veins is often characterized by a prevalence of long, slender or spear-shaped grains. The solutions carrying silica penetrate along

---

[*] W. Lindgren, 20*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 178 *et seq.*

the contact-planes of these grains and deposit their plates of microcrystalline quartz in the place of dissolved calcite; from these medial plates small quartz crystals grow into and gradually replace the calcite on both sides. The pseudomorphic plates do not, as a rule, follow the cleavage-planes; hence there may be in some cases considerable difficulty in determining the original mineral replaced by the quartz. The subject is more fully treated in my report, cited above.

Summit District, Colorado.—Some remarkable ore-deposits in the Summit district, Rio Grande county, Colo., have been described by R. C. Hills* as masses of quartz resulting from the alteration and silicification of eruptive rocks along contact-planes, especially between rhyolite and trachyte-breccia. The quartz, which contains gold, enargite, pyrite, galena and zinc-blende, gradually merges into rhyolite, varying in thickness from 3 to 30 feet. Thus silicification of the rhyolite is evident, and has resulted in a change of the ground-mass to compact quartz, while the phenocrysts of that mineral remain intact and conspicuous. The sanidine has been removed, and pseudomorphic quartz has been deposited. The surrounding rock is notably kaolinized, and contains no lime or potash. The alteration probably took place less than 300 ft. below the original surface.

The following is suggested in explanation of the chemical processes: Silica is practically insoluble in solutions containing sulphates and chlorides, hydrogen sulphide and free sulphuric acid. Under these conditions, aluminum silicates are dissolved and sulphates or chlorides of aluminum are formed, with simultaneous separation of silica; and to sulphuric acid as a reagent the writer believes the alteration to be chiefly due. Whether the metallic minerals were deposited simultaneously with this alteration, or subsequently, is left an open question, though it is believed that their simultaneous deposition would be possible.

8. *Sericitic and Calcitic Gold-Silver Veins.*

This important metasomatic class comprises an enormous number of veins, differing widely in age and in the character

---

* *Proc. Colorado Sci. Soc.*, vol. i., p. 20.

of the country-rock, but usually characterized by quartz-filling, enclosing auriferous and argentiferous sulphides (often also free gold), while the adjoining rock for a short distance on both sides is converted into an aggregate of quartz, sericite and calcite, with some metasomatic sulphides. Extensive alteration-zones are not common; and sometimes fresh rock may adjoin the vein. The relative quantity of sericite and carbonates may differ considerably, even in the same mine.

The Gold-Quartz Veins of California.—These, perhaps the most prominent representatives of the class, have been studied in some detail.* The gold-quartz veins of California are fissure-veins of Cretaceous age, largely filled with quartz along open spaces. A small amount of calcite may also occur. The ore-minerals comprise native gold, present in a free state at all depths reached hitherto, and a small amount of sulphides consisting of pyrite (never marcasite and rarely pyrrhotite), galena, zinc-blende, arsenopyrite and chalcopyrite. Tellurides are often found, but in small quantity only. The veins are practically independent of the character of the country-rock, cutting almost all the sedimentary and igneous rocks of the Sierra Nevada. Adjoining the veins the country-rock, for a variable distance, but seldom exceeding a few feet, is nearly always altered by metasomatic processes. Clay-slates and siliceous schists have been apparently least affected in this way, except that they are generally impregnated with pyrite. More detailed chemical examinations will probably show that even these rocks have been altered more than their appearance would suggest.

In the ordinary course of the metasomatic process, augite, hornblende, epidote, biotite and feldspars are first vigorously attacked. The ferromagnesian silicates are often converted into large foils of muscovite. The alteration proceeds along cracks and cleavage-planes, and a finely felted aggregate of sericite and calcite invades the grains until the replacement is complete. Though the ferromagnesian silicates are, for the most part, directly converted into the minerals mentioned, they form also a chlorite, very rich in iron, as an intermediate

---

* W. Lindgren, *Bull. Geol. Soc. Am.*, vol. vi., pp. 221–240; also in *U. S. Geol. Surv.*, 14*th Ann. Rept.*, pt. ii., pp. 249 to 284, and 17*th Ann. Rept.*, pt. ii., pp. 1 to 262.

stage, which is converted later into sericite. An interlacing structure of sericite foils, the triangular or polygonal interstices of which are filled with calcite (Fig. 12), is often noted. The quartz is also attacked, but with more difficulty; and in no case is it completely replaced by the attacking sericite-carbonate aggregate (Fig. 15). Magnetite seems to be converted mostly into ferrous carbonate, and ilmenite to rutile. Sharp cubes of pyrite form in the new aggregates, but also in the fresh primary minerals. The only other sulphide found is arsenopyrite, which, in some mines, appears as sharply defined rhombic crystals. The sulphides sometimes include fibers of sericite. The result of the process is the conversion of the rock to sericite, carbonates, quartz and pyrite, with retention of the original structure as shown in Fig. 27. The alteration of serpentine has already been referred to.

From many analyses the following eight are selected, A and A_1, B and B_1, etc., being respectively the unaltered and altered rock from each locality :

TABLE I.—*Analyses of Metasomatic Rocks from Gold-Quartz Veins.*

	A.	A_1.	B.	B_1.	C.	C_1.	D.	D_1.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	65.54	46.13	45.56	37.01	66.65	56.25	51.01	45.74
TiO_2	.39	.67	1.11	.85	.38	.25	.98	.36
Al_2O_3	16.52	15.82	14.15	12.99	16.15	17.65	11.89	5.29
Fe_2O_3	1.40	.89	1.20	.43	1.52	.76	1.57	.13
FeO	2.49	2.27	9.83	3.57	2.36	2.64	6.08	2.06
FeS_2	......	1.61	7.86	7.99	.02	2.87	1.73*	.49
Cu_2S	......	......	.10	trace	......	......	trace	......
MnO	.06	.09	.25	.24	.10	none	trace	.26
NiO, ZnO	......	trace	trace	trace	......	......	......	......
CaO	4.88	10.68	2.30	9.78	4.53	4.46	10.36	23.85
SrO	not det.	trace	trace	trace	trace	......	none	none
BaO	not det.	trace	trace	trace	.07	.03	none	trace
MgO	2.52	2.13	6.76	5.49	1.74	1.69	8.87	.94
K_2O	1.95	5.30	1.18	4.02	2.65	6.01	.15	1.29
Na_2O	4.09	.17	1.57	.13	3.40	.30	4.17	.11
Li_2O	......	trace	trace	trace	trace	......	......	trace
H_2O below 110° C.	......	.12	.23	.13	.18	.30	.24	.22
H_2O above 110° C.	.59	2.42	4.84	1.92	.72	2.36	2.09	1.07
P_2O_5	.18	.10	.14	.06	.10	.21	.17	.07
SO_3	......	......	.03	.04	......	......	......	......
CO_2	......	11.24	3.04	15.04	......	4.82	......	18.91
Total	100.61	99.64	100.15	99.69	100.57	100.60	99.31	100.79

* Probably present as Fe_7S_8.

A, Fresh granodiorite, Lincoln, Placer Co. Though not adjoining the vein, it indicates closely the actual composition of the fresh wall-rock. W. F. Hillebrand, analyst.—A_1, Altered granodiorite, Plantz vein, Ophir, Placer Co. W. F. Hillebrand, analyst.—B, Amphibolite schist, Mina Rica vein, Ophir, Placer Co. Fairly fresh, but contains pyrite and calcite. W. F. Hillebrand, analyst.—B_1, Completely altered amphibolite schist, Conrad vein, Ophir, Placer Co. W. F. Hillebrand, analyst.—C, Fresh granodiorite, Nevada City, Nevada Co. W. F. Hillebrand, analyst.—C_1, Altered granodiorite, Bellefountain mine, Nevada City. George Steiger, analyst.—D, Fresh diabase, Grass Valley. N. H. Stokes, analyst.—D_1, Altered diabase, North Star mine, Grass Valley. W. F. Hillebrand, analyst.

From the chemical and microscopical data the following compositions may be calculated (see reports cited). The only difference from the sources quoted is due to the fact that by later chemical examination the titanium mineral present has been shown to be rutile instead of titanite.

TABLE II.—*Mineralogical Composition of the Altered Rocks of Table I.*

	A_1.	B_1.	C_1.	D_1.
	Per cent.	Per cent.	Per cent.	Per cent.
Quartz	16.00	24.00	25.00	35.00
Sericite (with a little chlorite)	41.76	46.97	61.46	21.20
Calcite	17.53	18.87	7.23	42.15
Magnesite	9.67	2.93	2.70	.71
Siderite	5.76	3.67	.58	...
Rhodonite	.42	.14	...	...
Rutile	.85	.67	.25	.36
Pyrite	7.99	1.61	2.87	.50
Apatite	.13	.22	.46	.15
Total	100.11	99.08	100.55	100.07

As it seems probable that the alumina has remained fairly constant in the first three pairs of analyses in Table I., they may be directly compared for an approximate review of the chemical changes affected. A recalculation on the basis of constant alumina seemed scarcely worth while.

The silica has been in all cases greatly reduced. Except in A, which is not from the immediate vicinity of the vein of A_1, the titanic acid has decreased. Ferrous and ferric oxide are both reduced—the latter more than the former; and the whole or a part of this loss reappears as pyrite. Lime shows great increase except in C, where it is constant. Baryta in C shows partial loss. The loss of magnesia is considerable, except in C, where it is slight. Potassa is strongly increased throughout; and there is a corresponding loss of soda.

D_1 differs from the rest in an exceptionally high percentage of introduced lime and carbon-dioxide, and a corresponding loss of magnesia. Moreover, the alumina is so low that removal of this constituent must be supposed to have taken place.

The characteristic features of the process seem to consist in the decrease of silica, magnesia and soda, and increase of lime, potassa and carbon-dioxide—this calcitic altered rock strongly contrasting with the quartz-filled veins. Sufficient data are not available for the accurate determination of change of volume during the process, and of the actual losses and gains. They could probably be determined by analyses and specific gravity determinations of very carefully selected samples of the fresh rocks, and of altered rocks immediately adjacent to them. It seems probable that, in most cases, the added material has more than balanced the losses.

Idaho Types.—In the Rocky Mountain region appear other types related to that of California. These gold-quartz veins cut granites, diorites and various porphyries, and, like the California veins, are of pre-Tertiary, probably Cretaceous, age. They carry a strong percentage of sulphurets, but generally only a subordinate amount of free gold, most of the gold being closely held in the sulphides. The filling constitutes the rich ore, but the narrow zone of metasomatic rock may also yield some low-grade ore. In general character, the metasomatic action is similar to that of the California veins, though the details of chemical change may differ. Galena, zinc-blende and chalcopyrite, and occasionally also free gold, may appear in the altered rocks. The carbonates are less plentiful, and lime is more often subtracted than added. The following analyses illustrate the chemical changes in two prominent types. E and E_1 are the fresh and altered rock from Willow Creek district, Boise county. The narrow quartz-veins carry scarcely any free gold, but much auriferous galena, pyrite, arsenopyrite and zinc-blende. F and F_1 are the fresh and altered rock from the Crœsus mine, Wood River district, Blaine county. The narrow streaks of filling here consist of quartz, siderite, pyrrhotite and chalcopyrite, with a little galena, arsenopyrite and zinc-blende. Here again only a fraction of the gold is in free state. The ore contains very little silver.*

TABLE III.—*Analyses of Fresh and Altered Rocks from Gold-Quartz Veins.*†

	E.	E_1.	F.	F_1.
SiO_2	65.23	66.66	57.78	58.01
TiO_2	.66	.49	1.01	1.08
Al_2O_3	16.94	14.26	16.28	15.72
Fe_2O_3	1.60	.67	1.02	.64
FeO	1.91	1.33	4.92	3.87
CoO, NiO	...	...	.02	none
MnO	trace	trace	.15	.17
CaO	3.85	3.37	6.65	2.15
SrO	...	...	.07	none
BaO	.19	none	.12	trace?
MgO	1.31	.95	4.60	2.07
K_2O	3.02	4.19	2.22	4.79
Na_2O	3.57	none	3.25	.10
H_2O below 100° C	.18	.36	.34	.31
H_2O above 100° C	.88	2.16	.92	2.71
P_2O_5	.19	.17	.30	.31
CO_2	.25	3.67	.15	2.86
S	none	.95	.02	1.25
Fe	...	.84	...	1.52
Co, Ni	...	...	...	.12
Pb	...	...	...	.86
Cu	...	...	...	.05
As	...	...	...	1.65
Total	99.78	100.07	99.82	100.24

E, Fresh granitic rock immediately adjoining the Silver Wreath quartz vein, Willow Creek, Idaho. E_1, Altered rock, adjoining the same vein. F, Fresh quartz-pyroxene-diorite, adjoining the Crœsus vein, Hailey, Idaho. F_1, Altered rock adjoining the same vein.

The composition of the altered rocks may be calculated as shown in table on page 670.

The appearance of the altered rock F_1 from the Crœsus mine is shown in Fig. 25.

The specific gravity of E is 2.714. From the mineralogical composition given in the report quoted the specific gravity is calculated to 2.720, which is a close agreement, the difference possibly indicating a very slight porosity.‡

---

* For full calculations and description of E and E_1 see W. Lindgren, 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 640; for F and F_1 see W. Lindgren, 20*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 211–232.

† Analyst, W. F. Hillebrand.

‡ In this calculation the following figures for specific gravity are used: quartz, 2.65; sericite, 2.83; biotite, 3.00; oligoclase, 2.65; orthoclase, 2.56.

TABLE IV.—*Mineralogical Composition of E_1 and F_1, in Table III.*

	E_1.	F_1.
Quartz	42.00	36.18
Sericite	46.84	38.18
Chlorite	...	11.76
Calcite	4.80	3.11
Magnesite	1.96	1.26
Siderite	1.45	2.19
Rutile	.49	1.08
Apatite	...	.72
Pyrite	1.78	.58
Pyrrhotite	...	.15
Zinc-blende	...	trace
Galena	...	.99
Chalcopyrite	...	.15
Arsenopyrite	...	3.58
Total	99.32	99.93

The measured specific gravity of E_1 is 2.774, indicating that the rock alters to denser minerals. The calculation of the same specific gravity from Table IV. gives 2.796, which shows a decided porosity of the altered rock. Under these circumstances, no evidence of pressure being noted, it may be assumed with fair accuracy that no considerable change in volume has taken place; and by multiplying the percentages of E and E_1 by 2.714 and 2.774 respectively, and comparing the results, the absolute gains and losses per cubic meter may be obtained (see Table V.).

In the same manner the measured specific gravities of F and F_1 are compared with the calculated specific gravities.* This shows that similar conditions prevail here, the porosity being greater. By multiplying the percentages of F and F_1 by the measured specific gravities, and comparing these data, the absolute gains and losses are again obtained.

During the alteration of E to E_1, 291 kilograms were added and 229 lost per cubic meter; the net total being a gain of 62 kilos. During the alteration of F to F_1, 416 kilograms were added and 333 lost per cubic meter; the net total being a gain 83 kilos.

A perusal of the table will show very similar results in the

---

* 20*th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 211–232.

TABLE V.—*Gains and Losses per Cubic Meter of E and F, Table III.*

	E.				F.			
	GAIN.		LOSS.		GAIN.		LOSS.	
	Per Cubic Meter of E.	Percentage of, for Each Constituent.	Per Cubic Meter of E.	Percentage of, for Each Constituent.	Per Cubic Meter of F.	Percentage of, for Each Constituent.	Per Cubic Meter of F.	Percentage of, for Each Constituent.
	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.
SiO_2	79	4.5	...	...	48	2.9	...	...
TiO_2	...	...	4	22.2	2	6.9	...	...
Al_2O_3	...	...	64	13.9	...	...	4	.9
Fe_2O_3	...	...	24	55.8	...	...	10	34.5
FeO	...	...	15	28.8	...	...	27	19.4
CoO, NiO	...	...	...	...	...	...	1	100.0
MnO	...	...	...	...	1	25.0	...	...
CaO	...	...	11	10.5	...	...	126	67.0
SrO	...	...	...	...	...	..	2	100.0
BaO	...	...	5	100.0	...	...	4	100.0
MgO	...	...	9	25.7	...	...	70	53.9
K_2O	34	41.5	...	...	76	120.6	...	...
Na_2O	...	...	97	100.0	...	...	89	96.7
H_2O above 105° C.	36	150.0	...	...	53	203.8	...	...
P_2O_5	0	...	0	...	0	...	0	...
CO_2	93	nearly all.	...	...	79	nearly all.	...	...
S	26	all.	...	...	35	nearly all.	...	...
Fe	23	all.	...	...	44	all.	...	...
Co, Ni	...	...	...	...	4	all.	...	...
Pb	...	...	...	...	24	all.	...	...
Cu	...	...	...	...	2	all.	...	...
As	...	...	...	...	48	all.	...	...
Total	291		229		416		333	

two rocks: a moderate addition of silica and a strong gain of potassa; nearly complete loss of soda, baryta and strontia; partial loss of alumina, magnesia and lime, F, however, losing much more lime than E. In E_1 the amounts lost of Fe_2O_3 and FeO are nearly completely converted into Fe (in FeS_2). In F these losses are less and not sufficient to account for the gain of Fe; consequently iron must have been added. Phosphoric acid is constant, consistently with the fresh state of the apatite.

San Juan, Colorado.—In the San Juan region, southwestern Colorado, are vast eruptive masses of andesites and rhyolites, with their accompanying tuffs and breccias. Some of the gold-quartz veins of Tertiary age occurring in these rocks at Telluride have been described by Mr. C. W. Purington.* The ores consist of quartz containing native gold, with pyrite, galena and other sulphides. In some localities silver is also present in considerable amount. The principal gangue is quartz, though carbonates also are occasionally present, and fluorite in considerable quantities is mentioned from the Tomboy vein. This is worthy of note; since, in ordinary gold-quartz veins fluorite, if not entirely absent, at least is exceedingly rare. The quartz forms, as a rule, a well-defined filling of open cavities, and the principal ore is of this character, and not altered country-rock. There are, however, more or less wide zones of partial alteration alongside the veins. The veins are often accompanied by large amounts of white, soft clay-like material, which probably is extremely altered country-rock. All of this appears to be sericite. Mr. Purington mentions having failed to establish the presence of kaolinite, except in one or two places. The ordinary course of alteration in the diorites, andesites and breccias is distinguished by the development of much calcite and sericite, and is consequently very similar to the metasomatic processes characterizing the California quartz-veins. The altered rocks contain small, abundant and sharply defined crystals of pyrite, more rarely of galena. Much of this pyrite fills the spaces formerly occupied by ferro-magnesian silicates. This pyrite is of low value, compared with the massive mineral occurring in the vein-filling. The percentage of silica in the altered rock is low, and contrasts with the abundant quartz on the veins.

Rhyolite adjoining the veins is changed to felted sericite and some carbonates, as well as pyrite.

As an exceptional process Mr. Purington mentions a complete silicification of the diorite from the hanging-wall of the Butterfly vein, in the Terrible mine. This diorite, which consists of labradorite, hornblende and a little biotite, shows a complete replacement of the feldspar by cryptocrystalline silica, while the hornblende is replaced by pyrite. There is a little sericite, but no carbonate present. The cause of this abnormal altera-

---

* 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 745–846.

tion might be in a local occurrence of waters in which the H_2S had been oxidized to H_2SO_4. A partial analysis of the silicified diorite runs as follows:

	Per cent.
SiO_2.	70.30
Al_2O_3,*.	20.00
MgO,	0.31
CaO,	0.27
K_2O,	1.78
Na_2O,	0.64

The large percentage of alumina indicates the presence of kaolinite, so commonly accompanying silicification. Sericite is also present.

A further instance of silicification in part, probably, due to cementation, is mentioned in the case of certain sedimentary rocks adjoining the vein. Here again it is accompanied by a development of pyrite; and the silicification extends to a distance of 15 feet from the vein.

The Treadwell Mine, Alaska.—According to G. F. Becker,† the country-rock of the celebrated Treadwell mine consists of a sodium syenite, which is strongly altered and traversed by small seams, carrying a value chiefly in gold. The whole mass of seams and country-rock is mined and milled. The process of alteration consists in a change of the albite, which is the predominant mineral, into carbonates and pyrite. Sericite is also present, as well as a little chlorite.

Gold-Veins of Ontario, Canada.—Peter McKellar‡ describes quartz-veins in granite of Western Ontario at Lake of the Woods, which are supposed to be of Archean age. The quartz-veins are only from 3 to 4 in. wide containing auriferous sulphides of copper, lead, zinc and bismuth. These narrow veins are adjoined by from 2 to 5 ft. of altered granite, largely consisting of a greenish fine-grained mineral, probably sericite. Some of this altered granite contains gold, and from 0.5 to 3 per cent. of auriferous pyrite, while the above mentioned sulphides rarely appear in it. The principal ore consists of this altered rock.

Schwarzwald Fissure-Veins.—Much material of interest relating to the alteration of country-rock is found in the well-known

---

* Including Fe_2O_3, TiO_2, and P_2O_5.

† *18th Annual Report U. S. Geol. Surv.*, part iii., p. 64.

‡ *Trans.*, xxix., 104 (1899).

investigations of Prof. Sandberger.* In his discussions, as may be expected, superficial weathering is not always strictly separated from deep-seated alteration. In the fissure-veins of Schapbach, in the Schwarzwald, biotite of the granitic country-rock yields a chlorite rich in iron and a substance supposed to be pilite. The decomposition (alteration ?) of the gneiss in the same districts yields a mineral which Sandberger calls hygrophilite, derived from the alteration of oligoclase. It has a specific gravity of 2.70, and is closely allied to muscovite, if not identical with it. The alteration of the schistose gneiss near the veins, involving a formation of hygrophilite from oligoclase, shows a concentration of K_2O and a decrease of Na_2O. In one instance a conversion to carbonates was also noted. For a certain distance on both sides of the veins the rock is softened and altered. The extent of this alteration, which is supposed to be favorable to the occurrence of rich ore-bodies, corresponds to the extent over which its principal leaching has taken place. Sandberger thus derives the minerals of his veins directly from the adjoining country-rock. He further says:†

> "It is of the greatest importance for the understanding of the veins occurring in this granite area to examine the alterations which the rock has suffered by means of waters containing carbonic acid, and by means of weathering with free access of atmospheric oxygen."

In the silver-veins of Wittich, Schwarzwald, Prof. Sandberger finds that the alteration of the biotite is accompanied by the separation of TiO_2 as anatase or brookite. The oligoclase is transformed to a kind of pinitoid which Sandberger calls lepidomorphite, and which may simply be an impure and microcrystalline muscovite. Two analyses are given‡ of fresh and altered granite, the latter occurring close to a vein. The composition of the altered rock is almost the same as that of the fresh, except that a little iron, somewhat over one per cent. of lime, and an equal amount of magnesia, have been carried away. The potash remains practically constant, while about one-half per cent. of soda has been lost. The silica has suffered an increase of 2.5 per cent., the alumina of 1 per cent. Sandberger remarks with good reason that these slight changes

---

* *Untersuchungen über Erzgänge,* i. and ii.

† *Op. cit.,* ii., p. 343.

‡ *Op. cit.,* ii., p. 347.

could very well have been effected by waters containing a little carbon dioxide.

Near the vein of Wittichen the ore-minerals are not confined to the fissure, but are also present to a remarkable extent in the altered rock adjoining it. The gangue is here quartz, barite, calcite and fluorite. The ores consist of native silver and various cobalt-minerals. The ore-minerals mentioned, accompanied by small crystals of chalcopyrite, occur abundantly in the altered granite. The veins traverse not only the granite but also the overlying Permian formation, although in these horizontal rocks they lose their mineral contents almost completely. They are rich only in the altered granite, the oligoclase and mica of which have been completely, and the orthoclase partially altered. It is acknowledged that these veins were formed when 1500 feet of rocks rested on the granite, and that consequently the temperature and pressure must have been higher than at the surface. In conformity with Prof. Sandberger's well-known views, the sulphides occurring on the veins are explained by reduction of sulphates.

The veins of Schapbach may be compared with those described from the Central Plateau of France by Daubrée. The similarity in occurrence, gangue and ores is very striking; only, in the case of the latter we have undoubted proof of their intimate connection with actual ascending springs.

9. *Silicic and Calcitic Cinnabar-Veins.*

The quicksilver-deposits of the Pacific Coast have been described by G. F. Becker.* The cinnabar occurs chiefly in zones of fracture or in fissure-veins, and is almost always associated with quartz and chalcedonic aggregates. Opal is very commonly present in the ores, but the sulphide of mercury is very rarely if ever directly imbedded in it. The main deposit of opal preceded that of cinnabar and quartz.

Various rocks, such as diabase, diorite and serpentine, are adjacent to the quicksilver-veins. These rocks are nearly always more or less altered and converted into dolomitic carbonates. Many of them are also silicified, being converted into opal. Serpentine especially is often transformed in this man-

---

* Monograph XIII., *U. S. Geol. Surv.*

ner, and all transitions between the fresh rock and the pure opal may be found; the latter may retain the color and structure of serpentine. Certain glaucophanes from the Lake Quicksilver mine are altered into microcrystalline quartz. Although Mr. Becker recognizes the fact that the country-rock has been altered by carbonization and silicification, he insists that the cinnabar has been exclusively deposited in open spaces, and does not appear as a product of direct replacement of the wall-rock. The quicksilver-deposits are of special interest, because their intimate connection with ascending alkaline waters has been proved. These waters contain but little free carbon dioxide, earthy carbonates and earthy sulphates, but considerable sodic bicarbonate and sodic chloride, and some hydrogen sulphide.

10. *Sericitic Copper-Silver Veins.*

The copper-veins of Butte, Montana, which have been described by Emmons, Weed and Tower,* form an excellent illustration of this class and, according to Mr. Emmons, are typical replacement-veins. The deposits appear along well-defined fissures in granitic rocks; the principal gangue-mineral is quartz, the primary ores are pyrite, chalcopyrite, zinc-blende and galena. Bornite, chalcocite and covellite are regarded as sulphides formed later under secondary influences. In the vicinity of the veins the country-rock is impregnated with vein-material, generally pyrite and quartz. An impregnation of enargite has also been observed. Sericite and, later, kaolin have also been developed in the rock. The extent of the altered zone is generally proportional to the size of the ore-bodies, and may extend to a distance of 100 feet from the vein. According to the proportion of copper in such an altered mass it may constitute pay-ore or be considered as barren material.

11. *Silicic and Dolomitic Silver-Lead Veins.*

The association of silver-lead deposits with limestone and other calcareous sedimentary rocks is a well-known fact, occurring again and again in all parts of the world. Very many of these deposits are not fissure-veins, or connected with such. But even among those genetically related to fissures, the ores

---

* Folio 38, *U. S. Geol. Surv.*

seldom form well-defined tabular masses, but occur mostly as irregular bodies, while the ducts through which the solutions found access have received but scanty deposits of ore. This is due to the great tendency of galena and zinc-blende, which in these deposits form the principal ore-minerals, to replace the limestone. Beyond doubt such a replacement very often occurs. It was convincingly established by Mr. Emmons in Leadville, Colo., and by Mr. Curtis in Eureka, Nev. In both these cases the demonstration was furnished by the study of structural relations, without the aid of microscopic examination. Indeed, the latter was scarcely possible, since in both these mining districts operations were still in the zone of oxidation, which obscured the relations of primary ore-minerals to the limestone. Since these reports were published, the conditions governing the replacement of the galena have not been greatly elucidated, except in Spurr's study of the Aspen district. The chemical reactions involved were, and are yet, in some doubt; the principal question being whether the galena was reduced from solution of sulphate of lead or deposited from sulphide solution (see p. 617). The microscopic study of the attending phenomena must help to settle this point.

The ores are accompanied either by a gangue of jasperoid, cherty rocks chiefly composed of silica, or by different carbonates, such as calcite, dolomite or siderite. (Those accompanied by a siderite gangue will be treated as a separate class.) Sericitic minerals are absent. The gangue-minerals mentioned have also very largely replaced the limestone.

In the Elkhorn mine, Mont., studied by W. H. Weed,* bodies of galena appear in a crystalline limestone and are directly connected with a fissure-vein. The beginnings of replacement are shown in specks of intergrown galena and pyrite, scattered through the rock, and always accompanied by small crystals of secondary quartz. The larger grains of galena are surrounded by a narrow rim of pyrite (see page 617 and Fig. 29).

Mr. Emmons describes the fissure-vein of the Queen of the West mine, Ten Mile district,† Colorado. The principal fissure is partly filled with barren calcite, while galena and blende re-

---

* Unpublished notes.

† Folio 48, *U. S. Geol. Surv.*

place the country-rock, consisting of sandstone and intercalated sheets of porphyry. The vein is characterized, besides, by a number of parallel fault-planes, from which replacement has taken place.

Aspen, Colorado.—Mr. Spurr, in his description of the Aspen district,* with its wonderfully complicated system of faults, has given a valuable description of the metasomatic processes there observed. The Aspen deposits are not, strictly speaking, fissure-veins. The ores form irregular bodies of lead- and silver-minerals in limestone; but these irregular bodies are closely connected, genetically, with faults which yielded a pathway for the ascending waters. The processes consist in dolomitization, ferration, silicification, and lastly, the introduction of metallic sulphides. The ores occur in part as filling of pre-existing cavities, but more generally replace the limestone adjoining the fissures. The dolomitization which proceeds irregularly from the fissures is well shown under the microscope, the coarse calcite being broken up into smaller rhombohedral crystals of the yellowish tinge characteristic of dolomite. Silicification usually accompanies dolomitization. In the limestones the process goes on in the following manner. Many tiny quartz-grains first appear scattered through the rock, chiefly along areas of slight shearing or fracture (Fig. 3). Here and there appear long slender quartz crystals, entirely surrounded by fresh limestone. As silicification proceeds, the slender crystals multiply, forming a characteristic network, sometimes enclosing small areas of calcite which are sprinkled with small, irregular quartz-grains, down to the most minute dimensions. The final result is a rock made up of crystalline quartz-grains of varying size, in which the retiform structure is still apparent (Fig. 4), and which rock resembles a chert or a fine-grained and altered quartzite, and is generally somewhat porous, drusy, and also often colored red or yellow. In structure, appearance and origin, this cherty rock is identical with the jaspers of Lake Superior. Mr. Spurr proposes "jasperoid" as a term for this rock, consisting essentially of cryptocrystalline, chalcedonic or phanero-crystalline silica formed by the replacement of other rocks, chiefly limestone. At Aspen this jasperoid forms big reefs along fault-lines.

---

* J. E. Spurr, Monograph XXXI., *U. S. Geol. Surv.*

Dolomitization and silicification are always accompanied by a certain amount of ferration. Usually the iron appears in the partly silicified rocks as small rhombohedrons of siderite; but pyrite is also present, and in many cases the two minerals have been deposited simultaneously.

In the final process of mineralization, the altered limestone is always traversed by reticulated fractures. In every case the ores are first introduced along these crevices; and often this is the only method of mineralization. With greater alteration, metallic minerals penetrated from the fractures into the rock on both sides. The solutions traveled between adjacent crystals of calcite or dolomite, and also along the cleavage-planes of these minerals. In this manner a still finer network was formed, which, by spreading and consolidation, resulted in a continuous mass of sulphides. There is no doubt, Mr. Spurr says, that this is an actual process of replacement; the calcite or dolomite being taken up, molecule by molecule, and replaced by metallic minerals. The sulphides are often accompanied by granular quartz and dolomite, the relations of which show that they have been simultaneously deposited.

12. *Sideritic Silver-Lead Veins.*

In this class, which, like the preceding, ordinarily occurs in sedimentary rocks, not much secondary silica is formed. The principal gangue-mineral is siderite, often accompanied by other carbonates, and nearly always also with some pyrite; in fact the co-existence of pyrite (often also marcasite) and siderite is a notable feature. The other principal ores are galena and zinc-blende. The Eureka, Nev., deposits probably belong to this type.

Wood River, Idaho.—Prominent representatives of this class are the Wood river silver-lead veins, near Hailey, Idaho,* which occur chiefly in calcareous carboniferous shale, and are of pre-Miocene age. In the structure of the vein and arrangement of the ore-bodies replacement is clearly indicated; and galena often occurs as scattered grains throughout the shale. But some filling of pre-existing cavities has also taken place.

The rocks clearly contain much organic material; and the theory of deposition by the reduction of lead sulphate is pos-

---

* W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 190 to 231.

sibly applicable. But this argument is greatly weakened by the occurrence of veins of the same composition in a neighboring body of granite.

Cœur d'Alene Mountains, Idaho.—There exist, perhaps, no better instances of metasomatic fissure-veins than the celebrated silver-lead deposits of the Cœur d'Alene mountains, in Northern Idaho. They are clearly defined fissure-veins cutting fine-grained greenish quartzites and quartzitic slates of doubtful (though probably Algonkian) age. The principal ores are galena and zinc-blende, but there is also much finely distributed pyrite. Chalcopyrite is ordinarily absent. These are practically the only metallic minerals, and recur in all the deposits. The principal gangue-mineral is siderite, accompanied by minor quantities of quartz and barite. Fluorite is absent. The fissures along which the ore-bodies appear are well defined, and sometimes continuous for one or more miles. The ore-bodies do not show much clearly defined crustification or other evidence of having been deposited in open spaces. The siderite appears always as an undoubted product of replacement, while many veinlets of quartz have in part resulted from the filling of open small fissures. Evidences of gradual transitions from ore to country-rock are abundant, and are especially prominent in the mines carrying low-grade ore, as, for instance, in the Helena and Frisco. In the exposures underground, as well as in the specimens and thin sections, the evidence of replacement is complete and positive.

The greenish-grey fine-grained quartzite, which constitutes the prevailing country-rock, contains no sulphides when fresh. It is composed of small, rounded, or subangular quartz grains, closely packed—often, indeed, jointing closely, as in a normal quartzite. Usually, however, a little sericite, in bunches of small fibers, is present as cementing material between the grains. This sericite is apparently an autogenetic mineral, formed during the metamorphism of the sandstone to a quartzite. Occasionally small foils of it project into the quartz, showing a slight incipient sericitization of the latter mineral. There are few other minerals, except a little feldspar in clastic grains, small prisms of tourmaline, and some grains of calcite. Near the veins minute specks of siderite, zinc-blende, pyrite and galena appear in this quartzite; and these scattered grains gradually merge into bodies containing 3 per cent. and more of galena, thus forming a merchantable ore. The thin sections show how the rock near the veins is filled with small grains of branching and irregular form, which consist of siderite, developed by attack first upon the ground-mass and then upon the grains of clastic quartz. This process is well shown in Fig. 16, which is reproduced from a thin section of Helena and Frisco country-rock. Accompanying the siderite are small grains of zinc-blende, cubes of pyrite and irregular wiry masses of galena. All these sulphides appear not only in or near the siderite, but also in the cementing sericite, and in the apparently perfectly fresh quartz grains.

At a more advanced stage (Fig. 17) these areas of siderite extend until they join, and thus completely replace the rock. In the specimen from which Fig. 17 was taken, masses of siderite are seen to be merging gradually into the fresh quartzite. In the resulting ore lie scattered many small quartz grains, representing remnants of the clastic constituents of the quartzite. Occasionally larger masses of zinc-blende appear to form directly in the quartzite by metasomatic replacement of the quartz. The sericite in the quartz then disappears, though once in a while small foils of it may be detected. During the transition stage, seams and narrow veinlets in the altering rock are filled with sericite, apparently segregated there, when driven out from the main mass. In other specimens from the Helena and Frisco mine, the replacing siderite has a strong tendency to idiomorphic development. Imperfect rhombohedral forms are often seen, sometimes cutting straight across the clastic grains (Fig. 18). Certain specimens from the Bunker Hill and Sullivan mine show quartzose greyish masses of irregular outline, and apparently merging gradually into the normal greenish quartzite. These quartzose masses consist of very irregular interlocking grains of quartz, not in the least similar to the quartz usually deposited by processes of filling, but having every appearance of resulting from the silicification of the quartzite. This silicified portion contains irregular grains of pyrite, galena and brown zinc-blende, with a very little siderite.

The process, as outlined, is remarkable, as involving a metasomatic replacement of quartz by siderite, pyrite, galena and zinc-blende, and is the only clearly defined occurrence of this kind of which I am aware.

This description would not be complete without mention of certain interesting veinlets produced by replacement in the Bunker Hill and Sullivan quartzite. Certain specimens from this mine show a dark greyish-green, very fine-grained quartzite, traversed by minute veinlets, carrying quartz and surrounded by a greenish material. Under the microscope the rock is seen to be a typical fine-grained quartzite or quartzitic sandstone. The grains are separated, not only by fibers of muscovite, but also by a green mica, probably related to biotite. The veinlets are clearly formed by replacement along narrow cracks, and contain a mass of green mica in fine distribution, diminishing away from the seam, together with quartz, garnet, brown zinc-blende, and small prisms of tourmaline, and a small quantity of galena. I have mentioned these peculiar products of replacement because they differ so completely from the deposits as described above. Their formation must be sought in some local cause, involving a change in the mineral-bearing solutions, or in the conditions of the deposition. The presence of garnet in these veinlets is especially remarkable, as this mineral rarely occurs in fissure-veins.

13. *Sericitic Lead-Silver Veins.*

The Clausthal Veins.—The alterations produced in the clay slates adjoining the vein-system of Clausthal have been described by v. Groddeck.* The fissure-veins at Clausthal, which principally carry galena, pyrite and zinc-blende in quartzose gangue, are enclosed in black clay slate belonging to the Culm formation; and to the eye these slates, when enclosed in the vein or lying close to it, ordinarily present no alteration, except such as may result from mechanical deformation or crushing. By a series of analyses, v. Groddeck has shown that, as a matter of fact, these wall-rocks have suffered alteration considerable in degree, although not apparent to the eye. Some average analyses are given in Table VI.

Comparing the first two analyses, it is apparent that a large part of the protoxide of iron has been carried away, and that at the same time the magnesia has been considerably reduced. These subtractions result in an apparent increase of the other

---

* "Studien über Thonschiefer, Gangthonschiefer und Sericitschiefer." *Jahrbuch der königl. preuss. geol. Landesanstalt*, 1885, pp. 1 to 53.

TABLE VI.—*Analyses of Clausthal Rocks.*

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
SiO_2	56.59	59.31	79.12
Al_2O_3	23.14	23.72	13.93
Fe_2O_3	.61	1.13	.44
FeO	4.87	1.06	......
MnO	......	......	......
MgO	1.80	1.11	......
CaO	.35	.36	......
K_2O	3.05	3.91	3.18
Na_2O	.75	.80	.64
H_2O	4.01	4.60	1.56
Rutile	.38	.23	not dt.
Carbon	.64	.95	not dt.
Pyrite	.67	.85	not dt.
Apatite	.14	......	not dt.
Carbonates	2.56	2.02	1.60

I. Black normal clay slate of the Culm formation. Average of three analyses.—II. Black clay slate adjoining the vein or enclosed in it. Average of seven analyses. These black altered clay slates are always present in or along the veins.—III. Variegated clay slate adjoining the vein. Average of four analyses. These variegated slates are apparently extreme forms of alteration, and are conspicuous by means of their red or yellow color. It is remarked, however, that this form of alteration is an unusual one, only appearing locally in a few mines. The processes to which these altered rocks have been subjected are considered to have been different in kind from those producing the ordinary black altered slates.

constituents. Very notable is the fact that the alkalies remain nearly constant, and that no soda has been subtracted—a most unusual case. The lime, rutile, carbon, pyrite and carbonate have suffered but little change. The amount of alumina is almost identical in the two analyses; and on the assumption that this constituent has remained constant, the two analyses can be directly compared.

Comparing the first with the third, a very strong increase in silica and decrease in alumina is noted, accompanied by an almost complete disappearance of the protoxide of iron, magnesia and lime, the alkali apparently remaining practically constant. It is clear that the alumina has been carried away to a considerable extent, and the process is, on the whole, similar to the alteration which results from the action of the solutions containing free sulphuric acid on aluminous rocks. Sericite and chlorite form part of the fresh rock, and the former is a prominent constituent of the altered rocks. Basing the calculations on the following formulæ:

Sericite, $2H_2O + (K_2\ Na_2\ Ca)\ O + 3\ (Fe\ Al)_2\ O_3 + 6SiO_2$, and

Chlorite, $4H_2O + 5\ (Mg\ Fe)\ O + Al_2\ O_3 + 3SiO_2$,

and disregarding the small amounts of carbonate, pyrite, etc., the following results are obtained:

	Fresh clay slate.	Vein clay slate.	Variegated clay slate.
	Per cent.	Per cent.	Per cent.
Sericite, ...	39.24	47.45	34.89
Chlorite, ...	16.54	4.37	......
Quartz, ...	35.30	34.40	63.24

These are the averages of the calculations of all the analyses. The character of the alteration is thus clearly seen to consist in a chemical change of the chlorite into sericite, with simultaneous subtraction of FeO and MgO. The quartz is practically constant.

In the case of the variegated clay slates, the change appears to be of a different kind. A comparison of the third column with the first shows that the following reactions have taken place: 1. The chlorite has been completely destroyed; its bases have been carried away, and its silica has probably been added to the free quartz. 2. The percentage of sericite has been diminished (more, in fact, than the 4 per cent. shown by the comparison of the calculations, since we must consider the amount of the bases carried away). 3. The percentage of quartz has been increased by the introduction of free silica besides that obtained from the alteration of the sericite and the chlorite. It must again be emphasized that this process points to the action of a solvent, probably sulphuric acid, capable of carrying away considerable amounts of alumina.

The Democrat Vein, Hailey, Idaho.—The Carboniferous strata near Wood river, Idaho, contain masses of intrusive granite, or, as more specifically determined, quartz-monzonite.* This rock is cut by fissure-veins containing galena, sphalerite and tetrahedrite, with siderite and calcite gangue; the ore being due, partly, to filling of open fissures, partly to replacement. For a few feet on each side of the vein, the granite is altered and contains some pyrite, galena and zinc-blende. The altered rock is of greyish-green color and its texture unmistakably indicates its derivation. The biotite of the granite is converted

---

* W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii., pp. 206 and 212.

to large foils of muscovite; the feldspars are also completely changed to radial tufts and scaly aggregates of sericite, mixed with calcite grains. The quartz grains are in places vigorously attacked by sericitization and carbonatization, in the manner illustrated in Fig. 13. The apatite is completely unaltered, and the titanite is converted to bunches of rutile needles. A little chlorite remains. For complete analyses and calculations, the reader is referred to the report cited. The altered rock consists of: Quartz, 55.07; sericite, 31.78; chlorite, 7.21; calcite, 4.39; siderite, 0.05; rutile, 0.40; apatite, 0.23; pyrite, 0.19; pyrrhotite, 0.07; zinc-blende, 0.14; water (hygroscopic), 0.37; total, 99.90 per cent.

From the determination of specific gravity it is concluded that no change of volume has taken place, but the granite has altered to an aggregate of denser minerals; the result being a rock of considerable porosity. On this basis, namely, the comparison of equal volumes, the following changes, expressed in kilograms per cubic meter, have taken place:

TABLE VII.—*Gains and Losses of Country-Rock of the Democrat Vein, Idaho, During Alteration.*

	GAIN.		LOSS.	
	Per Cubic Meter of Original Rock.	Percentage of, for Each Constituent.	Per Cubic Meter of Original Rock.	Percentage of, for Each Constituent.
	Kilos.	Per cent.	Kilos.	Per cent.
SiO_2	......	......	49	2.7
TiO_2	......	......	3	2.3
Al_2O_3	......	......	99	24.7
Fe_2O_3	......	......	10	61.6
FeO	22	42.3	......	......
MnO	3	150.0	......	......
CaO	......	......	6	8.5
SrO	......	......	1	100.0
BaO	......	......	3	100.0
MgO	......	......	18	56.2
K_2O	......	......	33	29.0
Na_2O	......	......	80	93.0
H_2O below 105° C.	......	......	5	35.8
H_2O above 105° C.	31	155.0	......	......
P_2O_5	......	.....	1	25.0
CO_2	43	nearly all.	......	......
S	4	nearly all.	......	......
Fe	3	all.	......	......
Co, Ni	......	.....	......	......
Zn	2	all.	......	......
	108		308	

The result shows a total loss of substance of 200 kilograms per cubic meter. The losses extend over all the bases and the silica; baryta and strontia being completely removed without the appearance of barite in the vein. The gains chiefly consist in water, carbon dioxide, ferrous oxide, sulphur and zinc. Both potash and soda are removed; the former only partially, the latter almost completely. Calculated without regard to porosity, by comparing equal weights, the result is reached that the rock has received an addition of substance; but the manner here indicated is doubtless the correct way of regarding the process.

14. *Zeolitic Copper-Veins.*

The copper-deposits of Michigan are in part fissure-veins cutting across the beds of melaphyre and other basic igneous rocks so common in that district. It is true, however, that the ore-bodies of the large mines are not to be considered as fissure-veins, but rather as beds or strata along which copper has been deposited by a process of replacement. R. Pumpelly* investigated the copper-deposits of Michigan and published part of his results in 1873. Further contributions to the same subject are found in his celebrated paper on "The Metasomatic Development of the Copper-Bearing Rocks of Lake Superior."† In these investigations the theory of metasomatic replacement was applied to American ore-deposits, and in this field Prof. Pumpelly is clearly the pioneer in this country. The copper-bearing veins contain a number of minerals not ordinarily present in fissure-veins, and are, therefore, of special interest. Among these minerals are the zeolites: laumontite, apophyllite and analcite. There are also present as gangue minerals, prehnite, datolite, chlorite, delessite, calcite, orthoclase and quartz. The principal ore-mineral is, of course, the native copper. Of sulphides, chalcocite and bornite are sometimes, but very rarely, encountered.

According to Pumpelly's description, the veins must be due in part to filling; but very largely, perhaps predominantly, the ore results from metasomatic replacement. The stages of this alteration Prof. Pumpelly considers to have been: 1. A forma-

---

* *Geol. Surv. of Mich.*, vol. i., part ii.

† *Proc. Am. Acad. of Arts and Sciences*, vol xiii., 1877–78, p. 253.

tion of chlorite in the amygdaloid rock; 2. Individualization of non-alkaline silicates, such as laumontite, prehnite and epidote; 3. Deposition of quartz; 4. Introduction of native copper, accompanying which there was a replacement of prehnite by a green earth or delessite, often intimately connected with the copper; 5. Appearance of the alkaline silicates, such as apophyllite, orthoclase and analcite.

This occurrence of secondary orthoclase or adularia is of special interest in view of the fact that the same mineral has lately been found to form an important gangue-constituent in certain Tertiary fissure-veins in volcanic rocks of the West. It is considered that the alkaline silicates represent the final stage, namely, the decomposition of the labradorite of the original rock, while the chloritization represented the first stage of alteration, namely, that of ferro-magnesian silicates to chlorite. Prof. Pumpelly thinks that copper was originally present as sulphides in the rocks, and that the changes, consisting in leaching and re-disposition in veins, have been effected by surface-waters carrying carbonic acid and some atmospheric oxygen. The copper was deposited after the destruction of the ferro-magnesian minerals, and before the deposition of the products from the decomposition of the feldspars. From the state of sulphide, copper was converted to silicate, carbonate and sulphate. These salts were then reduced to a metallic state. He thinks also that there is a close genetic relation between this metallic copper and the ferric condition of the iron oxide in the associated silicates. The oxidation of the iron was caused by the reduction of the oxide of copper at the expense of the oxygen of the latter.

Prof. R. D. Irving, in his report on "The Copper-Bearing Rocks of Lake Superior,"* confirms in general the conclusions of Prof. Pumpelly. He considers the veins as very largely replacement-veins not sharply defined from the surrounding rocks, but simply the result of a rock-alteration entirely analogous to that which has brought about the deposition of copper and its associated vein-stone minerals within the cupriferous amygdaloids. They are alteration-zones, which traverse instead of follow the bedding. The replacement of wall-rock by cop-

---

* Monograph V., *U. S. Geol. Surv.*, 1883.

per masses is a common occurrence; and the paragenesis of the vein-minerals is identical with that of the copper-bearing amygdaloid rocks.

Especially remarkable is the series of replacements which, as shown by Pumpelly, has taken place in these veins. Prehnite is pseudomorphic after plagioclase; and many amygdaloids are largely prehnitized. This prehnite is again replaced by orthoclase; and finally, the latter may change into epidote and quartz. Sericite is absent.

These copper-bearing veins are clearly very different from the majority of fissure-veins, and have been formed under very different conditions—in fact, probably not by thermal waters. Of other classes, the orthoclase-albite-zeolite veins of the Alps are most closely related; while a certain slight resemblance also exists to the propylitic veins, emphasized by the chloritic alteration and the presence of orthoclase.

The veins of Kongsberg, Norway, and Andreasberg in the Hartz mountains, both of which also carry zeolites, are not sufficiently known in their metasomatic aspects to be discussed here.

Observed Alteration by Ascending Waters.

Extremely little exact work has been done in this most important line of investigation, namely, to ascertain actual alterations by waters of known composition. In veins we usually have only the altered rock as a known quantity, and must endeavor to draw conclusions from this as to the character of the waters.

Most interesting and well known is Prof. Daubrée's discovery of the alteration which the old Roman bricks and mortars have suffered at the place where the mineral springs of Plombières break through the granite, ascending on fissures carrying fluorite and quartz. The waters are thermal, having a temperature of 70° C., and may be characterized as weak mineral waters, containing sulphates and chlorides, with a little hydrogen sulphide; silicates of potash and soda are also present in them. In the bricks employed by the Romans as curbing for the spring, a number of minerals have been deposited. Chief among them are the zeolites. Chabazite, mesotype, and apophyllite are the principal minerals formed in the pores and spaces of dissolution in the old bricks. Besides these, opal and chalcedony have been deposited; and, on one piece of mortar, fluorite, scalenohedrons of calcite, and prisms of aragonite were also found. This is extremely interesting, as the fissures on which the spring rises contain much fluorite. The apophyllite also was found to contain a notable percentage of fluorine. An analysis of this altered brick gave the following result: SiO_2, 19.39; Al_2O_3, 17.33; Fe_2O_3, 5.37; CaO, 51.40; MgO, 0.75; K_2O, 5.94; Na_2O, 0.33; total, 100.51 per cent.

In this analysis the most remarkable fact is the strong prevalence of potash and the small quantity of soda present. It is scarcely to be assumed that the ordinary bricks of that locality contained the alkalies in this proportion. The porous bricks were evidently specially adapted for the formation of new minerals, and the large percentage of lime in the mortar also facilitated the process. Daubrée mentions that pieces of granite enclosed in the same mass show no zeolitization, and refers at the same time to the fact that pyroxene and feldspar show no alteration in the same superheated glass tubes in which glass is completely transformed into zeolites and into silica. This shows in a striking manner the dependence of the alteration of the country-rock upon its structure and composition.

Mr. W. H. Weed has recently* found a mineral vein in process of formation by a weak thermal water at Boulder, Montana. The vein-filling consists of quartz, calcite and some stilbite, while the adjoining granite is partly altered to sericite and kaolinite; these two minerals attacking all of the primary constituents (Fig. 19). A little free silica is also mixed with the kaolinite. In some specimens the kaolinite and sericite are subordinate and the feldspar appears partly silicified.

CONCLUSIONS.

Some of the following conclusions, drawn from the data presented in this paper, may seem trite repetitions of already known facts; but it is perhaps well to remember that our knowledge of the genesis of mineral deposits is not built on such firm foundations that it does not need fortification of its position by conclusions from all possible view-points.

1. Almost all fissure-veins are bordered by altered zones of

---

* Communicated to me from an unpublished paper.

varying extent and intensity of alteration. In the so-called "replacement-veins" this altered and replaced rock contains the valuable ore.

2. The metasomatic processes in different classes of veins show an almost kaleidoscopic variety. In one class of veins, quartz may be converted into calcite, while in a different class calcite may be converted into quartz. The action is usually intense, involving a great change in the chemical composition.

3. The hydration connected with the alteration is only very moderate.

4. The most prominent mineral formed by the metasomatic processes is a potassium mica (muscovite, sericite, zinnwaldite and many other related species). The most prominent process is the progressive elimination of soda and concentration of potash, closely connected with the formation of potassium mica.

5. The metasomatic processes in fissure-veins differ distinctly in most cases from those involved in ordinary static, dynamic and contact metamorphism, and the two classes of change have not generally taken place under the influence of the same conditions and agencies. Greisen is only found near cassiterite-veins. Granite, thoroughly changed to sericite, calcite and pyrite, is never found as a result of any other metamorphism than in fissure-veins, nor are fluoritized or sideritized rocks so found. The propylitic and biotitic alteration; the chloritic and zeolitic alteration of Lake Superior copper-veins; and the silicification in limestone and other rocks form exceptions, being similar to certain developments of dynamic, static and hydrochemic metamorphism.

6. Ordinarily, the alteration consists in the total or partial loss of certain constituents; the gain of others; and the introduction of new compounds and elements, usually carbon dioxide and sulphur. The net total of the change per unit of weight or volume may be a gain or a loss, perhaps more often the former. If sulphides are abundantly introduced, the result will usually show a strong gain in mass.

7. The processes observed are such as can only be explained by aqueous agencies. Possible exceptions are the forms of alteration connected with cassiterite, apatite and tourmaline-veins, in which pneumatolytic conditions may have partly obtained.

8. The intensity of the processes observed indicates that the aqueous solutions acted under moderately high temperature, pressure and concentration. No cold, pure surface-water could produce such results as are ordinarily found.

9. From the fact that the substances introduced, such as sulphur, carbon-dioxide, fluorine, boron and heavy metals, are only known to be contained in noteworthy quantities in thermal waters ascending on fissures, it is concluded that these waters were the agencies usually active in the process of alteration.

10. Many of the substances found in the filling of the open spaces along the fissure may be lacking in the altered rock, showing that the latter forms a septum not penetrated with equal ease by all constituents of the solution.*

11. The ascending waters are chiefly surface-waters, which, after a circuitous underground route, have found in a fissure an easy path on which to return. During their long downward passage they doubtless dissolve much material from the rocks which they penetrate; and this solution was facilitated by the gradually increasing heat and pressure with increasing depth. During the ascending period, much of this material is deposited. The metasomatic action on the wall-rock results in further exchanges of constituents, some being dissolved and others deposited.

For many veins, this genetic theory may be fully sufficient. But for many others, perhaps for the majority of fissure-veins, something seems to be lacking in this explanation. The difference in the metasomatic processes in veins and in other forms of metamorphism must be taken into consideration, as well as the abundance of certain constituents, such as carbon dioxide and hydrogen sulphide, in mineral waters. The presence of these constituents has not been satisfactorily explained, and cannot be, except in certain cases, on the theory of solutions derived from the solid country-rock.

I believe that the majority of fissure-veins are genetically connected with bodies of intrusive rocks, even when the actual deposits are contained in the overlying surface lavas. It is well known that the intrusive rocks, such as granite, diorite

---

* The existence of such osmotic conditions was first suggested by G. F. Becker (*U. S. Geol. Surv., Min. Res.*, 1892, "Quicksilver Ore-Deposits," p. 159).

and gabbro, may contain at the time of their intrusion water, carbon dioxide, fluorine, boron and sulphur. Under decreasing pressure, these substances have a tendency to leave the cooling magma; and as many of them form, with the heavy metals also contained in the magma, volatile compounds with a low critical temperature, these heavy metals may be carried away from the magma along with the "mineralizing agents" mentioned above. This is the well-known theory which was originated by Elie de Beaumont and Daubrée, and developed by other French investigators; but until recently it has hardly received the attention which it deserves. The results of these emanations is shown in the contact metamorphism and in the mineral deposits often appearing near the boundaries of intrusive bodies. Where fissures traverse the cooling magmas, and the rocks surrounding them, it is natural that these mineralizing agents carrying their load of heavy metals should ascend, at first under pneumatolytic conditions, above the critical temperature. Reaching the zone of circulating atmospheric waters, it is natural that they should mix with these, which probably greatly predominated in quantity. To this combination of agencies, found in the ascending waters of such regions of igneous intrusion, the formation of most metalliferous veins is probably due. This dependence of veins on intrusive bodies is most clearly perceived in certain cassiterite-, apatite- and tourmaline-veins; but from these all sorts of transitions may be found, to veins of more ordinary character.

I am by no means prepared to deny that some classes of veins may be due to circulating surface-waters alone; but I do not believe that the dissolving power of the latter is sufficient to account for all classes, or even for the majority, of fissure-veins.

DISCUSSIONS.

(SECRETARY'S NOTE.) The following discussion of the papers of Van Hise, Emmons, Lindgren and Weed, read at the Washington meeting, February, 1900, and printed on pp. 282 to 498 of this volume, comprises communications to the Secretary, received at various times before the Richmond meeting, February, 1901, and, for the most part, presented at that meeting. These communications are introduced at this point in the present volume, in order that they may precede the papers of Vogt, Kemp, Lindgren, Rickard, etc., presented at Richmond, and therefore not forming part of the material considered in them. Since many of the contributors have mentioned in one communication several of the papers referred to, no attempt is here made to divide their remarks and distribute the fragments under separate headings. In each contribution, however, the several topics are indicated by sub-titles.

R. BECK,* Freiberg, Saxony: *Prof. Van Hise's Paper.*—The paper of Prof. Van Hise (p. 282) represents a great step of scientific progress, in that the circulation of underground waters has never before been presented with such clearness, in the light of modern chemical and physical knowledge. The theories of the formation of ore-deposits which follow the author's general survey of the currents and solvent power of atmospheric waters in the earth's crust do not, indeed, seem to be novel, being essentially an amplification of Le Conte's views; but the proofs adduced in their support are in many particulars so original that no one can read without profit this portion of the paper.

Entirely new (though largely in agreement with the papers of Emmons and Weed, presented at the same meeting of the Institute) are the sections dealing with the formation of the rich sulphides of the precious metals, and especially the regeneration of normal sulphides, such as galena, etc., in vein-zones immediately beneath the ground-water level.

Nevertheless, it appears to me that Prof. Van Hise, in the course of his most instructive exposition of unquestionable, yet still locally limited, phenomena, has been too much biased in favor of the "descensionists." This is indicated by the small importance which he attaches to the intimate genetic relation between epigenetic deposits and the plutonic hearths of the earth's interior.

---

* Professor, Royal Saxon Mining Academy. Translated by the Secretary, and translation approved by the author.

In my treatise, just published,* I have proved from many instances that the formation of ore-veins is frequently a direct consequence of the plutonic intrusion, particularly of acid magmas. Prof. Van Hise recognizes such a relation only to this extent, that atmospheric waters, in their downward course, may have happened to reach eruptive masses, perhaps long since solidified, though, in common with the enclosing rocks, still warm, and may have extracted the disseminated mineral compounds from these old magmas. But we still hold to the conception of an immediate relation in time also. We hold as a primary principle that the gases and vapors contained in the fused magmas, and escaping as these cooled, must have played, as carriers of metallic compounds upwards from the region of the plutonic hearth, a very active part. Especially does the study of contact-metamorphism (*e.g.*, at Kristiania, Norway, in the Banat, and at Berggiesshübel in Saxony) strengthen us in this conviction.

As concerns the cassiterite-veins, this view has many adherents. The direct connection between granite intrusions and the formation of veins carrying tin-ore, I have lately been able to establish still more firmly by showing that at Zinnwald, in Saxony, small cassiterite-veins in the periphery of the granite mass of that district are cut by veins of a fine-grained "vein-granite." The deposition of the tin-ore must therefore have been still in progress at the time of additional intrusions of granite from below.

But there is by no means in the *Erzgebirge* a sharp separation between the veins of cassiterite and those of silver-lead-ores. The latter sometimes contain constituents characteristic of the tin-ore group; and they are likewise connected with the intrusive plutonic masses of the *Erzgebirge.*

The latest work of American observers upon gold-veins, especially that of Spurr and of Hussak (Brazil), has shown that, for many gold-quartz-veins also, there must exist a very intimate genetic and chronological connection with deep plutonic intrusions. Thus, the nature of many gold-quartz-veins is closely allied to that of the pegmatites—those peculiarly-modified derivatives from deep granitic hearths. In this department also, the purely hydro-chemical theory of Prof. Van

---

* *Lehre von den Erzlagerstätten,* Leipzig, 1901.

Hise appears to be inadequate. The facts suggest too strongly an active participation of subterraneous plutonic masses, particularly through the expulsion of gases, which may have become mixed with ascending waters.

The Papers of Emmons and Weed.—The meritorious work of Messrs. Emmons and Weed (pp. 433 and 473), opening as it does a wide field hitherto unknown, or, at least, entirely neglected, will certainly call forth a long series of confirmatory observations. I have not yet found time to ascertain by closer study to what extent our Freiberg district shows secondary sulphide-enrichment by descending solutions. To a limited degree it is certainly present, *e.g.* in the not infrequent thin, sometimes dendritic, coating of silver-glance or native silver on cross-fissures in older vein-fillings, or the druses of beautifully crystallized rich silver-ores in geodes. The crystals of stephanite in the interstices of a breccia in the Himmelsfürst mine, for instance, may fairly be considered as later deposits from descending waters. But it is very doubtful, to say the least, whether our great bonanzas belong in this category. In our case, the question is exceedingly complicated, because the ground-water level has probably been more than once displaced, upward or downward.

Our veins, admittedly formed, for the most part, before the Cretaceous period, may have stood long already, at the time of the great Cenomanian disturbance and erosion, with their upper zones above ground-water level. For only a couple of miles from Freiberg, and about at the same altitude, Cretaceous strata are now found lying upon the gneiss (in that locality deeply decomposed) which, near the town of Freiberg, encloses the veins. Thick masses of Cenomanian Cretaceous sandstones were unquestionably denuded again, in the Freiberg mining district itself, during the Tertiary. The vein-zones which, during the Cretaceous, were crowded deep below the ground-water level, must have been elevated again, therefore, in Tertiary times, above that level.

Exact observations and assured conclusions are moreover made difficult, practically, by the circumstance that, at the present time, only those vein-zones are being mined which lie far below the natural ground-water level.

Students at a distance might, perhaps, infer from descriptions of this district that the rich sulphide-ore-bodies found in our "barytic lead-ore formation," at its crossings with the veins of the "pyrite-blende-lead-ore formation," belong in the category of enrichments so well described by Emmons and Weed. The mineralogical composition of these bonanzas, with its abundance of argentite, proustite, pyrargyrite, acanthite, stephanite, polybasite, and native silver, is indeed similar to that of the bonanzas in Montana silver-veins. Yet the veins of our barytic lead-ore system do not at all exhibit the characteristics of "descensive" formations—their abundance in fluorite alone contradicts such a view. The rich ore-bodies at the intersections referred to must be rather explained as simply due to chemical reaction between the masses of normal sulphides (pyrite, galenite, chalcopyrite, arsenopyrite and sphalerite) in the older veins, and the ascending solutions in the fissures of the later barytic lead-ore system. Emmons himself (p. 472) concedes the probability of such reactions in many cases.

However great may be our pleasure and praise in connection with these latest victories of science, we must nevertheless be warned not to attach to them too universal a significance.

Mr. Lindgren's Paper.—With regard to Mr. Lindgren's paper, I will frankly say that since the death of Stelzner nothing has appeared in which the methods of microscopic-chemical research have been applied with such splendid success to the subject of ore-deposits. I agree (with insignificant exceptions) so thoroughly with the conclusions which the author has drawn from his brilliant investigations, that it would be useless for me to offer at this time any detailed criticisms. I can only express my delight that Stelzner's method has found in Mr. Lindgren an adequate American representative, master at the same time of the European literature of the subject.

L. DE LAUNAY,* Paris, France: *Papers of Emmons and Weed.*—The ideas set forth by Mr. Emmons (p. 433) on the secondary enrichment of ore-deposits, and by Mr. Walter Harvey Weed (p. 473)

---

* Prof., *École Superieure des Mines.* Translated by the Secretary, and translation approved by the author.

on the enrichment of mineral veins, agree almost entirely with my own; and I can only congratulate myself upon finding their observations so completely in accord with those I have had occasion to make, and thank them for the very kind way in which they have been good enough to cite my writings. I have recently twice reiterated my opinion on these subjects: first, in an article in the *Revue Générale des Sciences** on "The Variations of Metalliferous Veins in Depth;" secondly, in a little text-book on practical geology† (in the chapters on superficial formations and the alterations of outcrops, pp. 50 to 72). I have, therefore, little to add. As I have said in these essays, I attach more and more importance to the phenomena of secondary alteration, which have produced a number of important modifications (whether enrichments or impoverishments) in those portions of metalliferous deposits accessible to exploitation; and I fully adopt the conclusion of Mr. Weed as to the necessity of taking very careful account of these phenomena in practical and industrial estimates. I think, likewise, that in these secondary and comparatively recent reactions should be sought the interpretation of many of the phenomena of substitution, lateral alteration, or metasomatism, in the form in which they are now observed; while I continue to admit, with the school of Elie de Beaumont and Daubrée (to which Mr. Waldemar Lindgren brings valuable support), the primary influence of volatile mineralizers. These must have prepared the way by introducing into the enclosing rocks, or simply by depositing in the vein-fissures, elements such as sulphides, fluorides, chlorides, etc., which subsequently, dissolved anew by the circulation of superficial waters, have rendered to the latter essential aid in the processes of alteration. In this manner have been produced the large altered zones which are seen, for example, around pyritic masses in the south of Spain. This point I have fully elaborated in my "Contribution to the Study of Metalliferous Deposits."‡

In order to formulate the study of the phenomena in question, I have been led to distinguish in a very general way, in the alterations of terranes and of deposits, three zones (from

---

* For 1900; p. 568.

† *Géologie Pratique.* Published by Armand Colin, Paris, 1900.

‡ A book of 116 pp., Paris, 1877.

the surface downward) which correspond rather to those of Mr. Weed* than to those of Mr. Emmons,† the two first zones of Mr. Emmons (the reality of which I am far from denying) having been comprised in the first of mine; and I have thus defined them :‡

1. First superficial zone of *oxidation*, subject, in its upper part, to physical disintegration: a zone characterized by the peroxidation of iron, and, in the case of metalliferous deposits, by the presence of native metals, oxides, carbonates or chlorides (Mr. Weed's "zone of weathering").

2. The far more important zone of *cementation*, of *de-calcification*, and, more generally, of *complex chemical reactions* (such as the formation of secondary sulphides), liable to show at its base an increase of certain substances, which have been dissolved in the upper part and carried away by the descending waters (the "zone of enrichment").

3. The zone of *unaltered equilibrium* (unchanged sulphides), below the hydrostatic level (the "zone of primary sulphides").

With regard to the process of this alteration, I believe with Mr. Emmons that we ought not to attribute too absolute a value to what is called the hydrostatic level ("ground-water level"), and I have insisted at different times in my "Géologie pratique" (pp. 52, 152, etc.) on the necessary irregularities of this so-called "level," due to the variable structure of the terrane, and leaving, for instance, beneath a former hydrostatic surface, a zone in which the circulation of surface-waters rich in oxygen and carbonic acid could still take place.

Moreover, it must be noted that, even in the deep zone, the waters could not be absolutely still or incapable of exercising oxidizing chemical reactions, especially if there be great fissures or faults, permitting the introduction and rapid circulation of waters from the surface, such as appear to exist as correlatives, opposed to the ascent of thermal waters,§ and as Mr. Weed

---

* "Enrichment of Mineral Veins by Later Metallic Sulphides," *Bull. Geol. Soc. of Am.*, vol. xi., p. 181 (1900); "Enrichment of Gold- and Silver-Veins," *Trans.*, xxx., 424; this vol., pp. 473–497.

† "Secondary Enrichment of Ore-Deposits," *Trans.*, xxx., 177; this vol., pp. 433–472.

‡ *Géologie pratique*, p. 54; *Revue générale des Sciences*, 1900, p. 568.

§ *Traité des Sources thermo-minérales* (Baudry, Paris, 1899); chapters on the origin and outflow of thermal springs, in which I have called attention to the has well pictured in his Fig. 1.* This may explain the abnormal occurrence of certain alterations and secondary enrichments more deeply situated than might have been at first expected. Here is a very interesting fact which Mr. Weed deserves the credit of bringing to light.

Perhaps also, besides the descending waters, the ascending waters, heated by their deep circulation, or even by contact with eruptive phenomena, have in certain cases played a part which their high temperature may have augmented, although we may suppose them to have been robbed of oxidizing reagents by their subterranean circulation. We know, indeed, that Daubrée observed at Plombières, Bourbonne, etc., evident reactions of this kind, produced upon metals by prolonged contact with thermal waters of extremely low mineralization; and certain minerals, especially, which may be considered as secondary in copper-deposits, are produced under these conditions:—secondary sulphides such as those studied by Mr. Weed, who has elsewhere mentioned the possibility of this intervention of hot volcanic waters.

Furthermore, as I have long since remarked, when we are confronted with secondary reactions, the persistence of which in depth is surprising, and appears to contradict existing theories, there is reason to inquire whether the surface of the earth was not, by reason of remote tectonic accidents, very different at the time when these reactions took place from what it is today. I am very happy to see that in their admirable study of the copper-mines of Butte, Messrs. Emmons and Weed have been led not only to adopt a similar hypothesis, but to give it a local geological confirmation.

Finally, I beg again to mention an idea which I have never had occasion to state heretofore except incidentally, but which seems to me to deserve more thorough study. Namely, in regions of complex fractures, with numerous systems of intersecting veins, such as those studied so minutely in Saxony,

---

fact that, to constitute a thermal spring, there must exist, below the hydrostatic level, an active circulation which I have compared to that which might be produced in a pipe-elbow, plunged in a basin of water (*op. cit.*, pp. 23 to 31). The moving waters thus rapidly brought by accident into contact with the lower portion of a deposit might exercise upon it an unforeseen metamorphosis.

* *Trans.*, xxx., 428 (p. 477 of this volume).

Bohemia, etc., there is doubtless reason to attribute a very important rôle to secondary phenomena of enrichment, as explaining the variations in successive fillings, which have usually been interpreted as primary phenomena, and the cause of which has been sought in a series of internal movements more or less independent, separated by long intervals of time. Perhaps, for example, the occurrence of a late deposit of highly argentiferous mineral, often accompanied with calcite and cobalt, such as has been noted at Freiberg, Przibram, Wittichen, etc., is only the result of a simple secondary concentration. The same may be true of the cobaltiferous fillings with calcite and barite, which have been observed in sundry faults traversing the cupriferous schists of Mansfeld; and I believe that, in a general way, it is the cause of many enrichments noticed at the intersections of veins, at the junctions of cross-courses, etc., such as those described by Smith at Broken Hill and by Spurr in the Aspen district, which, judging from the published descriptions, Mr. Weed appears to me to have interpreted very justly.

ARTHUR L. COLLINS, Telluride, Colo.: *Papers of Emmons and Weed.*—Mining engineers owe a great deal to the suggestive papers of Messrs. Emmons and Weed (pp. 433 and 473), which throw much light on numberless facts in connection with ore-deposits, especially those of copper- and silver-ores.

In recent papers on this subject, no reference has been made to the remarkable copper-veins of Cornwall, which, only 60 years ago, furnished the major part of the world's copper-supply, but already seem to be almost forgotten. These deposits were described by a host of capable observers, including such men as Delabeche, Henwood and Smythe; and the separate zones of weathering, enrichment and unaltered ore which they exhibited were so strongly marked and so commercially important that one wonders that the relations of these zones were not recognized at the time.

The zone of weathering ("gossan") was often of great extent, reaching not only below present water-level, but far below the level of the neighboring sea. Thus, at Fowey Consols, the gossan extended 100 fathoms below the adit-level; and at Dolcoath "some of the earthy brown ore was found as far down as the 197-fathom level."* These gossans generally showed traces of copper; and it was recognized that they proved the former existence of sulphide-ores, from which they had been formed.

Immediately below came the great ore-bodies, such as that at Clifford Amalgamated, "16 or 18 ft. wide, of cindery copper pyrites from wall to wall;" or the "30 or 40 ft. of dredgy copper ore in the best parts of Devon Consols."†

These gradually gave place to poorer ores, until, one after another, the mines were abandoned. Some 16 years ago, when one of these old-time Cornish bonanzas, the Tresavean mine, was reopened, the hard quartz ore, sparingly sprinkled with pyrite, mispickel and chalcopyrite, which was encountered, seemed to justify fully its former abandonment. The recognition of the essentially superficial origin of rich copper sulphide ore-bodies of this type will be discouraging in many cases. But it only confirms an opinion long held, on other grounds, by mining engineers.

It is noteworthy that the reaction mainly relied upon for the removal of copper from the zone of weathering, namely, the decomposition of copper sulphides by ferric sulphate, is (or was, many years ago, when I was familiar with the district) employed at Rio Tinto on a very large scale in the commercial treatment of copper-ore. The liquors from the lixiviation of heap-roasted ore were run over "raw" fine ore—originally (as I recollect) to lessen the consumption of iron in the precipitating-tanks, and to secure a cleaner precipitate. But this was found to be also an efficient method of extracting part of the copper-contents of raw pyrites. And great heaps of mixed "raw fines," and lixiviated roasted ore, aggregating millions of tons, gradually giving up their copper in solution, largely by means of this reaction, became a feature of the Rio Tinto landscape.

The supposed reaction for the re-precipitation of copper in secondary copper-ores, from cupric sulphate solutions by pyrites, can hardly take place under these conditions—it would upset the commercial process.

The evidence of secondary enrichment in gold- and silver-

---

[*] T. H. Collins, *Journal Royal Inst. of Cornwall*, No. 38.

[†] Sir W. Smythe, *Trans. Royal Geol. Soc. Cornwall*, vol. xi., part iv.

veins is less striking than in copper-deposits. As to gold in particular, we are accustomed to look for far higher values in the oxidized surface-ores than in the sulphides immediately beneath. This may be due as much to the ease with which gold is precipitated from its solutions as to its original insolubility; for the native gold in oxidized ores often has every appearance of secondary deposition.

As to the Smuggler-Union workings (of which I am at present in charge), a personal examination might give Mr. Emmons reason to doubt the suggestion that the richer silver-minerals have been re-concentrated into a more recent foot-wall streak. Nor does any such streak remain unaffected by the faulting at the Pandora crossing, so far as our workings show. The great changes in the Smuggler-Union vein with depth seem rather to coincide with the changing strata through which it passes.

More striking cases might, I think, be found in the Silver Plume district of Clear Creek county, Colo., where the rich silver-minerals of the upper parts of the veins have given place to low-grade galena and ferruginous blende in depth, without any corresponding change in the enclosing rocks or gangue-minerals.

H. FOSTER BAIN,* Des Moines, Iowa: *Paper of Van Hise.*—The zinc- and lead-deposits of the Mississippi valley, which it has been my fortune to study, give particularly good examples of many of the principles of ore-deposition formulated by Prof. Van Hise. Perhaps there is nowhere clearer evidence supporting his fundamental tenet, that ore-bodies are to be regarded as a result, and as merely one of the phases, of the work of underground waters. The facts regarding the mines of the upper Mississippi valley have been given in some detail for Wisconsin by Prof. Chamberlin† and, more recently, for the mines west of the Mississippi by the Iowa Geological Survey.‡ Fortunately, also, the processes of underground water-circulation have been studied in some detail in connection with the

---

* Published by permission of the Director of the U. S. Geological Survey.

† *Geology of Wisconsin*, vol. iv., pp. 367–571.

‡ Leonard, A. G., vol. vi., pp. 9–66. Calvin and Bain, vol. x., pp. 480–597.

investigation of artesian waters throughout the region.* In Missouri and Arkansas the mines and ore-bodies have been much studied;† but the general problems of the circulation of underground waters have been neglected. During the season just closed the writer has been engaged in a re-study for the United States Geological Survey of the zinc- and lead-deposits of the Ozark region, with special reference to those of the Joplin area; and his full report is now in preparation. It has been interesting to note how fully the statement that the ore-bodies result from the general action of underground waters is here substantiated. Treated merely as parts of a problem of water-circulation, many of the difficulties regarding the ore-deposits vanish.

In brief, the Joplin area is one in which flowing wells would occur, if it were not for the numerous deep fractures which, permitting the free outflow of springs, has had the same effect, in causing loss of head, as the placing of wells too close together. The gathering-ground is the central plateau of the Ozarks; the overlying impervious layer is the Eureka-Kinderhook shale, which divides the Carboniferous from the Siluro-Cambrian. The aquifers are the porous dolomitic limestones and interbanded sandstones of the Siluro-Cambrian. At an earlier stage much of the water was transmitted down the dip through the Carboniferous limestones under a coal-measure cover. This earlier circulation seems to have been more important in bringing about the recrystallization of the limestone, and probably to some extent its replacement by chert, than in causing actual ore-deposition. The coal-measure cover is now, however, cut through. The present actual difference in head is about 700 ft. Water now rises in the Carthage well from the Silurian limestones to within a few feet of the surface, and in the Redell deep-rock well, at Joplin, to within 80 ft. of the surface.

That the ore-bodies were deposited by waters rising from these deeper limestones is proved by the following facts:

(a) The ores are everywhere associated with great quantities

---

* Leverett, F., *U. S. Geol. Surv.*, *Monograph* xxxviii., pp. 550–784. Norton, W. H., *Iowa Geol. Surv.*, vol. vi., pp. 115–428.

† See especially A. Winslow, *Mo. Geol. Surv.*, vols. vi. and vii.; and W. P. Jenney, *Trans.*, xxii., 171–225.

of dolomite. The lower limestones are dolomitic, while the Carboniferous limestones (the immediate country-rock) are not. It is also true that the Carboniferous limestones show no dolomitization away from the region of the ore-bodies, even though they have clearly been worked over by circulating water. The magnesia was evidently brought in at the same time as the ores. The magnesian limestones of the Siluro-Cambrian, in both the upper and the lower Mississippi regions, are almost everywhere associated with more or less ore. The Carboniferous non-magnesian limestones are nowhere associated with ore, except in this particular region, where, as has just been pointed out, the circulating waters passed in their course from the one to the other. These conditions of circulation have been stable for a long time.

(b) The ore-bodies of the Joplin region stand in relations, usually close, with a system of fractures and faults of such extent and character that we cannot but assume that they have broken the underlying Eureka-Kinderhook shale and allowed the intermingling of the two circulations above and below it. These fracture- and fault-planes have been much obscured by the irregular manner in which the Carboniferous limestone and its contained chert breaks up, and the very considerable solution which has taken place in this limestone. Nevertheless faults occur, of a minimum throw of 80 ft., traceable across the country for a mile and a half, and are not to be confused with the effects of mere settling as a result of surface-solution. Neither are faults of 140 ft. throw, accompanied by overthrust, to be referred to this category, or confounded with the effects of the pre-coal-measure period of erosion. Such faults were present before the concentration of the ore; and the ore-bodies stand in close relations with them. They served as the main channels for the upward flow of the ore-bearing waters. Once in the Carboniferous limestones, the solutions wandered widely, and deposited ore under many different conditions.

In the upper Mississippi region, the fact of general artesian conditions on the flanks of the Wisconsin axis is well recognized. The presence of alternating pervious and impervious beds affords several distinct circulations, one above the other. Differences in pressure, composition of the waters, etc., indicate, so far at least as the territory west of the Mississippi has been studied, that each circulation is practically distinct. The ores of the region are mainly found in the Galena-Trenton limestone, and especially in the upper, dolomitic portion, to which the name Galena is specifically applied. This lies below a heavy bed of practically impervious shale, to which the terms Maquoketa, Cincinnati, and Hudson River are variously applied. There are minor and local beds of shale in the Galena-Trenton, and a thin but persistent bed cuts it off from the St. Peter sandstone below. At an earlier period, as Prof. Van Hise shows, the waters in the Galena-Trenton were under hydrostatic pressure; but now erosion has cut deep into and through the ore-bearing strata, and for a long period of time the movement of the waters and the concentration of the ores has been downward. There are locally evidences of movement in the opposite direction, as at the Kane Brothers' mine near Dubuque; and throughout the district there are certain phenomena which are best explained by the suggestion of an earlier concentration by water under considerable head. The later effects of present conditions, however, are, in most of the Iowa mines, the more striking.

Prof. Van Hise has emphasized the importance of the impervious layer, not only as directing the general course of underground circulation, but often as closely connected with the deposition of the ore. In both the regions under discussion examples of this phenomenon are exceedingly common. In the Joplin region the constant association of ore with the small outliers of coal-measure shale, and the common tendency of the ore in soft ground to "make" against a bar, are essentially phenomena of this sort.

Decrease of temperature and pressure cannot be invoked to explain the ore-bodies in either region. There are neither hot nor warm springs in either, nor is there any independent evidence that any such have ever existed. The reactions involved in the genesis of the ores are all such as take place under present surface-conditions; and, when the time and quantity of water are taken into account, there is no necessity for other agents. In the Dubuque (Iowa) region, studies of the artesian wells make it clear that the circulation did not extend to a depth sufficient to make pressure quantitatively important. In Missouri, if the waters be limited practically in their lower circulation by the crystalline rocks, the same is true. There is no independent evidence that any considerable portion of the circulation extends into the crystallines; and many facts suggest the opposite view.

The mingling of solutions has been especially important in producing deposition in both regions. In the Dubuque and Wisconsin regions, this is shown in the fact that the main ore-deposits are found at points where two crevices cross each other. For instance, in the Stewart's Cave mine, near Dubuque, there are two parallel E–W. crevices, about 60 ft. apart. Along the south crevice a great deal of lead has been found; in the north crevice, practically none. In the south crevice, ore is found only at points where there are cross-crevices. In fact, the south crevice always carries ore where there was a chance for the waters from the other crevice to come in. In this case, one crevice evidently carried the solution which contained the mineral, and the other the precipitating agent. Where the two solutions came together, an ore-deposit was formed.

In the Joplin region, the same thing was clearly shown in the fact that the great deposits of zinc are found largely in the Carboniferous limestones, which are cut off from the Cambro-Silurian by a series of shale beds. It is only where these have been broken across by faults that ore-deposits are found. The Carboniferous limestone carries large amounts of bituminous matter—so much that, in certain of the mines, when the rock is broken it looks like asphaltum-mastic. This bituminous matter is widely distributed throughout the Carboniferous limestone of that region, and the waters circulating through these beds become highly charged with it, and hence are reducing agents. The sulphate solutions coming from below have been reduced to sulphides in the limestone, making the ore-deposits.

The general principle of the reduction of one sulphide by another does not seem to have been very important in the Missouri region, although we do find evidence there of that process. In the Iowa region, however, it has played a very important part. At the Pike's Peak, near Dubuque, it is constantly found that in the little cavities in the rock there is a lining of iron sulphide; that is, the iron sulphide is between the zinc and the rock, and apparently acted as the reducing-agent. The iron sulphide was there first, and the zinc sulphate, coming later, has been reduced by it to zinc sulphide.

Papers of Emmons and Weed.—The general principle of secondary enrichment, discussed by Messrs. Emmons and Weed also (pp. 433 and 473), finds exemplification all through the Joplin region. One of the best cases is the Boston-Get-There mine, at Prosperity, just south of Cartersville. At this mine about 15 acres have been mined out underground, for a thickness of from 10 to 20 ft. The mine is in the top of a big body of chert, underlying limestone. Between the layers of original white flint are thin sheets of black secondary chert; and in these bands the ore is found. The beds dip slightly SW., so that the waters falling there, as shown by the drainage of the mines, flow from NE. to SW. Going NE., up the dip, we encounter more galena and less zinc blende; and often we can find where the little pieces of zinc blende have been dissolved out of the chert matrix by the water, leaving cavities which have the characteristic form of the zinc blende crystals. It follows that blende has been taken away by the underground waters, and carried down the dip. Farther down the dip we find cavities filled with clear, sharp and apparently new crystals of zinc blende. We have here an instance of the removal of zinc blende by the oxidizing waters and its redeposition farther down the dip.

The general processes of secondary concentration and enrichment are also exemplified in the common fact that the great bodies of zinc blende occur at and below the groundwater-level, which, at Joplin, occurs almost at the surface. Until pumping was carried on vigorously, water was found at a depth of about 30 ft. Now the ore is mined at depths of 150 and 200 ft. by pumping out the water. That the general process, so far as the formation of the richer bodies is concerned, has been one of concentration downward, is shown in the fact that at the surface, and in the small deposits below the surface, where we have direct evidence of oxidation, we commonly get galena, while at lower depths great bodies of zinc sulphide occur. Of the common sulphides, galena, blende and pyrite, the galena is the last to go into solution in the presence of oxidizing waters; hence, where we have the three together, the general effect of the downward-flowing waters is to carry the zinc blende away from the galena, leaving the latter at the surface, and redepositing the zinc in the lower rich bodies of ore.

Another important principle, which is well exemplified in the region as a whole, is, that the form and character of the ore-body are controlled by the character of the rock in which the ore occurs. This is largely due to the fact that the fractures in rock are controlled by the character of the rock. Homogeneous rocks will yield under stress more uniform fractures than heterogeneous rocks. In the Joplin region, the Carboniferous rocks are interbanded limestones and cherts, which break irregularly; while the Cambro-Silurian limestones are homogeneous, and break with more regular fractures, like the Wisconsin limestones. The result is seen in the very irregular form of the Joplin ore-bodies as contrasted with the usual regular vein-like form of the deposits in the central, and portions of the south-eastern, districts.

The ores of the Ozark region in general, away from the southwestern district, were only studied for the light they would throw on the problems of the latter region. They are different in form, because they occur in a different sort of rock; but enough was seen to justify the statement that they are quite as closely dependent upon the general circulation of the underground waters as are the Joplin ores. In all essential particulars they follow the same general principles. The details of the investigation naturally cannot be given here.

DR. CHARLES R. KEYES, Des Moines, Iowa: *Paper of Van Hise.*—It is not too much to say that Prof. Van Hise's paper (p. 282) marks a new epoch in the science of ore-deposits. Few who are not expert petrologists, in the most modern sense of the term, can fully appreciate the profound significance of his remarks. His paper shows more conclusively than ever before that, if we are to make great advancement in the study of ore-deposits, it must be largely along geological lines. Geological occurrence, geological structures and geological relationships come in for first consideration.

It is a startling statement that ore-bodies are essentially surface-deposits, that is, they are mainly confined to the brittle shell of the globe,—that zone near the surface commonly called by the geologist the zone of fracture. Few of us are fully prepared to accept this proposition without some reserve. Yet a little reflection will show that it could hardly be otherwise. The phenomena connected with ore-deposition are merely special cases of a more general problem, with which geologists have long had to deal.

Specially opportune is Prof. Van Hise's discussion of the upper limit of groundwater, concerning the relations of which to the position and character of ore-bodies, it removes at once many obstacles which have long stood in the way of satisfactory explanation of apparently anomalous phenomena. Any change of position of this groundwater level necessarily produces important changes in the mineralogical nature of the ores. Yet some orogenic movements are known to take place much more rapidly than the ores are altered by weathering influences; and consequently we often find a marked discrepancy between the groundwater-line and the local character of the ores that we should expect to find. In the broader field of general rock-alteration we assume the truth of the observation made by Wadsworth that all such changes are from a less stable to a more stable condition. But this does not express the full significance of the phenomenon. The conditions themselves are continually changing. The process is essentially continuous, yet sometimes in one, and sometimes in directly the opposite, direction, as is the case with the better understood analogous processes in what we call the organic realm.

I am not sure that I fully understand the statement of the third premise of the paper, that " by far the major part of the water depositing ores is meteoric." In the absence of the full explanation it may be well not to discuss this point. However, this statement very materially broadens our ordinary conception. There is, perhaps, need of a new term here. But, as it stands, and taking into consideration the related "minor part" in all its aspects, the statement, reduced to its lowest logical terms, merely declares that water is water.

Although Prof. Van Hise's paper contains but little regarding the classification of ore-deposits, it has an important bearing upon that subject; and I am particularly interested in this aspect of it, because it is along the same line that I have been working for some time in a humble way, and it is on practically the same basis that I presented the first outlines of my own classification in my paper, read at the same meeting of the Institute.*

When Prof. Van Hise, summing up the situation, says that a "complete theory for many ore-deposits must be a descending, lateral-secreting, ascending theory," he certainly states a conclusion from which there is no escape. We can only attain an adequate explanation of ore-deposition by considering all of these currents, sometimes working independently, perhaps, but usually operating in conjunction and practically contemporaneously.

In my own work I was confronted by the labyrinthine complexity of any classification based directly on the metamorphic processes, as we know them operating upon the rocks. Prof. Van Hise appears to be profoundly impressed in the same manner.

My own position is that any classification of ores in order to be useful to the fullest extent must be, first of all, simple; secondly, capable of being readily applied in the field; and finally, useful as a guide to proper exploitation. No matter how refined and well-fitting a scheme we have, if it does not meet these three requirements, it will not be adopted or even be considered by practical men.

I need not here repeat the further arguments and explanations of these propositions which I have set forth in my paper, above-mentioned; and I content myself with saying, in conclusion, that if further progress is to be made in the study of ore-deposits, it must be along the lines laid down by Prof. Van Hise.

Paper of Lindgren.—We are certainly deeply indebted to Mr. Lindgren (p. 498) for so excellent a review of the subject of molecular interchanges associated with the production of ore-bodies occupying fissures. The importance of considering the changes of the wall-rocks of ore-veins has certainly never been adequately recognized. Lying, as it does, in no-man's land, between the territory of the miner and the province of the petrographer, the subject has been sadly neglected by both, instead of being made mutually productive.

---

* "Origin and Classification of Ore-Deposits," *Trans.*, xxx., 323.

While there is, no doubt, great need of an agreed technical terminology to express the multifarious conceptions and the various shades of meaning, I very much question the wisdom of even attempting to adapt, at least in its entirety, the petrographical nomenclature, already well established, to the recognized phases of ore-formation, where processes are not so well understood, and exact terminology must necessarily remain for some time yet indefinite.

The meaning commonly ascribed to metasomatism, when applied to ore-deposits, seems somewhat unhappily chosen. We sometimes get a clearer insight into things by referring to them under older and entirely different names. The title metasomatism as used by Mr. Lindgren is, I take it, almost, if not exactly, co-extensive with the somewhat older term of mineralogical metamorphism. The latter term has been widely used by petrographers generally, and has come to have a special significance in connection with the microscopic study of rock-masses.

So far as ore-deposits are concerned, these two terms may be, without serious impropriety, regarded as identical and interchangeable. But the fact should not be lost sight of, that besides strictly metasomatic change, there are other grand groups of molecular changes among which may be mentioned, in particular, paramorphic change. The latter, while it may have no immediate connection with ore-deposits, has an extremely interesting mineralogical rôle, which cannot well be overlooked, and which greatly elucidates some of the broader phases of rock-metamorphism.

As generally used by writers on ore-deposits, the term metasomatism does not signify a simple or definite process, or an assemblage of distinct processes. It is merely a vague title given to an indeterminate group of ordinary chemical activities, in which the only essential feature which the idea carries is that each chemical change is definitely located in space. Among ores it has special emphasis, for the reason that chemical substitution takes place with the desired stationary residuum. Emmons succinctly states the vagueness of the problem when he says that interchange of substance is "not necessarily molecule by molecule," but "in such manner as to preserve the original structure, form, or volume of the substance replaced."

To illustrate more clearly for present purposes, we may fancy a point of limestone bathed by a stream of moving, mineral-laden water. If the limestone substance is gradually carried away we have simple solution; if from out the stream mineral matter is left upon the limestone, we may have simple precipitation or incrustation; but if, as the molecules of limestone are dissolved, new molecules immediately take their places, we have substitution or replacement. This last, however, is not necessarily metasomatism, as I understand it.

To the student of the general metamorphism of rock-masses, metasomatism is a sharply defined chemical process by which, in the solid rock, usually, mineralogical transformation goes on. At least four well-marked phases are readily distinguished. A characteristic molecule may break up into two or more, with little or no addition or substitution of extraneous elements. Or, there may be reactions between adjoining crystals or substances. Or, thirdly, some of the elements entering into the composition of the new minerals may be brought in from a distance. A fourth phase may occur when a foreign substance entirely displaces a component, molecule by molecule. There are still other distinctions that may be made reference to which is not necessary at this time.

In all of these cases, the interchanges are assumed to take place in the rock-mass with no aid from circulatory waters other than those which may move through the ordinary micro-capillary pores of the stone.

In the mineralogical metamorphism of a rock-mass in a region undergoing dynamic compression, such as is initiated by mountain-making forces, the so-called circulatory underground waters are only of secondary importance. The fissures through which these waters pass are relatively local in influence; and changes that may take place along their walls may be regarded as affecting only a very small part of the rock-mass itself.

As thus understood, it is doubtful whether ore-deposits of any considerable extent are ever really formed through true metasomatic action. The conditions under which chemical change goes on in and immediately about cavities in rocks are so different from those under which the mineralogical changes in the rock itself take place that it appears inadvisable to attempt to extend the definition of a term already well established in microscopical petrography, and thereby to do away with its usefulness altogether.

Mr. Lindgren himself, I think, recognizes the force of this factor when he specifically calls attention to the wholly distinct character of the alteration taking place in the body of the rock-mass (to certain phases of which I have considered the term metasomatism restricted) from that of the change or replacement occurring in fissures, and says, " the metasomatic processes in wall-rocks of the fissure-veins differ generally from those of regional (static and dynamic) metamorphism."

The restricted petrographical idea of metasomatism is, no doubt, very attractive for application to ore-deposits. But the already widely-used term replacement seems to cover more fully and more appropriately the analogous phases, as exhibited by the ores.

The main usefulness of the idea of metasomatism, as applied to ore-bodies, is to give rise to a great taxonomic group of deposits which are formed often where no previous cavities existed, and hence to set these off, geologically and genetically, from all other classes of ore-formations.

It is important to note, in this connection, that the period of maximum activity in the mineralogical change of rock-masses does not often coincide with the period of maximum ore-formation. As a rule, the latter is long subsequent to the former, and is the immediate outcome of activities and conditions wholly distinct.

In its more extended signification, the term metasomatism is not very far from meaning practically the same as chemical change, at least so far as ore-deposits are concerned. In the sense intended by Mr. Lindgren, replacement appears to meet most nearly the requirements imposed by the conditions presented by the ore-deposits. The exact group of chemical processes involved, and the definite set of conditions existing in each particular case, are not what are first sought in ore-exploitation. The usefulness of the distinction is really inversely proportional to its success in avoiding expression of exact values.

In metasomatism proper, as a mode of rock-alteration due to static or dynamic metamorphism, there are recognized a number of distinct phases, the results of varying physical conditions and differences in chemical composition and mineralogical constitution. Such are uralization, sericitization, saussuritization, epidotization, etc. The suggestion of analogous alterations due to contact-metamorphism, or in connection with fissure-veins, does not appear to serve a similar useful purpose; and in the special case of ore-replacement in veins the central idea is completely lost. Topazization, tourmalinization, scapolitization, fluoritization, and the like, do not, to my mind, present practical features for the classification of ore-veins, or features which can be made use of in ore-exploitation.

Frank D. Adams,* Montreal, Can.: *Paper of Lindgren.*—Mr. Lindgren's paper (p. 498) is a valuable contribution to the literature of ore-deposits, bringing together as it does a great number of facts concerning the metasomatic changes developed by vein-forming solutions in the rocks which they traverse. It is also of much interest as an attempt to classify mineral veins according to the character of the metasomatic changes which accompanied their development, and especially according to some *predominant* metasomatic mineral, which they contain. This principle, however, as Mr. Lindgren remarks, seems to have serious limitations when adopted for purposes of classification—one of these being the fact that the same waters may give rise to different metasomatic minerals in the case of different rocks.

Furthermore, just as the various magmas with which Mr. Lindgren considers the various kinds of vein-making solutions to be severally connected pass into one another by imperceptible gradations, so do these solutions also; and thus, instead of a series of well-defined classes of mineral veins, an almost continuous series will be met with in nature. This difficulty, however, is shared by all systems of petrographical classification, and by most of the other systems proposed for the classification of mineral veins.

In the case of the cassiterite-veins (Mr. Lindgren's Class I.), for instance, the *predominant* metasomatic mineral is said to be topaz; but in the most extensive deposits of this class which

---

* Prof., McGill University.

are known—those of Cornwall—the predominant metasomatic mineral would appear rather to be tourmaline.

In the apatite-veins (Class II.), scapolite is taken as the predominant metasomatic mineral. This is true of the Norwegian deposits; but in the Canadian deposits, which are even more extensive, while this mineral is very common, it cannot be considered as *predominant*. These Canadian deposits, while in many cases at least occurring in association with basic igneous rocks, as in Norway, are usually found, not in contraction-joints of the intrusive itself, but as veins cutting the limestones and associated rocks of the Laurentian, which are penetrated by these intrusives. The apatite, unlike that of Norway, is a fluor-apatite, not a chlor-apatite; and the predominant metasomatic mineral is malacolite. So notably is this the case that the prospectors in the apatite-districts always look for "pyroxene," and regard it as an almost certain indication of phosphate in the vicinity. Next in abundance to the malacolite is, perhaps, mica (phlogopite and biotite), which in some cases is present in such large amount that apatite-mines which were abandoned on account of the fall in price of that mineral in the years 1893–94 have been, by reason of the more recent demand for phlogopite, opened up and worked anew for this latter mineral. While, therefore, the Norwegian and the Canadian apatite-occurrences undoubtedly belong to the same class of deposits, the former is characterized by the presence of chlorine minerals, while in the latter this element is largely replaced by fluorine, which is also so commonly found in association with cassiterite-veins. The chlorine-bearing scapolite thus cannot be considered in all cases as the *predominant* metasomatic mineral required by the definition of Class II.

Mr. Lindgren's views concerning the close genetic association of most mineral veins with igneous masses seem to be abundantly supported by the facts, as also his conclusions with regard to the preponderating influence of pneumatolitic action in the case of the cassiterite- and apatite-veins, as shown by the constant association of chlorine-, fluorine-, boron-, phosphorous-, titanium- and lithium-minerals with them.

Problems in the Geology of Ore-Deposits.

BY PROF. J. H. L. VOGT, UNIVERSITY OF KRISTIANIA, NORWAY.*

(Richmond Meeting, February, 1901.)

TABLE OF CONTENTS.

INTRODUCTION.

In the latter part of November, 1900, I received through the Secretary of the Institute the papers of Messrs. Van Hise, Emmons, Lindgren and Weed, presented at the Washington meeting of February in that year, with the request (urged also by Mr. Emmons) that I would furnish for the Richmond meet-

---

* Translated by the Secretary, and translation approved by the Author.

ing a contribution to the discussion of the geology of ore-deposits, with reference to these four papers. It is a pleasure and an honor to comply with this request. I entertain a high appreciation of the progress of the natural sciences in America during the last half of the century. We Europeans realize that in many departments of these sciences America is taking the lead; and it is our desire that the Old and the New World may come closer and closer together in scientific union. This consideration has impelled me to the preparation of the present paper, for the deficiencies of which I must be permitted to offer an excuse in the fact that it was necessarily written within the period from December 3 to December 31. In many respects, therefore, it is incomplete, because time was wanting for a more thorough and comprehensive work.

I. THE ORIGINAL SOURCE OF THE HEAVY METALS OF ORE-DEPOSITS.

It is well known that many investigators, even in most recent years, have sought to derive the heavy metals of ore-deposits from the inaccessible interior of the earth. This hypothesis was favored by the remarkably high specific gravity (about 5.6) of the whole globe, which was explained by assuming that the heavier metals were concentrated in its interior. A further confirmation was sought in the quantity of iron found in meteorites, and also (by spectral analysis) in the sun. The earth's interior was regarded as a liquid molten mass, and the products of volcanic eruption as furnishing samples of this mass, bringing with them, from the richly metalliferous hearth of interior fusion to the upper horizons, or even to the surface, small quantities of metals and metallic compounds. In support of this hypothesis, the beautiful synthetic production, by sublimation, of cassiterite,* specular iron, etc., performed by Daubrée and other French experimenters in the middle of the nineteenth century, and received with universal and significant interest, has often been cited.

This hypothesis is seductively simple, but cannot be maintained. We must accept as now proved, that the interior of the earth cannot be regarded as a liquid molten mass. In the

---

* According to the equation, $SnCl_4 + 2H_2O = SnO_2 + 4HCl$.

words of the distinguished Swedish physicist, Svante Arrhenius,*

> "Modern investigations of astronomers and physicists show that the deformations of the earth's mass under the influence of moon and sun (tides of the earth's crust), and the variations of the earth's axis (called precession and mutation) due to the same outside causes, present such a quantitative order as to be irreconcilable with the assumption of a liquid interior."

He concludes that the crust of the earth is solid to the depth of about 40 kilometers. At the temperature of about 1200° C., and the pressure of about 10,840 atmospheres, existing at this depth, most of the ordinary minerals are fused, and dissolve the less fusible materials. That is to say, at the depth of about 40 kilom. begins a liquid molten condition, which, however, cannot continue to much greater depth. For at about 300 kilom. the temperature must without doubt exceed the critical temperature of all known substances; and at this point the liquid magma passes gradually to a gaseous magma, subject to extremely high pressure. The viscosity and lack of compressibility of this gaseous magma may be greater than those of the liquid magma.

We must give up, therefore, the old conceptions of the earth's interior condition. There is no reason for supposing that the heavy metals of ore-deposits have come from the enormously compressed earth-interior—which, as some physicists declare, must be, in consequence of such compression, "as hard as steel." In fact, no connection has ever been shown between ore-deposits and this heavy interior mass.

We are forced, then, to the conclusion that ore-deposits are derived from the crust of the earth—this crust, however, being regarded as not one or two, but 10, 25, or even 50 kilometers thick. Indeed, as will be shown below, a notable number of ore-deposits may be referred to eruptive processes connected, not with the heavy interior, but with the crust, of the earth. Many deposits, as Van Hise has recently shown, are due to the action of ground-water.

Moreover, it has been shown within recent decades that many elements, formerly regarded as very rare—often as totally absent—in rocks, are in fact almost invariably present in de-

---

* *Zur Physik des Vulkanismus* (*Geol. Fören. Förh.*), Stockholm, 1900.

tectable (though, of course, generally minute) quantity. On this point I may mention the investigations of the American chemists, F. W. Clarke and W. F. Hillebrand, and also my own paper on the relative distribution of the elements, etc.,* from which I here introduce a brief passage.

Distribution of Elementary Substances in the Earth's Crust.

Of the entire earth-crust,—namely, the rocks, sea and atmosphere,—oxygen constitutes by weight about one-half, and silicon about one-quarter; the proportions of aluminum, iron, calcium, magnesium, sodium and potassium range from 10 down to 1 per cent.; those of hydrogen, titanium, carbon and chlorine from 1 to 0.1 per cent.; those of some eight elements, phosphorus, manganese, sulphur, barium, fluorine, nitrogen, pretty certainly also zirconium and chlorine (but probably no others, with the possible exception of strontium), from 0.1 to 0.01 per cent. Between 0.01 and 0.001 per cent. come nickel, strontium (?), lithium, vanadium, bromine, and pretty certainly also beryllium and boron, but probably not tin, cerium and yttrium, or other elements. Between 0.001 and 0.0001 per cent. are cobalt, argon, iodine, rubidium, pretty certainly tin, cerium and yttrium, and possibly also arsenic and lanthanum, but probably no others. In summary, therefore, we have:

Terrestrial Distribution of Groups of Elements.

Percentage.	Number of Elements.
10 to 1,	6
1 " 0.1,	4
0.1 " 0.01,	8
0.01 " 0.001,	7
0.001 " 0.0001,	7

Similar figures are obtained for the intervals 50 to 5, 5 to 0.5, 0.5 to 0.05 per cent., etc., proving that there is a law of quantitative distribution of the 34 most widely occurring elements, according to which some 4 to 8 elements fall within each decimally-reduced interval. From this law we may with some confidence further infer that of the remaining, say, 37 known elements, some would fall within the next following

---

* "*Ueber die relative Verbreitung der Elemente, besonders der Schwermetalle.*" *Zeitsch. f. prakt. Geologie*, 1898, pp. 235, 314, 377, 413, and 1899, p. 10.

smaller intervals, for instance, between 0.0001 and 0.00001, or between the latter and 0.000001 per cent.

It may here be noted that all the more widely distributed elements (O, Si, Al, Fe, Ca, Mg, Na, K, H, Ti, C, Cl, P, etc.) have relatively small atomic weights. The 25 elements having the lowest atomic weights (up to and including iron) constitute at least 99.8 (more probably 99.85 to 99.9) per cent. of the earth's crust, while the remaining (say) 46 elements (among which barium, strontium, nickel, etc., are the most widely distributed) make up a total of 0.1, or at most 0.2 per cent. This is a result, on one hand, of the laws which controlled the formation of the elements themselves, which are probably to be conceived not as original and simple substances, but as compounds; on the other hand, of those which controlled the formation of the earth-crust from the original fire-mist of Kant and Laplace.

The elements of highest atomic weight are, then, on the whole, relatively the rarest in rocks; but that they do exist therein, though in minute proportions, and doubtless in some rocks as original constituents, may be shown, by way of illustration, for the platinum metals.

These metals are found here and there—often together with segregations of chromite—as primary segregations formed by magmatic concentration, in very basic eruptive rocks (peridotite, and, as reported in one locality, highly basic olivin-gabbro)—a fact which clearly indicates their original presence in minute proportion in these rocks. Moreover, in recent years a small proportion of platinum-metals has been found (as at Sudbury, Can., and Klefva, Sweden) in the segregated sulphide-ores of gabbro rocks—a fact which requires the supposition that the gabbro magma originally contained them. Some conception of this original tenor of platinum-metals may be formed from the statement that the nickeliferous pyrrhotites of Sudbury contain, according to many analyses, from 25,000 to 90,000 times as much nickel as platinum-metals; while the original proportion of nickel in the gabbro magma may be set down as about 0.05 per cent. Hence, on the (somewhat arbitrary) assumption that the platinum-metals were concentrated from the magma to the same extent as the nickel, the magma contained, roughly, 0.000001 per cent. of these metals. This figure, of course, has no pretension to accuracy; but we have at least learned that even the platinum-metals are among the normal constituents of the basic eruptive rocks.

It can be similarly shown that minute quantities of gold and silver belong in eruptive magmas. For further discussion of this subject, and of the relative concentration of certain elements into the acid, and of others into the basic eruptives, I refer to my treatise cited above.

II. THE RELATION BETWEEN ERUPTIVE PROCESSES AND THE FORMATION OF ORE-DEPOSITS, ESPECIALLY SUCH AS HAVE BEEN PRODUCED BY ERUPTIVE AFTER-ACTIONS.

In his latest paper, Prof. Van Hise divides ore-deposits into three groups, namely, those of direct igneous origin; those which are the direct result of sedimentation; and those which have been deposited by underground water. His first and fundamental premise is that the greater number of ore-deposits are the work of underground water. He asserts, further, that the material for ore-deposits is derived from rocks within the "zone of fracture"; that by far the greater part of the water depositing ores is meteoric; and that the flow of underground water is caused chiefly by gravity.

According to his view, by far the larger number of ore-deposits are formed by underground water, ore-deposits of direct igneous origin being "probably of limited extent," and the same being true of those which are the direct result of sedimentation (some placers, etc.); while possibly some are due to sublimation.*

In this paper I shall not discuss the sedimentary ore-deposits; but I may remark here that, in my opinion, there has been, of late, a frequent tendency to underestimate in this connection the importance of sedimentation as a formative agent.

From Prof. Van Hise's interesting paper, so rich in new theoretical suggestions, I have learned much; I believe that he has furnished the key to the genesis of numerous ore-deposits; yet at the same time, in my opinion, he ascribes to his theory too great a range, and, in particular, attaches too little importance to the direct genetic relation between ore-deposits

---

* "Some Principles," etc., *Trans.*, xxx., 27, *passim;* this vol., pp. 282–432.

and eruptive processes. Many of the occurrences classed by him among the effects of underground water are, according to my view, the results of processes intimately connected with eruptive magmas, especially through eruptive after-actions (sublimation, pneumatolysis, pneumato-hydatogenesis, etc.) by which the heavy metals were in great part extracted from such magmas.

In order to make my view clear, I will here briefly mention a number of groups of ore-deposits :

Ore-Deposits Formed by Magmatic Segregation.

Ore-deposits formed by simple magmatic differentiation are confessedly infrequent, and therefore relatively subordinate in importance to other classes. Under this head may be named:* (1) The occurrences of titanic iron-ores in basic and intermediate eruptives, perhaps also of iron-ores in acid eruptives; (2) those of chromite in peridotites and their secondary serpentines (and also, according to J. H. Pratt, those of corundum in the peridotites of N. C.); (3) a number of deposits of sulphide-ores, particularly the nickeliferous pyrrhotites occurring in gabbro (at Sudbury, Can., Lancaster Gap, Pa., many places in Norway and Sweden, and Varallo, in Piedmont); (4) according to some authorities, the auriferous pyrites of Rossland, B. C.;† (5) according to B. Lotti, the high-grade copper-ores occurring in serpentinized peridotites in Tuscany and Liguria, Northern Italy (for instance, at Monte Catini), and analogous occurrences in other regions; (6) the occurrence of metallic nickel-iron (without economic value) in eruptive rocks; (7) those of the platinum-metals in highly basic eruptive rocks,‡ etc., etc.

It may be pretty safely assumed that the foregoing list will

---

* See my articles in the *Zeit. f. prakt. Geologie* during 1893, 1894, 1895 and 1900 (to be continued in 1901).

† Other authorities explain the Rossland occurrence differently. See "Biotitic Gold-Copper Veins," in Mr. Lindgren's paper, p. 564.

‡ Already mentioned on page 640. It may be added here that, so far as known, all primary platinum deposits were formed by igneous fusion, and that the platinum-metals are either wholly wanting, or only exist in minute traces, in deposits from aqueous solution. The latter fact may be due to the small susceptibility of these metals, which are, for example, much less soluble in *aqua regia* than gold. (See *Zeitsch. f. prakt. Geologie*, 1898, p. 321.)

be enlarged by future investigations, though it can never become very extensive.*

Ore-Deposits Formed by Eruptive After-Actions.

But a different case is presented by deposits connected with the eruptives by pneumatolytic, pneumato-hydatogenetic, and other similar processes, the heavy metals of which, as I conceive, were mostly extracted from the eruptive magmas.

To explain this proposition, let us first remark that the eruptive magmas—at least those of deep origin—are admitted to be hydato-pyrogenic—*i.e.*, to contain a more or less notable admixture of water, with other constituents of hydrous or gaseous character. This is shown directly by observations of volcanoes, and indirectly, for example, by inference from the contact-metamorphism along deep rocks, which is conceived as a recrystallization under the influence of interpenetrating steam. Another indication is given by the enclosures of carbonic acid in quartz.

Concerning the chemical and physical action of water upon the magma, I quote the following passage from the work of Arrhenius, already cited:

> "The water in the magma . . . acts as an acid (strong as compared with silicic acid), liberating free silicic acid, H_2SiO_3, and free bases. By mixture with the unaltered magma, these become acid and basic silicates—the access of water having rendered the magma more liquid."

As is well known, the ionization of water increases rapidly with its temperature. This explains the activity of water at high temperatures. Thus, for example, Barus has shown that water heated above 185° C. attacks the silicates composing soft glass with astonishing rapidity; and an experiment by Lemberg has proved that water at 210° C. slowly dissolves anhydrous powdered silicates.

---

* Prof. R. Beck, in the first part (which has just appeared—Berlin, 1901) of his *Lehre von den Erzlagerstätten*, classes (with some doubt) the tin-ores of Etta Knob, in the Black Hills of Dakota, among magmatic segregations. This seems to me incorrect. The deposit mentioned, carrying cassiterite with apatite, triphyline, tantalite, columbite, spodumene, etc., presents, in its mineral paragenesis as well as in its geological occurrence, all the distinguishing marks of the tin-deposits formed by pneumatolytic processes—in this case intimately connected with the eruption of the granite-pegmatite. To this point I shall recur later.

Of special interest in the study of pneumatolytic phenomena is the following passage from the same work:

> "So far as we know, all gases can be mixed with each other in any desired proportions. In the interior gaseous magma of the earth, therefore, there should be no permanent zones of segregation; but all occurring differentiations should lead to continuous transitions, and in the first rank of the forces operative in these would be osmotic pressures, of the detailed nature of which, at these high temperatures, little is yet known.
>
> "In cooling, however, it is highly probable that this magma—at least, if it contained sufficient water—separates into two layers, after it has assumed a liquid state. The division takes place at a proportionately lower temperature, the smaller the amount of water. When this is very small, the products of the separation appear only as enclosures of water, carbonic acid, etc., at a very advanced stage of cooling, when the mobility is too small to permit the small drops to flow together and form larger masses. On the other hand, when the water-content is considerable, the aqueous gas collects in larger volumes, and in these are concentrated the bodies which, at the existing temperature, are more soluble in water than in the silicate-magma. Among these bodies are carbonic acid, hydrogen sulphide, combinations of univalent ions, such as those of chloric, fluoric and boric acid, with the mostly positive ions, like the alkali-metals, and, less frequently, the earthy metals, calcium, strontium and barium. The univalent ions have a strongly marked tendency to go to the water, because their compounds are dissociated electrolytically with extraordinary force. And among them the foremost must be those which possess a strong tendency to ionization, or, in the older chemical phrase, show strong affinity. Those ions, also, the hydrates of which are highly soluble in water without becoming dissociated, are favored in this process. This group includes, among others, the ions of carbonic and boric acid and hydrogen sulphide. Of course, silicic acid is likewise taken up by water in proportion to its solubility. (The ions of the bivalent metals—iron, zinc, lead, copper and tin—seem also to follow by preference the negative ions named.) In this solution, composed of bodies so various, the positive and negative ions are to be conceived, not as bound to each other in a definite way, but as mutually independent, as in an ordinary solution, such as sea-water.
>
> "The cooling and the consequent separation into two layers occur soonest at the surface of contact between the eruptive and the cool adjacent rock; and it is natural to assume that later aqueous segregations will by preference accumulate with the earlier ones. Other portions are gradually collected as geodes and veins in the interior of the magmatic mass. By reason of the greatly superior mobility of the aqueous solutions, as compared with the magma, these segregations may send out branches in the form of the finest apophyses. The solution in aqueous gas now gradually cools, and one substance after another separates from it. By reason of the great mobility of the solution, and its consequent strong capability of diffusion, the minerals (provided the cooling be not too rapid) are segregated in large crystals, such as characterize a so-called pegmatitic structure. Gradually, also, the constituents which longest retain a gaseous form —such as water and carbonic acid—escape.
>
> "According to this view, all the products required for the formation of 'pneumatolytic minerals' are simultaneously present in the aqueous solution; and it is not necessary to imagine that they come in gaseous form from different regions, to meet at the point of segregation."

After this theoretic explanation,* we may return to our consideration of the pneumatolytic or pneumato-hydatogenetic ore-deposits, beginning with those of tin-ore, the genesis of which has been especially studied by French investigators.†

Cassiterite-Veins and Apatite-Veins.—As is well known, the cassiterite-veins, of the type found in Cornwall, the *Erzgebirge*, Banca and Billiton, Tasmania, etc., are, everywhere in the world,‡ in connection with acid eruptives, namely, granite and (now and then) the veinstones and ejected rocks of the granite family, such as quartz-porphyry, liparite and rhyolite. Partly for this reason, and partly because of the characteristic paragenesis of the cassiterite-veins (presenting many fluoride-, borate- and phosphate-minerals), and the pneumatolytic metamorphism of the country-rock (forming *Greisen*), Elie de Beaumont and A. Daubrée, as is well known, concluded as early as 1840–1850 that these veins were connected with the granitic eruptions, and that in their formation various volatile fluorides, boron-compounds, etc., took part. Daubrée was led to a detailed theory by his famous synthetic experiments in sublimation.§

The genetic relations between the cassiterite-veins and the granite-eruptions may be followed a step further. It is first to be emphasized that the cassiterite-veins were formed immediately after the eruption—often, indeed, before the complete cooling—of the granite. One proof of this (among others) is the occurrence of the tin-vein-minerals in many veins of pegmatite with the granite.‖ It has been proved also by K. Dalmer in a thorough geological study of the deposits of the *Erzgebirge*. And it follows that, in this class of cases, ordinary underground water cannot have been active. We may assert, further, that the cassiterite-veins are genetically independent of the immediately adjacent country-rock.

---

[*] An attempt to explain the physics of magmatic differentiation under the influence of water dissolved in the magma will be found in an article which I shall publish in an early number of the *Zeitsch. f. prakt. Geologie* for 1901.

[†] The following statement is mostly a résumé of my treatise in the above-named journal (Nos. 4, 9, 11 and 12, of 1895).

[‡] The peculiar silver-tin veins in Bolivia, described by A. W. Stelzner, are not here classed with tin-ore veins proper. Concerning contact-deposits of iron-ore carrying cassiterite, something will be said below.

[§] See above, p. 637.

[‖] See footnote, p. 643, above.

The geological features of these veins force us to the view that their material contents were extracted from the not yet fully congealed granite; and this view is confirmed by their mineralogical and chemical features. We find in these veins exactly the series of elements characteristic of the granite pegmatite-veins, such as potassium and lithium; also, tin, tungsten, uranium, niobium, etc., as well as beryllium (all also occurring with considerable frequency in the pegmatite-veins); and, finally, boron and fluorine.

Apatite-Veins.—At this point, I will briefly describe the Norwegian and North-Swedish apatite-veins. These veins are analogous to the cassiterite-veins, from which, however, they differ in many very instructive particulars.

The tin-veins are connected with granite; the apatite-veins with gabbro; and, in the latter case also, it can be shown that the veins were formed soon after the eruption of the rock, and that they cannot be explained by agencies acting upon the already congealed gabbro.

In both classes of veins we find a characteristic pneumatolytic metamorphism of the country-rock. Each class has in abundance a halogen-element: the tin-veins carrying fluorine (with a very little chlorine), and the apatite-veins chlorine (with a very little fluorine),* which occurs (1) in the mineral scapolite (containing about 2.5 per cent. Cl), abundantly represented in the metamorphosed zone along the vein-walls;† and (2) in the mineral chlorapatite.

In the tin-veins also, apatite or other phosphates are almost invariably found—sometimes, even, in considerable quantity.‡ This is specially noteworthy, because apatite is wholly (or almost wholly) lacking in lead-silver-ore veins, such as those of the *Erzgebirge*, the Harz, Kongsberg, Schemnitz, the Comstock Lode, etc., and in gold-veins generally.

Instead of the stannic acid, SnO_2, found in the tin-veins, we find in the apatite-veins titanic acid, TiO_2, as rutile (which is often so abundant as to be mined), ilmenite, titanite, etc.

---

* The Canadian apatite-veins carry a larger proportion of fluorine than the Norwegian.

† In the well-known apatite-deposit at Odegaarden, Norway, there is, on the whole, some 2.5 or 3 times as much chlorine as phosphoric acid.

‡ For example, the cassiterite-veins at Montebras in France are mined chiefly for the lithium phosphate, amblygonite.

The potassium- and lithium-minerals of the tin-veins are replaced in the apatite-veins by minerals of magnesium and calcium-sodium. The apatite-veins often contain some pyrites, and also, exceptionally, a little tourmaline—that is, a silicate containing boron.

While the characteristic elements of the tin-veins (Si, Sn, K, Li, Be; also W, Ur, Va, Ta, with F, B, P, etc.) remind us of the composition of the granite, we find in the characteristic elements of the apatite-veins (especially P, Ti, Fe, Mg, Ca, Na, Cl, etc.) a close analogy with the composition of the gabbro.

We conclude that the material of the apatite-veins was extracted from the gabbro magma in a manner similar to that of the extraction from the granite of the material of the tin-veins.

Since the halogens chlorine and fluorine respectively are so richly represented in these two classes of veins, we may conclude, further, that the magmatic extraction-process is based chiefly upon a reaction, in the pressure of water, of hydrochloric (or, as the case may be, hydrofluoric) acid, dissolved in the magma.

In my work of 1895, cited above, I have attempted to prove that by such an "acid extraction-process," operating in a granite magma, especially the elements K, Li, Be, Sn, W, Ur, Nb, etc., together with B and P, would be carried into the aqueous hydrofluoric solution; while, on the other hand, the aqueous hydrochloric solution in the gabbro magma would take up especially P, Ti, Fe, Mg, Ca, Na, etc. For this view I now find a support in the recent account by Arrhenius of the chemico-physical reactions of aqueous magmatic solutions.

Pegmatite-Veins.—A similar argument can be made concerning the "nephelin-syenitic pegmatite-veins of the southwest border-zone of the augite-syenite region," near Langesund-Brevig, in southern Norway, which have received so masterly an examination from W. C. Brögger.* We note specially that we encounter here a whole series of rare minerals, containing boric, zirconic, stannic and thoric acid (B_2O_3, ZrO_2, SnO_2, ThO_2), and also fluorine and chlorine; and that Brögger has established the following four phases of the vein-formation: (1) the phase of magmatic solidification; (2) the principal phase of pneuma-

---

* *Zeitsch. f. Kryst. u. Min.*, vol. xvi., 1890.

tolytic solidification; (3) the phase of the formation of zeolites; (4) the phase of the fluocarbonates, carbonates, etc. We note also that these veins are to be considered as contact phenomena.

Here we learn, on one hand, the action of the aqueous hydrochloric-hydrofluoric solution in the augite-syenite magma, and, on the other hand, the various stages of the vein-formation, in which the influence of (*a*) chlorides and fluorides, (*b*) water, (*c*) carbonic acid, etc., is operative.

From this brief digression outside the field of ore-deposits, strictly so called, we return to consider

Ore-Deposits of Contact-Metamorphic Origin.—These we may more briefly call "contact-deposits," in a limited sense of that term. As examples, we may take the iron-ore deposits of the Kristiania region, bordering the post-Silurian (pretty certainly Devonian) granites; also those of southern Hungary (at Vaskò or Moravitza, Dognaska, etc., in the Banat), bordering the late Mesozoic or Tertiary banatite eruptives; also those of the island of Elba, near Tertiary eruptives, particularly granite; and those of Dielette, in the department of Manche, France.*

The characteristics of this group of deposits are:

The ores (mainly magnetite and specular hematite, yet often also sulphides of copper, lead, zinc, etc.) occur within the metamorphosed contact-zone of deep eruptives, especially granite. Frequently they lie almost immediately at the boundary between the eruptive and the country-rock; frequently from 0.5 to 2 kilom. from that boundary, and sometimes even farther away (horizontally); but never outside of the metamorphosed zone. Not seldom they are found in fragments of metamorphosed slate or limestone, which have torn loose, and surrounded by the adjacent eruptive.

More particularly, the ores occur in limestones, marly slates and ordinary clay-slates, and are accompanied by the usual

---

* I believe that numerous ore-deposits belong in this group of contact-deposits. But it is sufficient here to describe these from typical representatives, upon the following authorities: For the Kristiania region, the studies of Th. Kjerulf and my own earlier ones (with references in the *Zeitsch. f. prakt. Geologie* for 1894, pp. 177, 464, and 1895, p. 154); for the Banat (which I have also visited personally, with Prof. F. Beyschlag of Berlin), the work of B. v. Cotta (1864) and Edward Suess (*Antlitz der Erde*); for the Elba deposits, the investigations of B. Lotti; and for the French deposits, a description by Michel-Lévy.

contact-minerals, garnet, vesuvianite, scapolite, wollastonite, augite, hornblende, mica, etc.—and also (in the clay-slates) by chiastolite, etc. In other words, the phenomena of contact-metamorphosis are the same here as elsewhere, except that the minerals in the immediate vicinity of the ores are developed as very large individuals; *i.e.*, these ores have occasioned a contact-metamorphism of high potency.

Sometimes the ore-deposits are traversed by apophyses of the eruptive, such as veins of granite, quartz-porphyry, etc.

The Kristiania Deposits.—A study of the Kristiania contact-deposits indicates that the formation of the ores preceded the solidification of the granitic magma. Even when the ores occur in slates immediately adjacent to the granite, or in the small Silurian fragments completely surrounded by granite, they are never found also in the granite itself. This is to be simply explained by the supposition that from the still liquid magma the ores were "blown into"* the adjoining rigid rocks. If they had been introduced later, they would have been deposited in the granite also. In the Kristiania field, the contact-ores are found in pre-granitic rocks of all kinds—not only in limestones, pure and impure, and clay-slates, but also in Archean gneiss and pre-granitic porphyry-outflows. Hence this final deposition is independent of the chemical composition of the adjacent rocks. The presence in these deposits of granitic apophyses, already mentioned, is another proof that they were formed before the solidification of the granite.

We conclude, further, that the material of the ores was derived, not from the surrounding rocks, but from the eruptive magma. In the first place, their chemical composition (in the Kristiania region, as often elsewhere, showing a predominance, now of iron, now of copper, or, again, of zinc, lead, etc., associated with some bismuth, arsenic, antimony, etc.) is independent of that of the country-rock. In the second place, we often find the ores in rock-fragments, completely surrounded by granite,† so small that they could not have furnished the requisite amount of ore-material.

Contact-metamorphism is usually referred, in accordance with

---

* I adopt this expression (*eingeblasen*) from my deceased teacher, Th. Kjerulf.

† Of 108 old mines and prospecting-pits in the Kristiania district, 16 per cent. are in small Silurian masses, completely enclosed in the granite; 20 per cent. im-

all probability, to the action of heated steam escaping from the eruptive magma and pressed into the surrounding rocks, where it produces a re-crystallization, in most cases without notable addition or subtraction of material. Contact ore-deposits form a special class of this metamorphism (involving "ferrization," etc.), and are explained by the presence of metallic compounds in the heated steam.

Other Contact-Deposits.—There is thus a close analogy between such contact ore-deposits as those of Kristiania, the Banat, Elba, etc., on one hand, and the tin-ore veins on the other—the latter being exclusively, and the former mainly, connected with granite eruptions. Indeed, there are also numerous intermediate transitional cases between these two. We may mention as instances the "tourmalinization" within zones of contact-metamorphism, well known in Saxony, and the similar "axinitization" of contact-metamorphic zones in the Pyrenees, which A. Lacroix has recently described. In these cases, that is to say, the boro-silicates, so well known in tin-veins, have been conveyed in great abundance into the metamorphosed zone. Fluorspar, tourmaline, axinite, etc., as well as the scapolite (which contains Na Cl), have also been found in our contact-deposits of iron-ore; while, on the other hand, specular iron is sometimes abundant in cassiterite-veins.

Moreover, there are metamorphic contact ore-deposits (characterized by garnet, augite, hornblende, etc.) which, besides magnetite, specular hematite, and sulphide-ores of copper, lead and zinc, carry also cassiterite, with its usual accompanying minerals. An instance is Pitkäranta in Finland, where, according to A. E. Törnebohm, the order of deposition was (1) iron-ore; (2) tin-ore; (3) copper-ore. Another instance is furnished by the "bed-impregnations" near granite, at Schwarzenberg in the *Erzgebirge*, recently described by K. Dalmer,* which carry as ore-minerals magnetite, specular iron, pyrites, galena, zinc-blende, etc., with cassiterite, wolframite, etc., further accompanied by pyroxene, actinolite, garnet, epidote, wollastonite, vesuvianite, etc., with fluorite, axinite and titanite. Under

---

mediately upon or near the contact between these rocks; 44 per cent. within the contact-zone, but farther away from the granite; and 20 per cent. in Archean rock and pre-granitic porphyry overflows, near the border of the granite.

* *Zeitsch. f. prakt. Geologie,* 1897, p. 265.

this head belongs perhaps also the peculiar occurrence of cassiterite and iron-ore in limestone near Campiglia in Tuscany,* 2.5 kilom. from a tourmaline-bearing granite.

Chemical History.—Chemically, however, the processes forming such contact-deposits of iron-ore, on one hand, and the cassiterite-veins on the other, must have been different. As already observed, the material of the latter was derived through magmatic extraction by an aqueous solution of hydrofluoric (and hydrochloric) acid; but in the ordinary, non-stanniferous contact-deposits of iron-ore the elements characteristic of the cassiterite-veins (Sn, W, U, Li, Be, B, etc.) are almost or wholly wanting, and, as a rule, fluorine is scantily represented. For these cases, therefore, an extraction by hydrofluoric and hydrochloric acid is apparently excluded. On the other hand, we may assume that the magmatic water itself has here played a specially energetic part, and has extracted iron from the magma. The detailed explanation is still an open question, in connection with which I may recall the theoretical proposition of Arrhenius, already quoted, that the water of the magma "acts, relatively to SiO_2, as a strong acid."

Pyritic Deposits.—As an appendix to the foregoing contact-deposits, I mention the pyritic deposits, typically represented at Vigsnäs, Röros, Sulitelma, etc., in Norway; Rio Tinto, Tharsis and San Domingo, in Spain and the adjacent part of Portugal; Agordo in Lombardy; Schmöllnitz in N. Hungary; etc. To these I would reckon also Rammelsberg in the Harz.

Concerning the genesis of these deposits, opinions notoriously differ. Some observers assert a sedimentary origin, while, in accordance with many others preceding me,† I ascribe the deposits to after-processes, following eruptive intrusions.‡

These deposits, which almost always have an apparently stratiform character, occur only either in rocks fully altered by dynamic metamorphism or in formations somewhat less powerfully compressed, and, generally, in close relation with erup-

---

* Described by B. Lotti and K. Dalmer, *Zeitsch. f. prakt. Geologie*, 1894, p. 400.

† Th. Kjerulf in Norway, K. A. Lossen in Germany, L. de Launay in France, Gonzalo y Tarin in Spain, etc.

‡ For my own works on this question, see *Zeitsch. f. prakt. Geologie*, 1894 (Röros and Rammelsberg) and 1899 (Huelva). I would mention also the studies of F. Klockmann, who defends the sedimentary hypothesis, *Id.* for 1895, p. 35, and *Sitzungsb. d. k. preuss. Akad. d. Wiss.*, Berlin, 1894, pp. 1173–1181.

tives. This last feature is highly characteristic of the numerous Norwegian deposits scattered between 59° 20′ and 70° of N. lat., along the old mountain-range which consists of Cambro-Silurian slates, probably folded in the middle Paleozoic (Devonian) age. Their distribution is such, however, that they appear only in those parts of the range where considerable outbreaks of eruptive rocks (gabbro, often accompanied by a granite rich in soda) took place, at about the period of the mountain-folding.

Of 28 Norwegian pyrites-deposits, enumerated in my treatise of 1894, 26 were proved to lie very near, or actually within, regions of compressed gabbro. I can now add that in one of the two cases then excepted we have found the eruptive rock near the mine. Since the deposits, moreover, are independent of the age of the slates (mostly phyllite- and mica-slates), their genetic relation to the eruptives is indisputable.

Some of them occur on shearing-planes in the compressed gabbro; but the great majority are in the slates surrounding it, most frequently at a distance of from 50 to 500 meters from the eruptive border, and rarely somewhat farther away.

We may note, further, that the pyritic deposits themselves (as has been shown by A. W. Stelzner and others) have sometimes been compressed—*i.e.*, they were completely formed before the end of the folding of the mountain-chain. Moreover, in many places they are traversed by apophyses of the eruptives, *i.e.*, they were formed before the solidification of the deeper portions of the eruptive magma.

It follows from these considerations that the Norwegian pyritic deposits are to be classed as phenomena of contact-metamorphism connected with the gabbro and its peculiar accompanying granite, and that their bed-like appearance must be explained by the occurrence of the gabbro eruption during the long period of mountain-folding. The ores were thus formed under extremely high pressure, which favored their introduction up and along existing planes of stratification.

The analogy of these cases with those of the ordinary contact-deposits already described covers also the origin of the ore-material, which we must assume to have been somehow extracted from the eruptive magma. This view is supported by (1) their independence of the adjacent slates; (2) their formation immediately after the gabbro eruption; and (3) the resemblance of their material to that of the nickel-pyrrhotite deposits, considered to be products of magmatic secretion. The chemico-mineralogical difference between the two classes is, that in the magmatically secreted pyrrhotite deposits nickel predominates over copper, while in the pyritic deposits the contrary is the case. Yet in chemical respects there exist complete intermediate transitional occurrences, which I hope to describe at some future day.

The detailed explanation of the magmatic extraction forming the pyritic deposits is an entirely open question; but we may conceive it to be the combined action of water with a sulphur-compound.

What I have said of the Norwegian pyritic deposits holds good, I believe, in its main features, though with modifications of detail, for the other deposits of this class, mentioned above.

Veins of Gold, Silver and Lead-Ore.—These may be divided into three main groups: (1) relatively recent gold and silver, or silver-lead veins; (2) old silver-lead veins; (3) old gold-veins.

Gold- and Silver- or Silver-Lead-Veins of Later Age.—As representatives of this class we may name those of Nagyág-Verespatak in Transylvania; Schemnitz-Kremnitz and Nagybanya-Kapnik in upper Hungary (all of which lie along the Karpathian range); Cripple Creek, and many other Colorado occurrences in the Boulder, San Juan, Silver Cliff, Rosita and other districts; the Horn Silver and many mines in Beaver county, Utah; the Comstock, Esmeralda, etc., in Nevada; and San Bernardino in California; the districts of Durango, Fresnillo, Zacatecas, Guanajuato, Pachuca, etc., in Mexico; Cerro de Pasco in Peru; Potosi, Huachuca, Oruro, etc., in Bolivia, and many others along the South American Andes; the Coromandel peninsula (Hauraki) in New Zealand; and, finally, many places in Japan. This list, though far from complete, may serve to give a notion of the wide distribution and the economic value of the deposits of this group.

Its general features were first described by F. v. Richthofen, forty years ago. We may also refer here to the work of E.

Suess,* and to numerous treatises which have appeared in recent decades.

The younger gold- and silver-veins stand closely related to recent (especially Tertiary, but sometimes late Mesozoic, and occasionally to Quaternary) eruptive rocks.† But they are not confined to any one of the recent eruptives. Many occur in andesites; others in dacites; others, again, in quartz-trachytes, rhyolites, etc., and some in phonolites; so that they are to be considered rather as products of general volcanic activity. In fact, they belong, as a rule, in each district to the latest, or one of the latest, epochs of volcanic activity for that district. Hot springs, solfataras, etc., are frequently found near them.

Very often they carry silver and gold in combination (Comstock, Schemnitz, Nagybanya-Kapnik, etc.), the gold being sometimes predominant, with little silver (Cripple Creek, Transylvania), and sometimes *vice versa* (at many places in Mexico, Bolivia, etc.). Galena is in some cases abundant, but often almost or wholly absent (Transylvania, Cripple Creek, Comstock). Ores of copper and zinc are, as a rule, scanty; arsenic and antimony pretty common; and the frequent abundance of arsenical and antimonial sulphides is noteworthy.

A special sub-group is formed by the tin-bearing silver-lead-bismuth-ore veins of Bolivia, examined some years ago by A. W. Stelzner,‡ which carry cassiterite, and occasionally also the sulphide, stannite, while the accompanying minerals usual in cassiterite-veins are wanting. Cassiterite has been found also in some recent ore-veins in Mexico (and wolframite at Kapnik, Hungary).

Tellurium occurs abundantly in some gold-veins (Nagyag; Cripple Creek and other places in North America—especially in Colorado; Hauraki, N. Z.),§ but is lacking, wholly or nearly, in most cases. Selenium occurs occasionally.

The gangue-minerals are chiefly quartz and carbonate-spars, sometimes heavy spar (barite). Fluorite is usually absent, but

---

* *Zukunft des Goldes*, 1877.

† What follows is a summary of my views as expressed in the *Zeitsch. f. prakt. Geologie*, 1898, pp. 416–420, and 1899, pp. 10–12.

‡ *Zeitsch. d. d. geol. Gesellsch.*, Bd. xlix., 51 (1897). Published after Stelzner's death by Bergeat.

§ The large tellurium-gold-veins at Kalgoorlie, W. Aust., probably belong, not to this younger group, but to the older one above mentioned.

occurs here and there in abundance, *e.g.*, in the celebrated tellurium-gold field of Cripple Creek, Col.,* and in the Judith mountains, Montana.

Of the characteristic alteration of the country-rock along the veins to propylite, with sericite, kaolin, carbonate-spars, etc., Mr. Lindgren's recent paper in these *Transactions* gives a general account. I shall say more concerning it in the next part of this paper.

The Older Lead-Silver Veins, and the Older Gold-Veins.—The lead-silver deposits of Freiberg, Annaberg and Schneeberg in the *Erzgebirge;* Clausthal and Andreasberg in the Harz; Kongsberg in Norway; Przibram in Bohemia, etc., and also the old gold-quartz veins of the Mother lode in Cal., Berezowsk in the Urals, etc., show in numerous instances an undeniable dependence upon eruptive processes and mountain-foldings. But here also it is impossible to establish a universal relation between a given kind of vein and any particular eruptive rock. The silver-ore veins, for instance, occur in connection now with basic, now with acid eruptions.

Between these older and the younger veins there are several well-known differences. The presence of both gold and silver, in considerable proportions of each, displayed by many of the more recent veins, has never been observed, so far as I know, in the older ones.

Again, the older veins do not exhibit the propylitization of the country-rock, so characteristic of the later ones; but there is, instead, in many cases, as described by Lindgren, a somewhat similar alteration (carbonatization or sericitization). Moreover, the quantity of sulphides or, generally, of compounds of arsenic, antimony and bismuth (and, in Bolivia, of tin) is, on the whole, not so large in the older as in the later veins.

Yet, notwithstanding these and other differences, we must, in studying the question of genesis, emphasize rather the analogies between the two classes. There is, for instance, a significant similarity in many respects between the late lead-silver-

---

* Some American observers have assumed a genetic relation between fluor-spar and tellurium (or the telluride gold-ores). This I cannot accept, in view of the absence of fluor-spar from other gold-tellurium districts. There is no trace of it at Nagyag, and, so far as I know, none, or in any event very little, at Kalgoorlie and Hauraki.

gold-veins of Schemnitz and the old lead-silver veins of Clausthal; between Zacatecas, Pachuca, etc., in Mexico, and the "noble" quartz-formation of Freiberg, etc. By reason of these mineralogical arguments, Prof. R. Beck, in his new treatise,* does not separate the older and younger vein-groups, but describes them together in categories determined by their mineralogical character, such as the pyritous lead-formation, the carbonate-spathic lead-formation, the barytic lead-formation, the precious (silver) quartz-formation, the noble silver-copper formation, etc.

In some cases it is doubtful whether veins should be reckoned as belonging to the older or the younger group. For instance, the deposits of Pontgibaud, in central France, show, on the one hand, the character of the old galena-veins, but lie, on the other hand, not far from the late eruptives of Auvergne, and parallel with the volcanic fissure of that field.

As L. de Launay has pointed out, it is quite possible that the older and newer gold-silver-lead-veins have a mutual relation somewhat like that of the formerly so-called "old" and "young" eruptives, which are now distinguished as deep or outflowing, their structural differences being ascribed to crystallization at different depths. To this subject I shall recur later.

Source of the Ore.—We may now inquire, Whence comes the ore of these veins?

For the older as well as the younger ones, we may declare that a clear genetic connection with eruptive rocks can be established. In some eruptive districts the latest eruptives of the series exposed are even later than the ore-veins; hence the formation of the latter must have occurred during the eruptive epoch.

Partly for this reason, and partly because of the fact that, on the whole, the veins are generally independent of the petrographic nature of the country-rock,† I think we are warranted, in this department also, in assuming, as a working-hypothesis, that the ore-material was extracted from a magma. With regard to the younger veins especially, we must keep in mind a possible extraction from a laccolitic magma in depth.

---

* *Lehre von den Erzlagerstätten*, 1901.

† In many cases there is a dependence on the country-rock, the nature of which has favored ore-deposition—as, for instance, in the fahlbands of Kongsberg.

In support of this hypothesis, we may cite the transitional or intermediate occurrences between the cassiterite- and the silver-lead-veins. Thus, in Cornwall, the tin-, the tin-copper- and the galena-veins are so closely related topographically and geologically that a common origin must be assumed for them. The same is true of the cassiterite-veins and the various silver-lead ore-formations of the *Erzgebirge;* and the peculiar tin-bearing silver-lead veins of Bolivia may be recalled in this connection.

These intermediate groups warrant the conclusion that there can have been no absolute essential difference between the genesis of the cassiterite- and that of the silver-lead-veins. If the tin-veins are to be explained by magmatic extraction, the silver-lead veins may not be attributable to the work of underground water.

We refer, also, to a recent paper by E. Hussak,* describing an auriferous pyritic quartz-bed-vein at Passagem in Brazil, and asserting that this vein is to be considered as an ultra-acid granitic apophyse.

Between the ordinary quartz-veins, deposited from aqueous solutions (and at high temperature), and the granitic apophyses, rich in aqueous solution and highly siliceous, there seem to be gradual transitionary types.

We may also recall the fact that ore-veins often continue to a great depth. As will be shown later on, mining is carried on in many places at a depth of not merely 0.75 to 1.25 kilom., but, in fact, as referred to the *original* surface, 3, 4, 5, perhaps 6 kilom.

The minerals in veins and the alterations of country-rocks show, in many cases, that the solutions in the vein-fissures were specially rich in carbonic acid and compounds of sulphur (hydrogen and alkaline sulphides, sulphates, etc.), and to these is often added an aqueous solution of silicic acid. As factors in magmatic extraction for such cases we would assume, therefore, water, carbonic acid, and compounds of sulphur, and, in general, not hydrofluoric or hydrochloric acid.

Copper-Ore Deposits.—The copper-ore veins in or near eruptive rocks (*e.g.*, Butte, Mont., and Cornwall), and also the quicksilver-deposits, permit the adoption of a similar genetic hypothesis.

---

* *Zeitsch. f. prakt. Geol.*, 1898, p. 345.

Conclusions.—That the ore-deposits first mentioned above, viz., the titanic iron-ores in gabbro, the chromite-occurrences in peridotites, the nickel-pyrrhotite deposits in gabbro, etc., were formed by magmatic extraction, I think I have scientifically proved beyond doubt; and I believe that the magmatic-extraction theory advanced for the cassiterite- and apatite-veins is in its main proposition correct. For the ore-deposits subsequently considered—the contact-deposits, the pyritic deposits, the gold-veins, silver-lead veins, copper-ore veins, etc.—the views here offered become confessedly more and more hypothetical. But they have much in their favor; and even if, following in particular the French observers, I have here ascribed to magmatic-extraction too great a significance, I believe, nevertheless, that the hypothesis is worthy of thorough scientific discussion.

At the same time, I wish to add emphatically that, beyond doubt, numerous ore-deposits may have been formed by the action of underground waters, so comprehensively investigated and described by Van Hise; *e.g.*, many deposits of iron- and manganese-ores; the veins of nickel silicate (garnierite); pretty certainly also the native copper of Lake Superior; and many other occurrences.

The precise tracing of the boundary between eruptive after-action and the work of the underground waters is a labor for the future.

III. THE NATURE OF THE ORE-SOLUTIONS IN VEIN-FISSURES, AND THE METASOMATIC ALTERATIONS ALONG THE ORE-VEINS.

The composition of these solutions may be deduced: (1) from the association of minerals in veins, and their relative order of individualization (Breithaupt's "paragenesis"); and (2) from the alteration of the country-rock proceeding from the vein-fissures.

The Association of Vein-Minerals.

Upon a knowledge of the quantitative relations among the various minerals which crystallized from the same solution we may base a conception of the physico-chemical mass-actions obtaining in the solution. For example, if a vein consists chiefly of calcite, with a little silver-glance, the silver, as well as the calcium, must have been present originally as $AgHCO_3$

and $CaH_2(CO_3)_2$ respectively, in an aqueous solution of carbonic acid, from which it is pretty certain that the silver was precipitated by hydrogen sulphide. Such a case is furnished by the deposits of Kongsberg, Norway.*

By parallel investigations of the paragenesis of the veins and the metasomatism of the country-rock, supported by experiments in mineral synthesis, the chemical nature of vein-solutions can be fairly well determined. The data at our disposal are now so abundant that this question must soon be ripe for final scientific decision.

Deposition of the Vein-Minerals.

These have generally crystallized under high pressure and somewhat elevated temperature. Under present conditions a depth of 1 kilom. in the earth's crust represents an increase of about 275 atm. in pressure, and 30° C. in temperature. In many ore-veins, as will be shown later, it can be shown that the minerals were formed at a depth below the original surface of 3, 4, or 5 kilom., or perhaps more. If we assume 4 kilom., and conditions like those of the present day, there must have been a pressure of about 1000 atm., and a temperature about 120° C. higher than at the surface.

But it must be considered that in the exceedingly numerous deposits connected in some way with eruptive processes, and often, indeed, formed in the later periods of the eruptive activity, the nearness of the igneous rocks must have caused an increase of temperature (and also of pressure ?). This is often so great as to exceed for heavy compounds the "critical temperature," as shown for a few substances in the following list.

Critical Temperatures.

	Deg. C.		Deg. C.
H_2O,	364	HCl,	52
H_2S,	100	$AsCl_3$,	356
CO_2,	31	$SiCl_4$,	230
CO, (about)	140	$SnCl_4$,	319
SO_2,	157	$TiCl_4$,	358

We note especially that the critical temperature of water occurs at 364° (or, according to earlier determinations, 375°)—

---

* See *Zeitsch. f. prakt. Geologie* for April and May, 1899. Concerning the solubility of silver carbonate as $AgHCO_3$ in water containing free carbonic acid, see a treatise by Chr. A. Münster, cited by P. Krusch, *Id.*, 1896, p. 103.

a temperature which certainly must have been exceeded by magmatic solutions at the moment of leaving the magma. In their upward course—especially determined, perhaps, by their lower specific gravity—the solutions cool; and (partly by virtue of this cooling, and partly through the encountering of various mutually reacting substances) the minerals are successively precipitated.

Alteration of the Country-Rock.

The scientific study of this phenomenon of vein-walls was begun in the '40s by Elie de Beaumont, A. Daubrée and others; yet Waldemar Lindgren's recent admirable paper* gives us for the first time a systematic scientific summary of the transformations which it involves. Mr. Lindgren's classification of veins according to metasomatic processes I here condense for convenient reference.

(1) Topaz-cassiterite; (2) scapolitic apatite; (3) tourmalinic gold-copper; (4) biotitic gold-copper; (5) propylitic gold and silver; (6) fluoritic gold-tellurium; (7) sericitic and kaolinic gold and silver; (8) sericitic and calcitic gold and silver; (9) silicic and calcitic quicksilver; (10) sericitic copper-silver; (11) silicic and dolomitic silver-lead; (12) sideritic silver-lead; (13) sericitic silver-lead; (14) zeolitic copper and silver.

Having busied myself somewhat with this class of problems, I will take the liberty to include here my attempt at a classification of the metasomatic processes caused by ore-solutions.†

Classification of Metasomatic Alterations.

1. Alterations forming greisen, mica-rock, cassiterite-rock, tourmaline-rock, topaz-rock, etc.
2. Scapolitization.
3. Propylitization (with chloritization, etc.).
4. Kaolinization.
5. Sericitization.
6. Carbonatization (with dolomitization, etc.).

---

* "Metasomatic Processes," etc., *Trans.*, xxx., 578; this vol., pp. 498–612.

† Taken from the manuscript of a half-finished paper which I began to write a year or two ago. But I may refer also to my article in the *Zeitsch. f. prakt. Geologie*, Nos. 4, 11 and 12 of 1895, and No. 12 of 1898.

The term "carbonatization," which was new to me, I took, a few years ago, from W. Lindgren's paper, "Characteristic Features of California Gold-Quartz Veins" (*Bull. Geol. Soc. of Am.*, 1895, vol. vi., p. 221); and I now add, still following Lindgren, the term dolomitization (as a process occurring along ore-veins).

7. Silicification.
8. Zeolitization.
9. Intense contact-metamorphism.

I would mention also the formation of alum-stone; quartz-alunite rocks; quartz-diaspore rocks, etc.;* and also the formation of bauxites, etc. But I do not know that these changes have been anywhere observed in genetic relation with ore-veins.

Between Lindgren's classification and this one previously written, though not published, by myself, there is, on the whole, a striking resemblance. My final heading, "Intense contact-metamorphism," is not included by Lindgren; but I believe that it plays an important part in connection, not, indeed, with the vein-fissures which he discusses, but with the contact-deposits described in a previous part of this paper.

Additional Observations.

To Lindgren's thorough treatise I venture to add, by way of complement and confirmation, a few isolated and fragmentary observations.

Kaolinization.—As is well-known, A. Daubrée† called attention to the fact that many of the principal kaolin-deposits in Cornwall, central France and the *Erzgebirge* accompany the tin-ore deposits of those regions. This may, perhaps, suggest the idea that the formation of kaolin, like that of cassiterite, must be explained in some way by the action of fluorides. Long ago, however, Forchhammer (1835) and Bischoff (1855), followed by many more recent authorities, ascribed kaolinization to the attack of water carrying carbonic acid;‡ and this must be the correct view, for the following reasons: (1) kaolinization is in many cases a surface-process, affected by the weak carbonic-acid solutions of surface-waters; (2) at somewhat greater depths, the feldspars of the rocks are often converted by similarly weak carbonic-acid waters into kaolin, sericite, etc., as well as calcite. Other instances may be given, in which the action of fluorides is excluded.

---

* See W. Cross, "Geology of Silver Cliff, etc., Colo.," and S. F. Emmons, "The Mines of Custer Co., Colo.," *17th Ann. Rep. U. S. Geol. Sur.*, 1896.

† *Études Synthétiques de Géologie Expérimentale*, 1879; and also in his earlier works.

‡ For the literature of the subject, see under "Kaolin," F. Zirkel's *Lehrb. d. Petrographie*, 1894, vol. iii.

It is notoriously orthoclase which is most frequently converted into kaolin. Forchhammer states the reaction as follows (in the old notation, which I retain):

Orthoclase,	Al_2O_3,	K_2O,	$6SiO_2$	
Subtracted,		K_2O,	$4SiO_2$	
Added,				$2H_2O$
Kaolin,	Al_2O_3,		$2SiO_2$,	$2H_2O$

Other feldspars and silicates of alumina, such as hornblende, augite, beryl, topaz, etc., are known to be occasionally converted into kaolin; but the study of the primary kaolin occurrences of granite shows that the potash-feldspar is much more easily or rapidly kaolinized than the silicates of magnesia and iron (magnesia-mica, etc.), while quartz is attacked but very weakly.

A few years ago, near Jösingfjord, at Ekersund-Söggendal, 4 or 5 kilom. from the ilmenite-deposit of Blaafjeld-Storgangen, in southern Norway, a kaolin-deposit in labradorite-rock was discovered, of such importance that it is now worked commercially. The kaolin was formed *in situ* from the labradorite, in which it occurs in pre-glacial fissures. The various stages of the alteration are illustrated by the following table of analyses (hitherto unpublished), some of which, unfortunately, are not complete:

Analyses of Labradorite and the Products of its Kaolinization.

	Labradorite.	Labradorite, Partly Kaolinized.		Massive Kaolin, More or Less Pure.					Normal Composition of Kaolin.
		I.	II.	I.	II.	III.	IV.	V.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	54.5	50.03	49.16	48.61	48.06	47.83	47.72	46.85	46.50
Al_2O_3	27.0	28.60	29.60	29.45	38.57	34.53	37.40	37.56	39.56
Fe_2O_3	2.5	1.62	1.88	3.40		1.70	1.59	1.00	0.00
CaO	9.0	4.21	3.47	0.68	undetermined.	0.48	0.23	trace.	0.00
MgO	1.0	2.95	1.67	0.49		0.59	0.11	trace.	0.00
Na_2O	5.0	about 1.00	undetermined.	undetermined.		undetermined.	0.76	undetermined.	0.00
K_2O	1.0						0.44		0.00
H_2O	...	11.90	13.63	16.38	12.95	13.76	11.66	14.44	13.94
Total	100.0	100.31	(99.41)	(99.01)	(99.58)	(98.89)	99.91	(99.85)	100.00

NOTE.—Labradorite-rock consists overwhelmingly of labrador-feldspar (containing about 56.25 per cent. SiO_2) with a couple of per. cent. of ilmenite and hypersthene, somewhat more richly concentrated here and there in spots. Hence the relatively high percentage of MgO in Analysis I. of labradorite, and of Fe_2O_3 in I. of kaolin.

Taken together with the macroscopic and microscopic study of the transitional stages, these analyses show: (1) that ilmenite and hypersthene resisted attack better than the labrador-feldspar; and (2) that from the latter its alkali-silicates were extracted.

The larger the amount of Na_2O, K_2O, CaO and MgO (with some SiO_2 and Fe_2O_3) removed, the smaller becomes the specific gravity. That of the labradorite unaltered is 2.727; of the slightly kaolinized, 2.666; of impure kaolin, still showing the feldspathic structure (Analysis IV. of kaolin, with 47.72 SiO_2), 2.254; of almost pure kaolin, 2.193 and 2.192; and of the purest kaolin of the district, 2.178. These determinations hold for the porous masses, including the pores: pure non-porous kaolin has a specific gravity of 2.6.

That in this case kaolinization has resulted from the action of carbonic acid waters, follows from the fact that occasionally, though rarely, calcite occurs with the kaolin, while most of the Na_2O, K_2O, CaO and MgO (as soluble carbonates), as well as the dissolved SiO_2, have been entirely removed.

If I correctly understand Lindgren, he seems, on pp. 614 and 664 of his paper, to intimate that stronger agents, such as sulphuric acid, may have operated or co-operated to form kaolin. In my judgment, it is not necessary to assume such stronger agents, especially in view of the well-known kaolinization, by ordinary weathering, of the feldspars of rocks. Moreover, sulphuric and sulphurous acid appear to produce transformations of a different sort (such as alunite, etc).

As already remarked, kaolin occurs in some cassiterite-veins (as well as in their metasomatized wall-rocks), and also in certain districts of sulphide-ores. Examples are found at Nagyag, Puda and other places in Transylvania, where propylitization has been occasionally accompanied, in a subordinate degree, by kaolinization. According to the descriptions of Béla von Inkey and Semper, this kaolinization took place along the veins, and was independent of recent weathering by surface-agencies.*

---

* See B. v. Inkey's *Nagyág u. Seine Lagerstätten*, Budapest, 1885; and Bergassessor Semper's *Beiträge zur Kenntniss der Goldlagerstätten des Siebenbürgischen Erzgebirges*, in the *Abh. d. preuss. geol. Landesanstalt*, 1900, p. 23. According to Kolebeck's analysis (given in the *Oest. Z. f. B.-u. Hüttenw.*, 1888, and referred to by Lindgren), the so-called kaolin of Nagyag is in reality mostly sericite or sericite

This seems to be true also of the kaolinization of the Cripple Creek district,* where occasionally not only granite but also phonolite and andesitic breccia have been transformed to kaolin. That this is kaolin, and not sericite, Hillebrand's analyses prove.

Again, at Schemnitz, Hungary, according to some accounts, propylitization has been accompanied, here and there, by kaolinization. For additional examples, I refer to Lindgren's paper, under "Sericitic and Kaolinic Gold and Silver Veins," and also to the article "Kaolin" in C. Hintze's *Handbuch der Mineralogie.* On the whole, kaolinization along ore-veins is rather scanty.

We note, then, as the result of many observations, that the formation of greisen (bordering cassiterite-veins), and also propylitization and sericitization, and probably silicification, are accompanied here and there by kaolinization, which, on the other hand, seems to be wholly absent in cases of carbonatization (along ore-veins), or, as Lindgren says (p. 614):

"Wherever abundant carbonates form metasomatically, together with sericite, kaolinite seems to be absent."

Calcite is also, as a rule, wholly absent from the primary kaolin-deposits, formed *in situ* from granite, gneiss, etc. Even in the kaolin-deposit of Ekersund-Söggendal there is scarcely any lime, though the original labradorite-rock carried considerable calcite.

Both kaolinization and carbonatization (or the latter with sericitization) result from the attacks of carbonic acid water, but with this important difference, that in the former, lime, magnesia, potash and soda are almost or quite removed, leaving the silicate of alumina; whereas in the latter, calcite, and generally also the *potash*-alumina silicate, sericite, are deposited or precipitated. This difference is due, pretty certainly, to quantitative variations in the constituents of the attacking solution. Thus, we learn from the weathering of granite, etc., that very weak carbonic-acid water can remove lime, magnesia, alkalies, etc., and produce kaolin; and, on the other hand, it

---

mixed with kaolin. The masses produced by kaolinic transformation, described by Semper as rich in kaolin, calcite and pyrite, probably contain considerable sericite.

* Messrs. Cross and Penrose, in 16*th Ann. Rep. U. S. Geol. Sur.*, Part ii., 1–209.

may be assumed that water rich in dissolved alkaline and earthy carbonates favors carbonatization and accompanying sericitization.

*Comparison Between Cassiterite-Veins and Lead-Sulphide Veins.**—The elder French school drew an absolutely sharp line between the tin-deposits and the sulphide-bearing veins. Some went so far as to divide all ore-veins into two classes: (1) the *filons stannifères*, products of fumaroles in granites; and (2) the *filons sulfurés dites plombifères*, deposited by thermal springs, and supposed by some observers to be always connected with basic rocks. It is true that the typical cassiterite-veins (Cornwall, Saxony, etc.) are, so far as known, connected with acid eruptions exclusively; but the converse proposition, that sulphide-veins are connected with basic rocks exclusively, does not fit the facts. As a single instance, *instar omnium*, we may mention the immense copper-silver-ore deposits in the Butte granite, in Montana.

The division into *filons stannifères* and *plombifères* is quite fitting†—only there are, here as elsewhere in nature, no sharp boundaries, but, on the contrary, gradual transitionary forms.

Among such transitions we may mention the frequent occurrence in cassiterite-veins of arsenopyrite and other sulphide ores; the tin-copper-ore veins in Cornwall; the connection, in the *Erzgebirge* and in Cornwall, between lead-silver veins and cassiterite-veins; also the cassiterite-bearing lead-silver veins of Bolivia, and veins in Tellemarken, Norway, which I have briefly characterized as "cassiterite-veins carrying copper-ore instead of cassiterite." Again, we may point out that tourmaline and other boro-silicates (axinite, datolite, etc.) have often been observed, even in abundance, in veins carrying sulphide copper-ores or gold. The general treatises of A. v. Groddeck‡ and A. W. Stelzner,§ and a series of other publications (some of which Lindgren cites under "Tourmalinic Gold-Copper Veins"), are authorities for this statement. Yet, so far as I am aware, galena-silver-ore veins carrying tourmaline in abundance are not known.

---

* The groups here indicated under these titles are those named by Daubrée, in his *Études Synthétiques*, etc. (1879), *les filons stannifères* and *les filons sulfurés dites plombifères.*

† Deposits of iron- and manganese-ore are not included in this classification.

‡ *Zeitschr. d. d. geol. Gessellch.*, xxxix., 78, 237 (1887).

§ *Zeitschr. f. prakt. Geol.*, 1897, p. 41.

As a characteristic mineralogical difference between the two classes of veins under consideration (*stannifères* and *plombifères*) we may point out that topaz, so characteristic of the former, has never been observed, either in the ordinary sulphide-ore veins (Freiberg, Clausthal, etc.), or in the tourmaline-bearing veins, whether with sulphide copper-ores or with gold. In the ordinary sulphide-ore veins, moreover, apatite and other primary phosphates are wanting, as is also the lithium-mica, so characteristic of cassiterite-veins.

Comparison Between the Formation of Greisen, etc., and Propylitization, etc.—Turning now to the metasomatism of the vein-walls, we find that topazization and the formation of topaz-greisen are confined exclusively to cassiterite-veins. On the other hand, we never encounter, along these veins, propylitization, sericitization and carbonatization, which belong to the veins of sulphide-ore or gold.

Kaolinization, on the contrary, takes place (although subordinately) here and there alongside of veins of either kind. The same is true of silicification, as illustrating which I may mention the formation of " quartz-rock " alongside of cassiterite-veins; also the silicification (Verkieselung) of the walls of some later gold-veins (as in a part of the Verespatak district, in Transylvania) and of some quicksilver-veins.

Again, here and there along the cassiterite-veins as well as the sulphide-veins, we find the country altered to mica-rocks, which, although not for the two classes mineralogically identical, present so many analogies that they must have been formed under pretty similar conditions. The mica-rock along the cassiterite-veins is petrographically allied to greisen (and tin- or topaz-bearing greisen), topaz-rock, etc., and consists chiefly (or wholly ?) of lithium-mica. On the other hand, at Telemarken, Norway, a biotite-granite is likewise altered to mica-rock, along certain quartz-veins carrying chalcopyrite or bornite; but here the mica, which appears often in large crystals, contains no lithium, being a potash-mica (muscovite). In the same locality, subordinate fissures in the vein-material are often lined with mica crystals (1–2 cm. in diameter), exactly as are the similar fissures in the well-known cassiterite-deposits of Zinnwald, in the *Erzgebirge.*

As in the ordinary alteration to mica-rock and topaz-greisen, so likewise in propylitization with chloritization and sericitization, it is, as a rule, the iron-magnesium-silicates (mica, augite, hornblende) which first (before the feldspars) suffer alteration —in other words, offer the smallest resistance to the attacking solutions. On the other hand, mica, augite and hornblende are more resistant than the feldspars to the processes of alteration which form kaolin.

Concerning the alteration of the later eruptions (andesite, dacite, trachyte, rhyolite, etc., sometimes also basalt) to propylite, I would refer in particular to the well-known monograph of G. F. Becker on the Comstock Lode (1882), and the investigations of B. v. Inkey, Dölter, Judd, Koch, Szabó and many others.*

In propylitization, as is well known, the iron-magnesium silicates (augite, hornblende, mica, etc.) are converted chiefly into chlorite, with sericite, actinolite, epidote, serpentine, iron oxides, spathic carbonates, etc. The feldspars lose their luster; their cleavage is impaired; and they are impregnated with products of decomposition, particularly chlorite, epidote, calcite, etc. Moreover, the re-formation of pyrite is very characteristic; and, as a rule, the further propylitization has progressed, the larger the quantity of pyrite. Becker has shown that this pyrite has been derived from the iron-magnesium silicates and the iron oxides (magnetite, ilmenite, specular hematite) of the original rock, through the action of solutions containing alkaline sulphides or hydrogen sulphide.†

Rosenbusch describes propylitization as "a process of solfataric and thermal‡ alteration." Nearly related to it are chloritization and sericitization. It is confined to later ore-veins, connected with extensive rocks, and is absent in the corresponding veins of earlier origin. Possibly the reason of this difference

---

* See chapters on propylite in Rosenbusch's *Microsc. Physiogr. d. mass. Gesteine* (1896), ii., pp. 913–917; Zirkel's *Lehrb. d. Petrographie* (1894), ii., pp. 584–595; and on "Propylitic Gold- and Silver-Veins" in Lindgren's paper, this vol., p. 565.

† Here we are reminded of the chemical nature of the solutions of the recent quicksilver-deposits at Steamboat Springs, Sulphur Bank, etc. (investigated by Becker and others), where the quicksilver is found combined with a sodium sulphide, HgS, nNa_2S.

‡ SECRETARY'S NOTE.—I understand this term, as used in German, to mean the action of heated aqueous solutions.—R. W. R.

may be that the "old" veins were formed at much greater depths, and hence under much higher pressure, whereby the escape of solutions (and especially the dissolved gases, H_2S, etc.) into the country-rock was hindered. I shall presently return to this point.

A priori, it is natural to conceive the metasomatism along veins has been generally accompanied by a considerable change (now addition, now subtraction) of material. This does indeed occur in some instances, especially in topazization, tourmalinization (with axinitization) and kaolinization; but in many other metasomatic alterations the change of material is relatively insignificant. This is the case in scapolitization; in intense contact-metamorphosis; in many alterations resulting in greisen and mica-rock; and also in propylitization with chloritization and sericitization. How small, in the latter processes, are the chemical differences between the original and the altered rock, I have learned with astonishment from the analyses collected by Lindgren.

Conclusions.—In conclusion, I will attempt to give a summary of the agencies operative in processes of alteration:

1. Topazization, the formation of topaz-greisen, tourmalinization, axinitization, etc., are chiefly due to the action of fluorides—in the two latter cases, of boro-fluorides.

2. Scapolitization is due to re-crystallization under high pressure, with access of a chloride (particularly sodium chloride) solution.*

3. Propylitization is a solfataric and thermal alteration, effected by attacks of hydrogen sulphide or alkaline sulphides, and often also of carbonic acid.

4. Kaolinization, sericitization and carbonatization are produced by the action of waters carrying carbonic acid, or carbonates of alkalies and earths, in variable proportions. (In kaolinization, the waters carry so much carbonic acid that the alkaline and earthy carbonates are nearly or wholly removed, together with the dissolved silica. In sericitization and carbonatization, on the contrary, there is a deposit of potassium silicate or calcium carbonate.)

5. Silicification results from percolation by a solution of silicic acid.

---

* See, on this subject, *Zeitsch. f. prakt. Geol.*, 1895, pp. 447, 455.

6. Zeolitization is also produced by silicic acid, but under different conditions (probably, as a rule, by a solution containing silicates of sodium, potassium, calcium and aluminum).

7. Intense contact-metamorphism involves a recrystallization under high pressure, with penetration by heated aqueous vapor, and is, *per se*, accompanied by a comparatively subordinate change of material. Sometimes, however, it occurs in connection with ferrification, silicification, tourmalinization or axinitization, etc.

8. The formation of alum-stone or alunite is chiefly effected by the penetration into the rock of a solution of sulphuric or sulphurous acid.

Frequently several of the above agencies operate in combination, rendering the results more complicated.

IV. Differences of Depth in the Original Positions of Epigenetic Deposits; and the Secondary Alterations of Deposits.

The attention of both miners and geologists was long ago drawn to these theoretically interesting and economically important problems; yet only in recent years have they received thorough and comprehensive treatment. The valuable contributions made to the *Transactions* of this Institute by Don, Emmons, Rickard, Posepny, Van Hise, Weed and others, are familiar to its members, as well as the work of R. A. F. Penrose and his associates of the U. S. Geological Survey, and other American observers Much may be learned from the recent treatise of our celebrated professional colleague, Prof. L. de Launay.*

These two phenomena—namely, the original differences of depth connected with the formation of ore-deposits, and the secondary alterations of such deposits, occurring often, perhaps even millions of years later—are in many cases, as genetic factors, very widely separated; yet it may often be difficult to decide what is to be referred to the primary and what to the secondary process. Partly for this reason, and partly because, as Van

---

* "Les variations des filons métallifères en profondeur" (*Rev. Gén. des Sci. Pures et Appliquées*, xi., 1900; discussed by P. Krusch in *Zeitsch. f. prakt. Geol.*, Oct., 1900). See also De Launay's *Contribution à l' étude des gites métallifères* in *Ann. d. Mines*, 9 Série, vol. xii., p. 119 (1897).

Hise's last paper shows, the two factors go, in many localities, hand in hand, I think they may be, with advantage, discussed together.

Original Differences of Depth.

In considering the original differences of depth, it must be kept in mind, as De Launay has pointed out in the treatises just cited, that the present surface is, in general, very far below the surface existing at the time of the ore-formation. The geological investigations of recent decades have shown that the work of denudation (or abrasion or erosion) must be measured on a larger scale than was formerly suspected. In the Archean and Algonkian mountain chains (now often removed by this agency down to their base-level), and also in the Paleozoic ranges (showing, as a rule, the effects of extremely energetic denudation, as, for example, the Ural and the Norwegian mountains), the difference between original and present levels is to be generally reckoned, not in such units as 0.1, 0.25, 0.33 or 0.5 kilom., but rather on the scale of 2, 3, 4 or 5 kilom., or even more. Even in the Mesozoic and Tertiary, many denudations of astounding depth have been recognized.*

In many epigenetic ore-deposits of Archean-Algonkian or Paleozoic origin (*e.g.*, Kongsberg, Cornwall, Przibram, the Keweenaw peninsula at Lake Superior) mining has been carried

---

* As instances of great denudation, the following may be named:

On the E. side of the Kristiania fiord, in Norway, this process has removed, (1) a series of Devonian conglomerates and porphyry overflows, with Silurian and Cambrian rocks, of an aggregate thickness (according to W. C. Brögger, *Nyt. Mag. f. Naturv.*, vol. xxxviii., for 1900) of 2500 meters; (2) also a large part of the Archean surface—first, during the long period preceding the Cambrian, and again after the removal of the Cambrian, Silurian and Devonian strata. This thickness must also be measured in thousands of meters; so that we have here at least 4000, perhaps 5000, 6000 or even more meters of thickness removed.

The fiords of the W. coast of Norway are often 1.5, sometimes 2 to 2.25 kilom. more deeply eroded than the adjoining high plateau; and the latter frequently consists of deep eruptives, without any remains of the extensive overflows—showing that on the plateau a very extensive denudation, probably to be measured in kilometers, has taken place.

In the Aspen silver-district, Colo., 5 kilom. of strata (according to Spurr) have been removed by erosion from a range of Tertiary origin. (I quote from Krusch's review of De Launay, *Zeitsch. f. prakt. Geol.*, 1900, p. 317.)

In California, according to Lindgren, denudation has extended to a depth of 500 to 1500 or more meters. So far as I know, this denudation has taken place since the beginning of the Cretaceous period.

Numerous other similar instances could be easily adduced.

to depths of 0.75, 1 to 1.25, and 1.25 to 1.5 kilometers. Taking the depth roughly as 1 kilom., and assuming that in some districts the present surface has been denuded 3, and in others 4, kilom. below the surface at the time of the ore-formation, we may say that mining has reached a depth of 3 to 4 or 4 to 5 kilom. below the original surface.

These figures are, of course, somewhat arbitrary; but modern investigations of the extent of denudation justify us in saying that they are not too high for some districts belonging to the ancient geological periods above named.

It may be observed, also, that in many deposits of deep and geologically old origin, the deepest portions of the mines have shown no change in the nature of the fissure-formation. Occasionally, as at Przibram, Bohemia, and Dolcoath, Cornwall, the richest ore-bodies have been encountered in the deepest mine-workings.

We conclude, then, that, under favorable circumstances, the ore-veins may continue at least to a depth, below the original surface, of 3, 4, 5 or more kilometers.

In opposition to this view, Prof. Beck declares* that he has come to the opinion

> "That ore-veins, and mineral veins generally, can by no means extend to great depths, geologically speaking. . . . Even if we could assume the existence, at a depth between 4000 and 6000 meters, of fissures filled with water, it would be inconceivable that, at that depth, mineral deposits could be made from solutions."

I believe, notwithstanding, that future determinations of the extent of denudation, together with the mining of many deposits to the depth of 1.25, 1.5, or even, perhaps, 2 kilom. below the *present* surface, will prove that Prof. Beck's conclusion is not correct.

It may also be remarked, in passing, that mineral deposits may be made from solutions at above the critical temperature (364° C.) of water—for instance, the deposits of cassiterite, wolframite, apatite, topaz, tourmaline, and even pyrites, in many granite-pegmatite veins.

In his latest treatise, which is rich in new conceptions, De

---

* *Lehre von den Erzlagerstätten,* 1901, p. 139.

Launay compares ore-deposits occurring relatively near the surface, in less denuded regions, with those deep below the surface in strongly denuded regions. As instances of the former, he takes the quicksilver-deposits, which occur chiefly in recent rocks, near volcanic eruptives, while from older ranges, partly destroyed by erosion, they have disappeared, with other débris. As instances of the latter class, he takes the pyritic deposits (Röros, Huelva, Schmöllnitz, etc.), which have been found in old mountain-chains or in districts of regional metamorphism, and are to be explained as of deep-seated origin. He also mentions very briefly the lead-silver veins.

Induced by his description, I have already suggested in this paper the hypothesis that the differences between the later gold-silver-lead veins (Nagyág, Comstock, Potosi, etc.) and the old gold and silver-lead veins (Kongsberg, *Erzgebirge*, Harz, Przibram, etc.) may be explained by their formation at different depths. The relative or total absence from the older veins of the propylitization which is so characteristic of the later ones may, perhaps, be due to the fact that hydrogen sulphide (or sodium sulphide), which was a very important factor in this process, could not, under the great pressure due to great depth, make its way from the solutions in the fissures into the country-rock.

The later silver-lead veins are, on the whole, richer in silver than the older ones. This may be connected with the fact, inferred on physico-chemical grounds by Van Hise, that at great depth lead sulphide separates in larger proportion than silver-sulphide or sulpho-salts. According to this view, the precious silver-veins (carrying relatively little galena and zinc-blende) of recent eruptive ranges become, at a very great depth, richer in galena and zinc-blende. This seems to be sometimes the case. (Instances are given further on.)

This hypothetical view is not contradicted by the fact that many of the older silver-lead veins, as at Andreasberg and Kongsberg, are highly "precious"—*i.e.*, relatively poor in galena and zinc-blende; for this character may be due to the small proportion of lead and zinc in the original vein-solutions.

In view of the range *below the original surface* through which mining is carried on, beginning, not at that surface, but already thousands of meters below it, we may easily see that, in many districts, the directly observable differences in original depth have little significance. For instance, at Kongsberg there is no difference in the character of the veins from the present surface to 0.5–0.75 kilom. below it.

In other districts, however, very important differences of original depth have been established. For instance, these differences were very distinct in many Cornish mines, where the veins carried: (1) at the uppermost level (in the tin-bearing gossan) tin-stone and a little copper-ore (the latter as the result of a secondary process, the original sulphides having been mostly leached out of the gossan); (2) their copper-ore, with some tin-stone (in the Dolcoath mine, to the depth of 0.3 to 0.33 kilom. below the present surface); (3) still deeper, first, a zone of mixed tin-stone and copper-ore, and under that almost exclusively tin-stone. The veins traverse, in depth, chiefly granite; at higher levels, slates. But zones 2 and 3 are not confined to either rock. In this case, then, the tin-stone was originally deposited at a greater depth than the copper-ore.

In many silver-lead-zinc veins there is an increase in the proportion of zinc-blende with depth. The Clausthal veins, and many in Mexico (Pachuca, Zacatecas, etc.) are instances. In the latter, very important differences in the depths of original deposition are often observed. (1) Near the surface are very rich silver-ores (the so-called *colorados*, containing cerussite with chloride, bromide and iodide of silver, and native silver), the richness of which is the result of secondary processes.* (2) Below these, after an intermediate zone of transition, appear for the first time the so-called *negros* ores—galena, silver-glance, silver sulpho-salts, etc.; and (3) in the deep workings, say 0.5 kilom. below the present surface, the so-called *fuego*-ores,† carrying much zinc-blende and galena, with a scanty admixture of true silver-ores. It is possible that the Tertiary Mexican veins have in depth a character resembling that of the older rather than that of the younger group described in a previous part of this paper.

---

* According to the Mexican geologists and miners at the Paris Exposition of 1900, these ores extend, as a rule, very little below the ground-water level.

† That is, "fire"-ores, or, in other words, smelting-ores. The surface-ores are treated by amalgamation.

With regard to the increase of zinc-blende in depth, which has been observed in many places, I have already observed that Van Hise, in his last paper, concludes upon theoretical grounds that from an ascending solution containing zinc and lead, the zinc sulphide would be deposited lower down than the lead sulphide. In many veins carrying copper and iron sulphides, the richest copper-ores are found at the higher levels. As Emmons and Weed have shown for the Butte district, this is in numerous cases the result of a secondary process. In sundry localities, however, the influence of original differences of depth may be recognized. This is the case, for instance, at Vigsnäs in Norway, where the ore, a fine-grained mixture of chalcopyrite with pyrite, occurs in several (about seven) nearly vertical "stocks." In the upper levels the pyritic mixture carried easily 3 to 4 per cent. of copper; at the depth of 735 meters the thickness of the mass was, on the whole, tolerably well maintained; but the copper-content had sunk to about 1 per cent., or a trifle more.

A corresponding phenomenon is not presented, however, by the flat-lying pyritic masses or "lineals" at Röros, which dip respectively 9°, 9° and 15°, and have been worked in these dips to distances of 1080, 1350 and about 2000 meters.

In the pyritic deposit at Huelva (at Rio Tinto, Tharsis, etc.) the secondary concentration in the "zone of enrichment," immediately below the "iron hat," plays a very important part; but there appears to be, besides, a primary distribution according to which the copper diminishes as depth increases.*

According to many American reports, there are also in the United States and in Chile many known instances of the deposition, from an ascending ore-solution, of pyrite and chalcopyrite, in which the former was, to a considerable extent, deposited deeper than the latter.

Not only in the sulphide-ore deposits, but also in those of iron and manganese oxides, primary differences of depth are recognized. Thus at Romanèche in the Department of Saône et Loire, France, the ore-deposits, occurring in granite, consist of psilomelane (named romanechite by Lacroix, on account of its constant considerable percentage of baryta) and specular

---

* See *Zeitschr. f. prakt. Geol.*, No. 7, 1899.

hematite, with quartz and heavy spar, a very little fluor-spar, and traces of calcite. The mine is, with one exception, the largest producer of manganese-ore in France. For our present purpose, the interesting feature is the change of proportion, at different levels, between psilomelane and hematite. Above, the psilomelane predominates; going down, the proportion of hematite increases with considerable regularity. During a visit which I made in the summer of 1900, together with my friend and colleague, Prof. L. de Launay, Mr. L. Chamussy, the director of the mine, called our attention to the fact that this relative increase of iron-ore in depth is found in many manganese-deposits. His explanation was, that the solution containing manganese and iron compounds came from below, and the ores were precipitated mainly through oxidation by the oxygen of the air contained in surface-waters; that iron thus oxidizes more easily (*i.e.*, sooner) than manganese,* and therefore, on the whole, the larger proportion of iron-ore would be deposited lower than the manganese. This seems to me quite plausible.†

Secondary Alterations of Ore-Deposits.

Concerning the secondary alterations more or less directly connected with surface agencies, I would observe, first, that such phenomena have very little importance in the Norwegian and Swedish deposits, which are generally found in very solid rocks, such as gabbro, gneiss, granulite, mica-slate, phyllite, etc. The occurrrences of magnetite, specular hematite and ilmenite show, as a rule, no trace whatever of a zone of weathering—except that here and there apatite has been, to a slight extent, leached out. The dense, massive magnetite resists

---

* That from a solution containing protoxides of iron and manganese (*e.g.*, in carbonic-acid water) iron is precipitated by oxidation before manganese has long been known. The literature of the subject is given in my work "*Salten og Ranen*" (1890–91), in which a geological application of this order of precipitation was attempted. See also *Zeitschr. f. prakt. Geol.*, 1894, p. 33, and 1895, p. 39; also "The Chemical Relation of Iron and Manganese in Sedimentary Rocks," by R. A. F. Penrose, *Jour. of Geol.*, 1893, vol. i., p. 356.

† I regret that this contribution must be prepared for publication in such haste that I have not time to obtain by correspondence further details concerning this primary difference of distribution in the manganese-deposits. Nevertheless, I venture to give here the above theoretical explanation.

even denudation, so that, for instance, the extraordinarily large deposit at Kirunawara-Luossawara, in northern Sweden, forms a real "iron mountain," rising about 100 meters above the surrounding rocks. The same is true of the Taberg, a mountain of titanomagnetite-olivinite, in southern Sweden. Even the pyritic deposits, like Röros, Sulitelma, Vigsnäs, etc., and the nickel-pyrrhotite deposits, like Erteli, 5 to 10 meters in thickness, show a zone of weathering seldom more than one or two meters deep. At Fahlun, where the pyritic mass was very wide, the "iron hat" was probably deeper.

This insignificance of the secondary alterations, even in the pyritic deposits, is probably due to two chief causes: (1) that the surface was polished clean by the Quaternary ice-sheet; and (2) that the solidity of the country-rocks has permitted very little circulation of water.*

In sharp contrast stand the thick pyritic deposits of Rio Tinto, etc., in the Huelva district, where the "iron hat" extends to 35–50 meters. Here the Quaternary ice-period was lacking, and the country-rocks were much more porous than in the corresponding Scandinavian formations. Concerning these secondary alterations, I would refer to an earlier work of my own, which is mentioned, among others, in the papers of Messrs. Emmons and Weed. Especially noteworthy here is the re-formation of rich sulphides in the "zone of enrichment," and the very characteristic re-formation in Mass II., at Rio Tinto, of a narrow zone, rich in gold and silver, on the boundary between the "iron hat" and the underlying pyritic mass.

Concerning the chemistry of the secondary alteration of ore-deposits I can add little, in this hasty review of the subject, to the excellent discussions of Don, Emmons, De Launay, Penrose, Van Hise, Weed and others.† Especially interesting are

---

* I know several deep mines in Norway, in which the lowest pump-station is only about 250 meters from the surface. In one of them, water for use in drilling below that level has to be carried down.

† I will only introduce some observations upon the solvent effect of the ferric salts, $Fe_2(SO_4)_3$ and $FeCl_3$, upon sulphide ores. To test this point, I made in November, 1896, the following experiment:

Samples of 6 grammes each of pulverized chalcocite, bornite, chalcopyrite, pyrrhotite and pyrite were separately treated in Erlenmeyer jars, 100 cub. cm. of neutral aqueous solution containing 30 grammes of $FeCl_3$ being poured upon each sample, after which they were allowed to stand quietly at the ordinary the proofs furnished of late years from North America that secondary alteration often extends far below the ground-water level and the re-formation of sulphides in the zone of enrichment, investigated especially by Emmons and Weed.

I would here refer to the collection of specimens from the gold-district of West Australia which was exhibited last year at Paris under the direction of Mr. A. G. Holroyd. That the gold of many localities had been first dissolved, most probably in $Fe_2(SO_4)_3$, and afterwards precipitated, could be clearly seen in a whole series of specimens.

1. From the zone of weathering in many veins were shown small and exquisitely beautiful crystals of gold, sitting upon

---

house-temperature of about 14° C. After a few weeks the chalcocite was almost entirely dissolved, and the bornite had been very strongly attacked. On the other hand, at the end of nine months the chalcopyrite was affected but slightly, the pyrrhotite a little more, and the pyrite not at all.

At the present time, after the lapse of 4 years and 1 month, the chalcocite and bornite have long been completely dissolved; the pyrrhotite is almost all dissolved; the chalcopyrite has been somewhat further affected (by far not so much as the pyrrhotite), and the pyrite has been attacked, though very slightly. From the first four, and probably also to a small extent from the pyrite, sulphur has separated. The filtrates from the chalcocite and bornite showed with $BaCl_2$ a weak trace of H_2SO_4; that of the chalcopyrite a somewhat stronger trace; and that of the pyrite a trace stronger still, yet, after all, amounting to little. The formula is:

$Cu_2S + 4FeCl_3 = 2CuCl_2 + 4FeCl_2 + S$, or $Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S$.

Weed gives the formula thus:

$Cu_2S + 5Fe_2(SO_4)_3 + 4H_2O = 2CuSO_4 + 10FeSO_4 + 4H_2SO_4$.

In the reactions with Cu_2S and CuS, however, the sulphur does not appear to be oxidized to sulphuric acid, though this occurs in subordinate degree in the reactions with FeS and FeS_2.

The above experiments were made, as stated, at ordinary house-temperatures. At higher temperatures the process is very much more rapid. I was present in 1893 at an experiment in the Siemens-Halske metallurgical testing-laboratory at Berlin, when pulverized unroasted pyrites from Rio Tinto, containing 3 per cent. of copper and nearly 50 per cent. of sulphur, was stirred in a weakly-acid solution of ferric sulphate (50 grammes of iron to the liter), at 80°–90° C. After 6 hours, the percentage of copper had been reduced to 0.4. Zinc-blende is also attacked, though not as strongly as chalcopyrite. These reactions are metallurgically utilized in the Siemens-Halske electrolysis of copper-ores, and in the present leaching of pyrites at San Domingo, Tharsis, etc., in the Huelva district.

Metallic silver also is very rapidly attacked by $Fe_2(SO_4)_3$. Gold will be considered below.

Pyrite is one of the commonest minerals in sulphide-deposits; its weathering yields $Fe_2(SO_4)_3$, which plays an exceedingly important part in the secondary alteration of ore-deposits, as I have shown in earlier publications.

cobalt-manganese-ore (asbolite), which is unquestionably a secondary mineral, yet older than the gold which has been precipitated upon it.

2. In many samples from gravels or placers, gold could be seen in small breaks in iron-ocher, limonite, etc.

3. Gold appeared also in stalactites, or "drip-stones," consisting chiefly of iron-ocher and calcite. In this case the gold was unquestionably in a ferric solution.

4. Again, gold from various localities was seen as a very thin tarnish, "breathed," as it were, upon the pebbles of the placer-conglomerates.

5. Several tree-roots were exhibited, upon which gold was sitting.* Here the gold had been reduced or precipitated from solution by organic substances.

6. Finally, gold was to be seen, in several cases, in fine cracks in the dried clay of the placers, into which it had percolated while dissolved, to be precipitated as a thin coating upon the clay.

I am aware that series of similar instances have been described already from America, Australia and South Africa; but I have dwelt upon these new exhibits from West Australia because they plainly show that the solubility of gold may play a *quantitatively* important part.†

The same collection showed beautifully the weathering of the telluric gold-veins of Kalgoorlie. The mines, as is well known, carry in depth (down to 1150 feet, in the year 1900) very rich gold-tellurides (calaverite, sylvanite, kalgoorlite, petzite), sometimes in masses of extraordinary weight (50–100 kilog).‡ In the neighborhood of these, the ordinary phenomena of flake-, sheet- and wire-gold are often found, the native gold being sometimes intergrown with the telluride mass, and sometimes independent of it. In the highly oxi-

---

* The label read: "Great Boulder Main Reef. Root of tree, found at 70-ft. level. Two pieces of wood, with gold-deposition. (Very rare.) W. A."

† The platinum metals, on the contrary, are to be regarded as practically insoluble by the chemical reagents encountered in nature. See note on p. 131.

‡ I will not enter here upon the discussion of so many years' standing concerning the "mechanical" *vs.* the "chemical" origin of gold-nuggets in placers. (Notwithstanding the solubility of gold, I adhere to the "mechanical" explanation.) But I may say, in passing, that in West Australia the masses of gold-tellurium found in the veins are as large as the placer-nuggets of other regions.

dized upper vein-zones, the gold-tellurides have been entirely decomposed, metallic gold and derivative compounds of tellurium being formed,* and this metallic gold, appropriately called "sponge-gold," "mustard-gold," etc., could be easily distinguished by its peculiar structure from the native gold occurring in depth. This is an indication that the deep native gold is not a secondary formation from gold-telluride, but a primary metallic precipitate. Secondary alteration thus helps us to decide a question which has been discussed for many years, especially in Austria-Hungary, where each of the views just stated has been held by many observers.†

It is well known that in numerous ore-deposits, all over the world, unusually rich ore-bodies have been formed by secondary processes more or less directly connected with the surface. We need mention only Pachuca and Zacatecas, in Mexico; Pasco, in Peru; Potosí and Oruro, in Bolivia; Chañarcillo,‡ in Chile; Broken Hill, in Australia; Mednorudjansk, in the Ural, etc. Our knowledge of the secondary formation of very rich bonanzas is now specially enlarged by the investigations of Emmons and Weed on secondary sulphide-enrichments below the ground-water level, as at Butte, Montana.

Since in the development of science it has been so often seen that new ideas or impulses are liable to be overestimated, I will here add that there are innumerable rich "shoots," "chimneys," "*edle Säulen*," "*Adelsvorschübe*," "bonanzas," etc., which have nothing to do with secondary processes, being of exclusively primary character, and dependent upon the laws which governed the original ore-deposition. I may cite as examples Kongsberg, Andreasberg, Schemnitz, the rich shoots in the Transylvanian gold-veins, etc. And my study of the literature

---

* The same is known to be true of Cripple Creek.

† On other grounds, I have formerly expressed my adherence to the latter view—namely, the primary character of the ordinary native gold of the deep zones. *See Zeitschr. f. prakt. Geol.*, 1898, p. 418; 1899, pp. 179–180.

‡ See F. A. Moesta, *Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen, u. s. w.*, *besonders in Chili* (1870). He points out that at the outcrop of the silver-veins of Chañarcillo, etc., the relative proportions of chlorine, bromine and iodine to one another are about the same as in sea-water, to the percolation of which he attributes the formation of these haloids. The explanation given by R. A. F. Penrose (*Jour. of Geol.*, vol. ii. (1894), p. 34, for the presence of silver-haloids in the arid regions, which connect them with neighboring salt lakes and marshes, seems to me more acceptable.

of the Comstock lode has given me the impression that its famous bonanzas were of primary, not secondary, origin.

The question, What is of primary and what of secondary nature? will doubtless long remain an interesting and often difficult problem for discussion.

Postscript.

The foregoing contribution is in many respects much less complete and more fragmentary than I would have it. If, with some hesitation on that account, I have decided notwithstanding to send it to the Institute, it is in the hope that its defects of form will be judged in the light of the fact stated in the introduction, that the manuscript was begun on the 3d and finished on the 31st of December.

I close this work of mine on the last day of the nineteenth century, with a miner's hail, "*Glück Auf!*" to my numerous American colleagues, unknown to me personally, yet well known through their scientific labors, and held in high esteem. Undoubtedly the new century will fill up many defects and solve innumerable riddles and doubts in the science of ore-deposits.

The Rôle of the Igneous Rocks in the Formation of Veins.

BY J. F. KEMP, NEW YORK CITY.

(Richmond Meeting, February, 1901.)

CONTENTS.

INTRODUCTION.

THE saying that "of all the known regions of the universe, the most unsafe to reason about is that which is under our feet,"* might well be the motto of the present paper, in view of the writer's profound appreciation of the difficulties and uncertainties of the subject. In such a field, the temptation is very strong to announce a probable proposition, and then to defend it with a loyalty insensibly graduating into partisanship. Conscious of this danger, the writer has endeavored to maintain an impartial and candid form of statement, though others may feel that he has not been wholly successful.

The subject, as here considered, falls naturally into two di-

---

* Fisher's *Physics of the Earth's Crust*, p. 89.

visions. In the first, the competence of igneous magmas to supply both the contents of veins and the solutions which are the common carriers of the minerals is set forth. In the second, the phenomena and the more or less current conceptions of the groundwater are taken up.

This paper is limited to "veins," as the term is ordinarily understood. It practically excludes the common deposits of those metals which appear in appreciable percentages in F. W. Clarke's latest estimated composition of the earth,* namely, Al, 8.16; Fe, 4.64; Ti, 0.41; Mn, 0.07; Cr, 0.01; Ni, 0.01. Of these, iron and manganese are admittedly favorable subjects for circulating meteoric waters, which are conceded to be of themselves effective in the outer 1000 to 2000 ft. of the thickness of the earth's crust. It is one thing, for example, that deposits of iron-ore in the Lake Superior region should result from the rearrangements of iron and silica in a rock which contains 15 to 25 per cent. of the former, and quite a different thing for the less common metals, and above all the precious metals, to be concentrated in veins from what we have reason to believe is a condition of excessively sparse dissemination in compact rocks. Experience gained with the former conditions should not be unduly influential in the study of the latter.

Of the commoner metals cited above, iron (with titanium), chromium, nickel and perhaps aluminum are at times abundant enough in the original minerals of igneous rocks to constitute ores.

It may be interesting and valuable as an aid in establishing a correct perspective to note the relative proportions of the ordinary metals in the product of the United States for 1898, the latest year for which statistics have been furnished by the U. S. Geological Survey. Reducing the weights to grammes, and taking the weight of the gold-product as unity, the ratios are found to be as follows: Iron, 120,950; copper, 2487; lead, 2098; zinc, 1090; aluminum, 26; silver, 22; quicksilver, 11. This calculation would be more significant if it covered the product of the world; but the necessary data are not available. It affords, however, within limits, a certain conception of the relative abundance of the several metals.

---

* *Bulletin of the U. S. Geological Survey*, No. 168, p. 15.

I. THE COMPETENCE OF THE IGNEOUS ROCKS TO SUPPLY THE MATERIALS OF VEINS.

The Demonstrated Presence of the Metals in the Igneous Rocks.

Within recent years many assays of rocks have been made, in order to throw some light on the source of the metals in ores. In selecting the samples for analysis, certain precautions are essential. Fresh rock must be taken; and the possible impregnation with small amounts of infiltrated metals must be avoided, or else the significance of the results will be vitiated. The amounts to be measured are excessively small, and their determination taxes the resources of the chemist to the utmost. For example, one ounce to the ton means $\frac{1}{320}$ of 1 per cent.; and in some dry assays even fractions of a grain—there being 480 grains to the ounce—are determined. Reagents (particularly the litharge used in dry assays for gold and silver) must be pure to the last degree.

All these precautions have been observed, however, in a large number of cases; and a very considerable amount of trustworthy data has been accumulated, going to show that the common metals are certainly present in igneous rocks, and that one or another of them is contained in nearly all the commoner igneous types (acid, intermediate and basic). Some metals seem to favor one rock and some another—a feature which has been treated at some length by De Launay* and Vogt,† and more briefly summarized by the writer.‡ It has been shown also that the ferro-magnesian silicates are richer in the metals than is the rock as a whole, and that they are probable sources of the metals. The metals appear in them either as bases or as metallic inclusions.

It was the original purpose of the writer to tabulate these results; but the mass of data was found to be too large to be practicably handled in this way, and therefore only the above general statements are made. Many references, however, are given in the work last cited.

We must bear in mind that the results of these assays and

---

* L. De Launay, *Annales des Mines*, August, 1897. Reprint, p 45.

† J. H. L. Vogt, *Zeitsch. für prakt. Geologie*, vi., 225 (1898).

‡ J. F. Kemp, *Ore-Deposits of the United States and Canada.* Third edition (1900), p. 35.

analyses have, to a large extent, but general interest and application. Only from the point of view of a lateral-secretionist of the Sandberger type does it follow that the ores in a vein have been derived from the wall-rocks which are accessible for assay. In instances like Butte, Mont., in which two sets of veins, of greatly contrasted mineral contents, are found in the same country-rock, other sources must be assumed for at least one series of them, no matter what are the theoretical predilections of the observer. Nevertheless, it is a fact of the greatest importance that the presence of the metals in igneous rocks has been established. Not all igneous rocks have yielded such results on assay. The general experience has been that when samples of several varieties have been collected in a given district, some have proved barren; and it must be admitted that some negative results have been obtained. As a rule, however, they are decidedly fewer than the positive results. It is likewise true that not all igneous districts contain veins of ore. Great areas of surface-flows, such as the basalt plains of Idaho, Oregon and Washington, are notably barren, probably for reasons that will be subsequently advanced.

The elements of the minerals which form the common varieties of gangue are found in all the igneous rocks, and in the sedimentary rocks as well. Quartz is much the commonest of the gangue-minerals, and silica is universally present in the rocks. Calcite and fluorite may derive their calcium from an equally wide range of rocks and minerals. Barium and strontium are "understudies" of calcium, and available iron for siderite is present on every hand. Where rock, in a stage of greater or less alteration, forms the gangue, it has no special significance in this connection; and gangue-minerals other than those cited are relatively uncommon and unimportant.

The Presence of the Metals in the Sedimentary and Metamorphic Rocks.

Wherever the metals are found in the sedimentary or metamorphic rocks, it is logically necessary to refer them to original sources in the igneous rocks, from which they have been derived either by solution or abrasion.* In the former case,

---

* *Ore-Deposits of the United States and Canada.* Third edition, p. 32.

the processes of introduction are essentially those to be subsequently discussed; in the latter, except in the case of placers (which are negligible, in this connection, on account of their small amount), the distribution of the metals is extremely sparse. If we begin with a rock which contains but hundredths or thousandths of 1 per cent., and imagine it broken up by the processes of erosion, its minerals subject to solution and dispersion, and to commingling with foreign matter,—or, if they are heavy, to concentration in placers,—the resulting sediment is a less favorable source of supply for migrating solutions than was the original igneous rock. The assays and analyses which have been made confirm this general statement, but they are hardly as abundant, taking the world over, as are those which have been prepared of the igneous rocks. An exception is the really remarkable work by J. R. Don* in Australia.

In making assays and analyses of sedimentary and metamorphic rocks, it is important to observe the same precautions as were outlined for the igneous rocks; and, in interpreting them, secondary impregnation must be guarded against. The following brief summary of the results of several workers will give an idea of the evidence in hand. Dr. Don has made and tabulated a vast number of analyses of the wall-rocks, chiefly sedimentary, of the Australian gold-veins. He was able to determine the presence of gold in fractions of a grain per ton of rock in a large number; but his tests indicated that only those rocks which also contained pyrites gave any returns for gold.† There is, therefore, the presumption that the gold and pyrites were introduced as an impregnation; pyrites not being a mineral favorable to sedimentation. Mr. Winslow,‡ in connection with his most valuable investigations of the lead- and zinc-deposits of Missouri, engaged Mr. J. D. Robertson to prepare a series of analyses of the rocks of Missouri, both sedimentary and igneous, for lead and zinc. The samples were taken in, near and remote from mines, and in not a few cases

---

* *Trans.*, xxvii., 564.

† It may be again remarked that a grain is $\frac{1}{480}$ of an ounce, and that these values were therefore thousandths and tens of thousandths of an ounce per ton. If one thirty-thousandth of this remote decimal is then calculated, the values in true decimals will be given. They are almost inconceivably small.

‡ Arthur Winslow. *Geol. Surv. of Mo.*, vol. vii., p. 479.

amounts were found equal to several thousandths of one per cent. When, however, we compare the analyses of the sediments with those of the igneous rocks, we find that the latter, as a rule, are by one place of decimals richer than the former, and to that extent are, generally speaking, more favorable sources of the metals. These results justify the statement made above that erosion and sedimentation tend to disperse the original metallic contents of the igneous rocks, and to place them in conditions less favorable for concentration by solution.

With regard to the metamorphic rocks especially, it may be said that increasing experience and more accurate knowledge have tended to prove the presence among them of crushed and sheared igneous types, whose foliation is of mechanical origin. Considered as favorable sources of the metals, the same remarks would apply to them as those already made regarding the unaltered igneous rocks. A good illustration is the gold-belt of the Southern States, which is now recognized to embrace amid its schistose types a very large proportion which are of this original character.

Conclusions.—Sedimentary rocks are far less favorable sources of the metals than are igneous; but the statement must not be interpreted as a law, though preponderating experience justifies it. Omitting the metals excluded in the opening paragraphs, sedimentary districts not associated with igneous rocks are, as a matter of experience, pre-eminently barren. The lead- and zinc-deposits of the Mississippi valley are almost the only important exceptions which can be suggested, and of these it is fair to say that increasing observation gives some ground for connecting them with dislocations, certainly in southwest Missouri, and to a less degree, perhaps, in southeast Missouri, and for favoring the views which have been especially advocated in recent years by W. P. Jenney. The ores are, however, confessedly hard problems. Concentration from the neighboring wall-rock has been upheld in the case of the veins of the Upper Mississippi, more especially within a year past, by C. R. Van Hise.* Although there is no known occurrence of igneous intrusions in the two regions cited, or in the gash-

---

* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 103 (p. 77 of pamphlet edition); this vol., pp. 282–432.

vein district of Wisconsin, yet it is true that peridotites have been discovered with the lean veins of western Kentucky,* and rocks of this type have elsewhere been found in regions where no eruptives were suspected or anticipated on the basis of the local geology.† In the larger lead- and zinc-districts, however, there is no reason, based on observation, for thinking that such rocks are present; and in the present state of our knowledge, these districts must be considered as exceptions to the general rule.

The Abundance in Igneous Rocks of Vapors or Dissociated Gases which will Yield Water on Emission and Cooling.

The ordinary analyses of cold samples of igneous rocks are of little if any value as an indication of the vapors and gases which were present in the hot, fused magma. The observer must turn to active volcanoes and streams of molten lava for his evidence; and from these we may judge of the composition of intruded masses of rock which never reach the surface. Practically all students of volcanic phenomena are agreed that steam and its dissociated representatives in the molten rock are the chief, if not the only cause of eruption. The paper by Prof. J. H. L. Vogt, presented at this meeting,‡ discusses at some length the condition of water in the fused rock. All observers are agreed that the first eruption at any volcanic vent must be caused by the steam which is brought up with the lava from the depths of the earth; but there is a very general disposition to refer the subsequent outbreaks to meteoric or oceanic waters, which percolate through the rocks near the vent, and which in some way become involved in the molten rock. When the pressure produced by them becomes sufficient, an eruption occurs.

It is very generally admitted to be inconceivable that water from any outside source should be able to follow cavities larger than capillary size through solid rock, heated nearly to fusion, to and into molten rock at a temperature of over 2000° F. Any water entering even the outer and moderately heated solid rock would be evaporated and driven outward. It is necessary

---

* J. S. Diller. Mica-peridotite from Kentucky. *Amer. Jour. Sci.*, Oct., 1892, 286.

† For example, at Syracuse, Manheim and Ithaca, N. Y.

‡ "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., 125; this vol., pp. 636–680.

therefore to fall back on the capillary conduits, through which to introduce into the magma the accessions of water. In order to prove the possibility of this introduction, recourse is had to Daubrée's famous experiment, which has, however, been shown by Osmond Fisher* to have no bearing on the case in point. Daubrée† took a slab of sandstone, two c.m. (about 0.8 in.) thick, and cemented it between an air-chamber below, and a chamber above which could be filled with water. The temperature of the lower chamber was raised until the air-pressure was about two atmospheres. The water from the upper chamber was drawn down by capillary attraction, even against this pressure of two atmospheres, and moistened the under side of the slab. It is evident from this that capillary attraction can draw water downward against a pressure; but, as Fisher acutely remarks, the capillary force was effective because it operated toward a free air space. In fact, it is only under these conditions that the difference in surface-tension, which is the real cause of capillary movement, appears between the air and water on the one side and the water and walls on the other. The experiment gives no ground for thinking that water would move through the heated walls confining a reservoir of molten rock and become involved in the latter. There is also some uncertainty about the efficiency of capillary force in rocks which are under great pressure. As I learn from my colleague, Professor R. S. Woodward, no assumptions of its efficiency are based on experimental data.

Again, active volcanoes are known, such as Cotopaxi in Ecuador, which are nearly 20,000 feet above sea-level. They must draw on reservoirs below tide, and yet even at tide-level cavities in the rocks, through which water might reach the magma, will have become impossible by reason of the pressure.

It would therefore seem necessary to believe that the ejected steam and other vapors of lavas have been brought up with them from the depths; but it is only fair to say that many think otherwise, although apparently without careful analysis of the problem. Of the abundance of the vapors there can be no question. They often exceed in volume the lava itself. The question of their origin only affects in a minor way the argu-

---

* *Physics of the Earth's Crust*, pp. 91, 92.

† *Géologie expérimentale*, p. 236.

ment to be subsequently made regarding the cause of movement of the groundwater.

Beyond question, intruded sheets and laccolites are provided with gases similar in all respects to surface-flows; but, in the nature of the case, the gases are yielded much more gradually, and through longer periods of time. They undoubtedly continue to appear until the rock is nearly as cold as the boiling-point of water at the depth at which they stand. It must be admitted that the hot vapors and waters yielded by an intrusion under these circumstances are extremely vigorous chemical reagents* and are incomparably superior to the ordinary groundwater, even when the latter exists in any serious amount below 1500 to 2000 ft. It is also important to remark that the presence of even a very small dike in any region is proof of the existence of a relatively very large reservoir of igneous rock, at some point beneath the surface, and at unknown but not great depth.

The Sequence of Eruptions.

One of the most interesting features of eruptive districts is the sequence of the eruptive rocks. One kind of rock has followed another until, in some instances, a considerable list can be made up. All will recall von Richthofen's observations on the Pacific coast in the late sixties, which led him to infer that eruptions habitually begin with rocks of medium acidity, pass then through a series with increasing silica up to rhyolite, and terminate with basalts. Increasing observation has shown many exceptions to this simple rule; but of the general fact that molten rocks are poured out one after another from what would appear to be a common reservoir, there is no question; and students of the subject have been more and more disposed to explain them by a breaking up of some original parent magma of intermediate composition into the several diverse products.

This succession of eruptions holds good in many localities of extensive vein-formation. At Butte, Montana, for example, a basic granite was followed by an acid granite, and both by quartz-porphyry, with which latter the introduction of the ores seems to have had some connection. After the ores had been

---

* Regarding this point, a very valuable paper is that of A. C. Lane, *Bulletin Geol. Soc. Amer.*, v., 259.

deposited, a great outbreak of rhyolite took place, with no attendant vein-formation. At present the quartz-porphyry is by far the least extensive of them all, and forms but a few minor dikes; yet it is quite possible that it may represent some greater intruded mass, far below, from which the ores have come; and for the very reason that it is visible in small amount it may be the most important of all the rocks in connection with the genesis of the ores.

Again, for example, at Douglass Island, Alaska, albite-diorite (sodium-syenite) and gabbro have been identified by G. F. Becker in the order of their outbreak through slates; but it was only just before or along with the intrusion of a small dike of analcite-basalt that the ore entered. On the Comstock, we find a considerable variety of eruptives in sequence. There is a decided difference of interpretation between Mr. Becker, on the one side, and Messrs. Hague and Iddings on the other; but if the latter are correct in considering Mr. Becker's "later diabase" as the same as the "basalt," which is the youngest eruptive, then it was after the intrusion of the "black dike" of diabase or basalt which is met in depth, that the ores came in along a line of faulting. At Mercur, Utah, a great stratum of carboniferous limestone was penetrated by a sheet of quartz-porphyry, which itself forked into two thin prolongations. Immediately beneath the lower fork of the sheet are silver ores, after the deposition of which an interval ensued. Later on, gold-ores were deposited beneath the upper fork, having been introduced, as is thought by J. E. Spurr, through the influence of a laccolite, assumed to exist in depth.

Dikes may not at first be evident in mines—as was the case in the Ontario at Park City, Utah. In the early work the vein apparently filled a fissure in quartzite, but in depth a dike was met, which formed one of the walls.

Over and over succeeding eruptions have taken place, and then at some stage (usually after a minor intrusion, so far as the exposures give the observer an indication) the ores were introduced, and one may not be able to say whether they came in with or just after it. It is thus evident that some eruptive rocks are unfavorable in themselves, or unfavorably situated in their present positions, for vein-formation, and that one may appear later whose advent is a signal for the ores to enter.

The Sequence of Vein-Formations.

There are also cases of successive and contrasted vein-formation. More than fifteen years ago R. C. Hills recognized three sets of veins in the San Juan region of Colorado, each with different ores; and the recent work on the Telluride quadrangle of the U. S. Geological Survey has shown in detail many of the structural relations.* There are in this district four sets of fissures, but only one carries the ores—a remarkable state of things if the ores are due to the universal circulation of the groundwater. In one instance, the Smuggler vein is faulted by the Pandora, a later vein which does not carry ores sufficiently rich to be mined profitably.

The district of Freiberg, Saxony, is a very complex case. If we include with it some of the veins of the *Erzgebirge* that lie at a moderate distance, the following groups may be distinguished: *Die Zinnerzgänge; die kiesige Bleierzgänge; die edle Bleierzgänge;* and *die edle Quarzformation.* All these are recognized as genetically connected with the great eruptions of granite and porphyry in Carboniferous-Permian times. There are, in addition, three other varieties of veins which have usually been considered as later, and even middle Tertiary, viz., *die Kobaltsilbererzgänge; die barytische Bleierzgänge;* and *die Eisenmanganerzformation.* They have been referred to later eruptions of igneous rocks. K. Dalmer, however, develops† some proofs that the first and third date back before the late Cretaceous, and even into the period of the older series. But the point of interest here is the connection with eruptive rocks, which is emphasized by nearly all observers.

It is often assumed in such cases that new series of fractures have tapped new sources of ores; but the hypothesis is not to be ignored that new intrusions may have been responsible for the change of solutions—and experience thus far gained gives the latter at least equal claims with the former. Indeed, new series of fractures can only go down through practically the same rocks as older ones, unless new material is brought in by igneous intrusion; and hence the second hypothesis, in the absence of proof to the contrary, would seem to have preponderant claims over the first.

---

* See C. W. Purington, 18*th Ann. Rept. U. S. Geol. Surv.*, part iii., p. 745.

† *Zeitsch. für prakt. Geologie*, Jan., 1896, p. 1.

Contact-Metamorphism.

The observed facts of contact-metamorphism and the conclusions which have been drawn from them have an important bearing on this question. It is well known that some intruded igneous rocks have exercised a profound influence on the wall-rocks through which they have come, while again other intrusions have produced little or no effect. The results depend very largely on the nature of the walls, earthy limestones and argillaceous strata being the most favorable, and quartzose sandstones the least so. Of the igneous rocks, all kinds, in one place or another, have produced notable results, but the acidic and intermediate are the most efficient. Abundance of dissolved vapors seems to be the essential thing for profound effects, as relatively dry fusion is unfavorable. The intruded igneous rock should also stand in contact with the walls for long periods and at a depth reasonably great below the surface. All these points are very much the same as those which have already been stated regarding the igneous rocks as producers of veins.

A divergence of views exists as to the amount of material actually contributed to the metamorphosed rock by the igneous agent. Observers on the continent of Europe have considered the amount to be in some instances large, especially of soda; while from facts noted at Westmoreland, England, where a basaltic tuff is penetrated by granite, a limit of one-twentieth of an inch is set by Alfred Harker for the migration of material. The changes produced in contact-metamorphism are in this instance almost entirely those of rearrangement. All observers must, however, admit the general introduction of fluorine, boron and steam, because the distinctive contact-minerals are characteristically provided with these elements. They are therefore described as *mineralizers*, or as being *pneumatolitic* in their nature. Tourmaline, fluorite, fluoric micas, chondrodite and topaz are illustrations of the resultant minerals; while biotite, garnet, albite, wollastonite, vesuvianite and a number of other silicates are common associates. If, now, ores are found associated with these minerals and along the contacts with igneous intrusions, and not extending far back into the wall-rocks, the inference is well-grounded that they have been derived from the eruptive. In the last paper of Professor Vogt, already cited, the cases of tin-ores and iron-ores to which these views apply are given at length; and in the paper of Mr. Lindgren* copper-deposits of similar nature are cited. Fissured wall-rocks which stand immediately above laccolites rich in mineralizers would be in the situation most favorable for these changes; but opportunities for observation are restricted because the laccolite is only revealed by their removal. When they do persist, however, and are thick, the existence of veins would suggest the presence of the laccolites.

Pegmatites.

Pegmatites have furnished for many years a disputed question. They are beyond doubt connected with great masses of intruded rock, more often with granite than with any other, and are after-births of the eruptive. Whether they are themselves to be considered as true eruptives, or whether dissolved vapors have played so large a part in their genesis that they are veins rather than dikes, or whether some belong to one of these types and some to the other, does not immediately affect the question now before us—their connection with eruptive rocks being the important point.

Pegmatites usually present the mineralogy of the granites on a very coarse scale, but they have, in addition, more abundant amounts of the pneumatolitic minerals. They may be rich in feldspar and less rich in quartz, or they may be extremely rich in quartz with only subordinate feldspar or other minerals. The writer believes that in some regions of their extensive development all gradations can be found, from granitic mixtures to veins of pure quartz. The north shore of Long Island Sound is a case in point. Pegmatites are abundantly developed in connection with granites, and all grades are shown up to practically pure quartz. The great quartz-vein at Lantern Hill, Mystic, Conn., is one of the largest quartz-veins known, being apparently 1000 ft. wide across the comb-in-comb structure, which is at times pronounced. I think it belongs in the pegmatite series, and is only a huge development of veins of a smaller size which are abundant around Narragansett Bay and elsewhere.† Certain parts of the Lantern Hill quartz show

---

* "The Character and Genesis of Certain Contact-Metamorphic Deposits," *Trans.*, xxxi., 226; also page 716 of this volume.

† J. F. Kemp, *Bulletin Geol. Soc. Amer.*, x., 372, 1899.

the presence of ferruginous minerals and have yielded on assay a few cents of gold per ton.

The gold-bearing pegmatite of Passagem, Brazil, described by Hussak,* has been referred to by Prof. Vogt. In the Triassic diabase of the Palisades, pegmatite veins richly charged with pyrite are not uncommon. Last summer, the writer spent several days at Copper Mountain, on the Similkameen river, near Princeton, Yale Dist., B. C., and found a great mass of gabbro, shattered along a wide belt. Into the minute fissures bornite had been introduced in some places, and minute veins of pegmatite in others, while in the Copper Cliff and Copper Reef claims, on the banks of the river, a huge pegmatite vein or dike carried here and there large masses of bornite. The bornite impressed the observer as being as much an original mineral in the vein as any of the other components.

In view of the above facts, which could indeed be much amplified, the following statements seem to be justified: Pegmatites are a more or less pronounced pneumatolitic result of igneous intrusion. Pegmatites grade insensibly into quartz-veins. Quartz-veins not visibly associated with pegmatites are open to the same interpretation unless there is positive evidence to the contrary. On the other hand, pegmatites, although widely developed, are but rarely provided with metallic minerals in notable amounts, and the same is true of the quartz-veins visibly associated with them. But it is also true that many regions of great development of pegmatite-veins are devoid of ore-bearing veins, as, for instance, New England, and it is probable that the magmas did not contain the necessary metals for their production.

Frequency of Pneumatolitic Minerals in Veins.

Some of the common gangue-minerals contain those elements which are justly associated with pneumatolitic processes. Of these, fluorite is the most important; and while it cannot be always asserted that it implies the neighborhood of eruptive rocks, it yet creates a presumption in favor of their genetic influence. The gold-ores of Cripple Creek, Colo., and the Potsdam ores of the Black Hills, are cases in point. Lindgren

---

* *Zeitsch. für prakt. Geologie*, October, 1898, p. 345.

has already emphasized this connection in his extremely valuable paper on "Metasomatic Processes in Fissure-Veins";* and therefore it is only cited here in a brief way.

Surface-Flows of Igneous Rock Unfavorable to Vein-Formation.

The vapors contained in surface-flows of igneous rock pass off directly into the atmosphere, and therefore do no geologic work of this character. The most that could be expected of them would be small incrustations in the cracks in their upper and first chilled portions, such as the copper-minerals and specular hematite found in the crevices of Vesuvian lavas. The absence of ore-deposits in flows of this character argues nothing against the efficiency of other forms of igneous rocks.

II. THE GROUNDWATER.

The Common Conception of the Groundwater.

The general conception of the groundwater, that has been hitherto held, has involved the existence of a standing body, quite universally present, and at a fairly definite depth below the surface, which depth is characteristic of the particular district. The upper surface is thought to be sharply marked and to be revealed by the boundary between the oxidized or enriched ores and the unaltered sulphides in an ore-body. The supply of water is kept up by the contribution of that portion of the rainfall which neither runs off nor immediately evaporates, but which sinks into the ground, feeds wells and springs, and necessitates pumping in mines. Rocks being more or less porous and crossed by faults, joints and cracks, it has been inferred that the waters continually migrate downward, partly by capillary attraction, partly through small crevices and partly through large ones, until, meeting the hotter interior zones of the earth, they are forced by the head of the descending currents (that is by gravitative stress), reinforced by the loss of density due to accessions of heat, to rise again to the upper world. During their journeys they move laterally as well as downward, pass through vast masses of rock, relieve them of their mineral and metallic contents, and deposit this dissolved material more especially on their upward journey. The fact

---

* *Trans.*, xxx., 691; p. 498 of this volume.

that we find a great body of standing water not far below the surface in regions of heavy or moderate rainfall would make it necessary, according to this conception, to believe that the rocks are pretty thoroughly saturated with water down to the depths at which the return journey begins; in fact, as Van Hise often expresses it, there exists a sea of the groundwater. Van Hise in particular rejects specifically the igneous rocks as significant contributors either of material or of energy, and expresses, in the premises or propositions which he seeks to establish, his belief that the waters which fill the veins with minerals are meteoric, and that gravity is their motive power. It is fair to add that the conception is a time-honored one, and has found frequent previous expression; but we owe to Van Hise an exceptionally clear and logical exposition of it.

There are, however, grave objections to this conception, and we may justly examine it in the light of the experience which has been gained in very deep mines and wells, as well as on certain general theoretical grounds.

Experience in Deep Mines and Wells.

Mines exceeding 2000 or 2500 ft. in depth are of extremely modern development. In several important instances of this class, as well as in many mines of smaller depth, it is possible to impound all the water within a short distance, it may be within 500 ft., of the surface. Below this level the workings are dry and, in a few cases, dusty.

The copper-mines on Keweenaw Point are most favorable in their geological structure to the downward passage of water. The shafts, several of which are now between 4000 and 5000 ft. deep, cut a series of sheets of trap and amygdaloid that dip 36° to 39°, and include one or two beds of conglomerate. They are fissured, and at times even brecciated.* As shown by the chart opposite p. 167 of the Report just cited, the North Tamarack Shaft, No. 3, at a depth of 3818 ft. had cut 73 different trap and amygdaloid layers. It is fair to infer that the new shaft which has recently grounded in the Calumet conglomerate at 4760 ft. must have cut correspondingly more. Yet the deep workings of these copper mines are not only dry, but in some

---

* *Geol. Survey of Mich.*, vol. v., part i., p. 112.

cases dusty; and the water is impounded either at the surface or a short distance down the shaft. Such water as trickles down the shafts from the top is occasionally baled out, and water for the drills has to be specially sent down into the headings.

At Calumet, the only water encountered in the deeper workings, or indeed below some such depth as 500 ft., is a highly alkaline variety, tapped in insignificant amounts from occasional fissures. It has a painful effect upon cuts and is avoided as far as possible by the miners. As a whole, the rocks are free from visible water.

Posepny says that the deep workings at Przibram have afforded a similar experience. Below 800 meters there is no water to be raised, because evaporation removes whatever exists there. Much that has been pumped from the levels immediately above 800 meters is doubtless water that has escaped impounding nearer the surface, and has followed down the openings made by the mine itself. The deepest workings at Przibram mentioned by Posepny are 1110 meters.*

Experience gained in the deep Cornish tin-mines, like the Dolcoath, would be important in this connection, but at the time of going to press it is not available. Mr. B. B. Lawrence has mentioned, in some informal remarks at this meeting, the Pelican-Dives mine, near Georgetown, Colorado, which has now attained a depth of over 2000 ft. The water has been allowed to follow the workings down and is raised from the bottom, but no more is pumped now than when the bottom sump was located in the upper levels.

The cases cited merely express the general experience of mining engineers, all of whom are aware that, with impounding of the surface-water, increase of depth, especially below 2000 ft., means almost invariably dry workings. Even if the rocks are "dry" in the miner's sense only, and not in the strict scientific sense, if their contributions of water are removed by evaporation so as not to be noted; or if, in a great artificial excavation, far larger than the vast majority of natural waterways, no pumping is necessary, the water in the rocks may be neglected as a producer of veins. The deep mines which are known to be wet, such as those of the Comstock lode, are in

---

* *Trans.*, xxiii., 248; xxiv., 971.

regions of expiring vulcanism, as will be emphasized a little further on.

Many mines, especially collieries, have been driven under bodies of water, and even under the sea, and yet they have been but slightly if at all troubled by water, and sometimes have been absolutely free from it. Tight shales, in a sedimentary series, would partly account for this; nevertheless the general experience is worthy of emphasis.

Artesian borings have in a few cases yielded similar testimony. The deep well near Wheeling, West Va., which has been made famous by the measurements of Professor Wm. Hallock on the increase of temperature with descent, reached a depth of 4500 ft. The last water was cased off at 1500 ft., so that for 3000 ft. the hole was dry. In this 3000 ft. the well penetrated shales and some sandstones, both of marine origin. Shales are admittedly the least favorable of rocks for circulating waters, but it is a surprising fact that this great section afforded a dry hole.* The Pittsburgh well is still more remarkable. In February, 1897, the well had reached a depth of 5386 ft. It was cased only to 900 ft., or slightly beyond, and for over 4400 ft. was dry. The well penetrated a section similar to that at Wheeling.

On the other hand, the deep wells at Sperenberg, Schladabach and Reibnik, all in Germany, are wet, so far as the published descriptions of the measurements of temperature inform us, but as they were bored with the diamond-drill, it is believed that they were not cased. I have, however, no definite information regarding this point.

All these facts, except the last, go to show that the outer portion of the globe is much less permeable to water than has often been assumed, and that, in many places at least, the downward percolation is a negligible factor. The groundwater which is met at small though variable depths, and which fills abandoned mine-workings, is held there by the tight rocks beneath it, and is not to be considered the upper part of a mass of water reaching down to 10,000 ft., or any such depth, in the

---

* Wm. Hallock, *Proc. Amer. Assoc. Adv. Sci.*, xl., 257, 1891; *School of Mines Quarterly*, xviii., 148, 1897. The latter gives details of the Pittsburgh well also. The section of the well at Wheeling will be found in *West Va. Geological Survey*, vol. i., p. 364, 1899. Professor Hallock states that the well was plugged with an oak plug after his measurements; two years later, when the plug was removed, the hole was full of water, which all believed leaked in at the end of the casing.

interior. On the contrary, something like 2000 ft. appears to be its limit, and in some regions it ceases at 500 ft.

The explanation lies, no doubt, in the plugging of fissures and crevices with attrition or residual clay, and in the feebleness or disappearance of capillary attraction with increase of pressure. The efficiency of a very thin seam of clay in keeping back water is well known to all miners who have been engaged in wet ground. A layer a quarter-inch thick is water-tight, and often every precaution, as remarked by Dr. Raymond at the present meeting, is taken by the miners not to break through even this small thickness. As to the efficiency of capillary attraction with increase of pressure, I learn from Prof. R. S. Woodward, as I have already said, that our knowledge is very limited, and he at least would hesitate to affirm that it operates. It has been shown, moreover, as I am informed by Dr. A. A. Julien, that when, in testing the absorption of building-stones, pieces are merely soaked in water, the penetration of the water is insignificant; but if the air in the stone is exhausted under an air-pump, or by boiling, or if the block of stone rests on wet felt, then absorption takes place.

The extraordinary impenetrability of some rocks is emphatically shown by the storage of petroleum and natural gas. Both of these, but more especially the former, are wanderers to a remarkable degree, yet they are confined in the ground under very great pressure and are unable to escape. Edward Orton, Sr., satisfactorily demonstrated in 1889 that the pressure of the gas in the comparatively shallow wells of Ohio (1000 ft.) was hydrostatic and due to the groundwater. Nearly all geologists believed the same agent to be the universal cause of the rock-pressure of natural gas; but when the deep gas-wells of New York were drilled from 2250 to 2600 ft., to the Trenton limestone, it was found that some other factor must enter, because the pressure is too great for a hydrostatic cause. Prof. Orton, therefore, and others with him, have abandoned this view.*

In some deep mines water has been encountered in uprising springs, and the same is true of not a few shallow shafts; but I do not think that any springs at less than 1500 or 2000 ft. depth have a bearing on this question. Posepny† mentions

---

* *Bull. Geol. Soc. Amer.*, ix., 95–99.

† *Trans.*, xxiii., 223.

one in the Einigkeit shaft, Joachimsthal, Bohemia, that was met at 533 meters (1774 ft.); but in the next paragraph we learn that the uprising waters at Joachimsthal were tapped along the contacts of the veins with basaltic rocks of comparatively late origin, and therefore in a situation involving expiring vulcanism. I do not cite this and the subsequent cases with a view of necessarily referring the waters to exhalations from fused and consolidating or consolidated magmas, but I do mean to use them, along with other considerations, to show the impotence of purely gravitative motive power.

The Comstock lode is the most famous case of a deep, wet mine. Church, King and Becker have all discussed the waters in their several monographs. Water was tapped on the 2200-ft. level of the Savage, and rose both in it and in the Hale and Norcross to the 1750-ft. level; but there it stopped.

Mr. Becker says that two kinds of water have been met in the lode. One is pent up in confined bodies. It was the tapping of such a body that let the water into the Savage and Hale and Norcross, as just observed. In another case, a cross-cut from the Palmer shaft was invaded by a body of water that rose 100 ft.* and had a temperature of 104° F. The other kind of water rises from the depths. No one doubts that the high temperature of these waters is due to expiring vulcanism, and the focus of the heat is placed by Mr. Becker at not less than two, and more probably four miles in depth.† The region is arid, and it is believed that the water must have come from a distance. A source for it in the Sierras, 12 or 14 miles to the west, is tentatively suggested by Mr. Becker; but there is good reason for thinking some of it, at least, to be a contribution from the eruptives themselves.

Emmons‡ has recorded a very interesting case of an uprising spring in the Geyser mine at Silver Cliff, Colo. The shaft was sunk so that it cut at 2000 ft. the contact between overlying porous rhyolite tuff and the underlying granite. Water in small amount and charged with carbonic acid, and different in composition from the descending waters, which had ceased far above, bubbled into the workings along small fissures parallel

---

* *Fortieth Parallel Survey*, iii., 87.

† *U. S. Geol. Sur.*, Monograph III., p. 264.

‡ 17*th Ann. Rep. Dir. U. S. Geol. Survey*, part ii., p. 458.

with the contact. Here, again, the spring is in a region of vulcanism of rather recent date, geologically speaking, and it is impossible to assert that an abnormal rise in the isogeotherms from this cause is not a factor in the circulation, although the water exhibited only the temperature of the drifts themselves..

It is not my purpose to attempt to show that water does not descend into the earth below 2000 ft., for I believe that it does, although not by any means in the amounts which have sometimes been assumed. I wish to make clear that the amount is probably comparatively small; that there are good grounds for believing that it only descends to great depths by relatively large fissures; and that these are exceptional. To the same degree that the meteoric waters are limited to the relatively large fissures, they are unfavorably situated for the solution of sparsely distributed minerals and metals. I hope to establish, further on, that even if they descend in this way, by a trickle here and a little seepage there, they can never be brought again to the surface, so as to form springs, by gravity and the normal rise of temperature alone.

At the same time, I fully recognize that there is ground for a different view, and that a strong case can be made out for the very slow circulation of water at great depths. But even if it be admitted that this is the case; that the waters become charged with ores; and that they have some tendency to pass upward, by reason of the heat acquired through the normal rise of temperature with depth; it remains true that, in again ascending, they meet descending currents or mingle with relatively stationary water; and they become dilute and disseminated and comparatively weak agents, when contrasted with the much superior efficiency which may be locally conferred upon waters by igneous intrusions. While one cannot deny that, by the former type of circulation and in the long course of geological time, something might be accomplished, yet, *a fortiori*, all the results *might* have been brought about, and there is abundant reason to think that they *were* brought about, by the aid of igneous rocks, as I shall endeavor to show subsequently, by proof additional to what has already been said.

The interrupted passage of the waters, when they do descend, has an important bearing upon the hydrostatic head. Whenever, for example, capillary transmission occurs, the previously acquired head is lost, and the emerging water proceeds on its way only under a newly accumulating head. So far, therefore, as capillary transmission may be assumed, ordinary calculations of hydrostatic pressure, based on distances from the surface, are false. In any event, even with the assumption of channels larger than capillaries, we are forced in these calculations to believe in the practically standing body of water, reaching nearly to the surface, to which objections have been already raised.

Artesian Basins.

The experience which has been gained with artesian wells is the chief foundation of much that has been written upon the circulation of the groundwater; and yet artesian basins furnish one of the strongest arguments for the storage of water comparatively near the surface, and against its descent to great depths. Within the limits of an area thus supplied with underground reservoirs, it is obviously impossible for waters to descend below the impervious stratum which is the cause of the reservoir, and it would follow that the lower lying rocks would be dry, except so far as they are supplied with waters which have migrated in from points on the surface outside the limits of the catchment-area. In many cases this would involve a journey of many miles, possibly more than a hundred.

Artesian basins of themselves permit but slight circulation of the imprisoned waters, and are most unfavorable places for the formation of anything like veins. They represent just so much water cut off from active work, like a convict in a penitentiary. They may occasionally be tapped off, downward or upward, by faults, just as once in a while a convict escapes, and then the waters may become geologically active. If they are invaded, however, by igneous intrusions with the attendant cracking of the overlying rock, the accession of heat or energy may make them again active agents. The standing waters, and, what is practically the same thing, the waters which rest under such pressure that they do not reach the surface and flow off, are considered to be too inefficient to be important in the formation of veins.

In cases like the Wheeling and Pittsburgh wells, in which from 3000 to 4500 ft. of marine sediments are apparently dry, one cannot but wonder what has become of the sea-water which they must have contained when they were deposited. Instead of receiving new supplies, they have apparently been deprived even of the little which they did possess. Undoubtedly the pressure of overlying masses has effected this result, or else the water has become combined in some chemical way in the rock itself, and has been thus locked up.

Hot Springs.

The most suggestive of all geological phenomena in connection with the formation of veins are hot springs; and there is ground for believing that they cannot be explained on any other assumption than that of an abnormal local rise in the isogeotherms. As Osmond Fisher has shown,* the isogeotherms cannot conceivably be raised except by igneous intrusions or by the mechanical production of heat along faults, or belts of shattering; and the latter do not compare in effectiveness with the former.

If for a moment we analyze the familiar increase of temperature with descent, a truer conception will be gained. As ordinarily stated, and as a fair average, it may be assumed that the temperature increases one degree Centigrade for each thirty meters of descent, which would be about one degree Fahrenheit for each 55 ft. In a region whose mean annual temperature is 50° F. or 10° C. (that of New York is about 51° F.), in order to reach a depth at which the temperature is 100° C. we would be obliged to descend 2700 meters, or not far from 10,000 ft. Now that meteoric waters may flow from the surface as a hot spring, which has derived its abnormal heat from this deep-seated source, they must descend to a depth which is at least a large fraction of 10,000 ft. and then return. The depth is a larger fraction of the 10,000 ft. than the temperature of the spring would of itself indicate, because the uprising waters have traversed cooler rocks and necessarily have received accessions of descending colder waters. One other important factor bearing on this question is, moreover, the irregular and more or less choked conduits which have already been emphasized.

The following argument has been sometimes advanced, and

---

* *Physics of the Earth's Crust*, pp. 240–241.

notably by Van Hise,* in supporting the view that hot springs are the result of normal terrestrial circulations, without accessions of heat other than those which would be received through the ordinary increase of temperature with depth. It is argued that, as the descending column of cold water is heavier, and the ascending column of heated water is lighter, therefore a hydrostatic head is afforded. Water expands about 4 per cent. between 0° C. (or, more precisely, 4° C.) and 100° C., and, for illustration, the case is imagined of a descending column at 0° and an ascending one at 100°. This assumption, or any similar one, loses practically all its force if we bear in mind the following important considerations:

1. That the descending column becomes gradually heated, so that, even if the conduits formed practically a long U-tube, there would be little difference in head.

2. That the descending column may move in part in a capillary way and lose its head.

3. That water under great load or pressure does not expand according to the 4 per cent. rate named. On the contrary, it may be held by the pressure at fixed volume, despite the added heat. If, for example, we roughly assume a column of water, one square inch in cross-section and two feet high (it is really about 2 ft. 3½ in.) as equal to a pressure of a pound to the square inch, in 10,000 ft. we would have a pressure of something near 5000 lbs. or over 2 tons to the square inch; and in the face of this the expansion of water from an added temperature of 100° C. practically becomes a negligible quantity as contributing to hydrostatic head.

4. We must bear in mind also that the standing body of cold groundwater fills the interstices of all rocks near the surface, except those in very arid regions, and exerts a retarding influence on uprising currents.

When these objections are all appreciated, I think we must admit that, except so far as waters are fed from heights into artesian basins and thence tapped again to the surface, perhaps slightly warmed from having gone to comparatively shallow depths, such a theory of hot springs, or even of warm springs, is impossible. Hot springs can only be developed in

---

* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 48; p. 303 of this volume.

the presence of an abnormal rise of the isogeotherms, which rise can only be effectively produced by intruded masses of igneous rock. I will even go so far as to say that it is in the highest degree improbable that any waters which have reached depths even approximating 10,000 ft. can ever again reach the surface and yield flowing springs, except through the propulsion of stores of energy contributed by still heated masses of igneous rock. I regard it as extremely improbable that the water of any natural spring, whose flow is due simply to hydrostatic head, has ever reached more than a very limited depth below the point of emergence. These statements are made in the belief that unless underground water ultimately emerges upon the surface, so as to maintain an activity of movement which this condition implies, its efficiency is so slight and its stagnation so pronounced that it is of small probable importance in connection with vein-formation of any magnitude. Professor Sandberger and those who stand with him are the only logical lateral-secretionists.

Even in areas showing the structure of an artesian basin, and possessing a theoretical head of hundreds of feet, the water sometimes rises to a given level in a well and then stands below the surface. Abnormally heated waters, such as those of South Dakota, described by N. H. Darton,* can only be accounted for by the presence of eruptives, although Mr. Darton seems loath even to mention igneous rocks as a possible explanation. Yet they would appear to be the only reasonable one, and in this region there is ground for inferring their existence.

In passing from laboratory-experiments in hydraulics to the phenomena of the earth, there is grave danger of error unless one proceeds with great caution. It is much the same difficulty that formerly arose in drawing profiles of country with exaggerated, vertical scales. The sense of true perspective was lost. Mr. Rickard's illustrative figure of the hot-water circulations in a household heating-plant,† likewise cited by Professor Van Hise, would give a very false conception unless used with so much allowance as to be destructive of its force. The open pipes in a house, extending but 50 or 100 feet in altitude, and

---

* *Am. Jour. of Sci.*, March, 1898, p. 161, and especially p. 168.

† *Trans.*, xxiv., 950.

with an intense source of heat in the cellar, are not comparable to conduits of irregular size, often choked, at times capillary, and with 10,000 feet of gradually warming walls before even a temperature of 100° C. is reached.

In brief, therefore, I believe it to be highly improbable that hot springs are ever produced except in regions of expiring vulcanism; but it is, on the other hand, highly probable that hot springs have been the great producers of veins.

The Irregular Distribution of the Groundwater near the Surface.

Recent observations of Emmons and Weed have emphasized the fact that the level of the groundwater is not a regular and sharply marked surface, but is, on the contrary, very irregular and subject to much fluctuation. The presence of oxidized or enriched minerals in some places at depths below the ordinary groundwater level has given rise to this inference. It would appear as if waters become charged with metals within the limits of the gossan, and, descending, react on leaner sulphides so as to enrich them, and that they do so even by diffusion through the standing groundwater and below its level. But it also appears as if there were no standing groundwater and no means of preventing quite deep oxidation and enrichment along some belts, which, because of their open character, may allow the waters to go down, turn and rise again as a spring at some lower point; and this, although neighboring ground, impervious in character, may retain the groundwater at a sharply marked and higher definite level. Naturally, in interpreting the phenomena of gossan-minerals apparently carried downward, we must bear in mind the later geological history of the district, because subsidence, together with the choking and elevation of surface-drainage, may raise the groundwater above its old level, and it may be that some of the minerals regarded as enriched (bornite, chalcocite, etc.) have been deposited by uprising currents.

In regions where the rainfall is small, and where the contributions to the groundwater are correspondingly slight, its level may be very far down; or, if the rocks are shattered, standing groundwater may be entirely lacking, and oxidized ores, so far as they can be produced without the aid of much water, may extend to depths indefinitely great. On the other hand, in an arid region galena may actually outcrop. In the

Geological Museum of the Columbia School of Mines there is a large specimen, about a cubic foot in volume, that was pried out of the cropping of the Half-Moon vein at Pioche, Nev., by Prof. Geo. W. Maynard. It is galena and quartz, the former only oxidized on the surface.

All of these points are, however, matters of the anatomy or pathology of already-formed veins, and do not touch the fundamental problems of genesis, to which, in fact, they are related much as are bodily disorders and amputations to embryology and growth.

III.—The Distribution of Mining Districts.

When one considers the country at large (leaving iron-ores out of the question), it is evident that districts favorable to actual mining are very sparsely distributed. Even in regions like the mountainous parts of Colorado and Montana, where we commonly think of mining as being extensively practiced, the productive areas are separated by vast stretches of country without workable and, I think one may say, without notable vein-development. One rides in a train for hours between the camps, and only for minutes in them. Even making due allowance for lack of outcrops, for forests and for veins concealed by the wash, the mining districts must be described as limited areas of intense local vein-formation, which alternate with vast areas of barren ground.

In the mining districts igneous rocks are present, practically without exception. If we assert that the assumed circulations of meteoric waters, which are thought to be universal in the rocks, and to be due to the ordinary and ever-present increment of temperature with depth, are the causes of vein-formation, we encounter grave difficulties in trying to explain this general absence of veins. Dislocations are everywhere present, and we ought to find veins in a similarly great abundance. On the other hand, if we remember the points made regarding the igneous rocks at the outset, we shall have a much more rational explanation both of the presence and of the absence of the veins.

It must be appreciated by all who are adequately familiar with both the literature and the phenomena, or with either, that ore-bearing veins, especially when of large size, are altogether exceptional and rare occurrences, and their causes are local and exceptional in their nature. No one with a correct sense of perspective can possibly be face to face with the huge stopes of ores of comparatively scarce metals, which some of our mines afford, without marveling greatly that they *ever* happened to be produced in the course of Nature; and in dealing with the elusive but irresistibly attractive problems which their genesis affords, one cannot be too appreciative of the local and exceptional nature of the causes which have produced them. One may, therefore, in endeavoring to explain vein-phenomena as a minor corollary to an all-embracing theory of metamorphism, based on the normal circulations of the groundwaters, miss the very kernel of the matter and fall into the same error that von Buch and other disciples of Werner committed, in the early part of the nineteenth century, in endeavoring to establish for rocks in general a "universal hypothesis."

Résumé.

The thesis of vein-formation, however presented, is necessarily one of greater or less probability, rather than one of demonstration. The following points may be made in favor of igneous rocks.

1. Igneous rocks contain the metals and the elements of the gangue minerals more abundantly than do sedimentary rocks.
2. Igneous rocks are richly provided with vapors which come up with them from great depths. Igneous rocks are enormous reservoirs of energy.
3. Igneous districts, or districts of combined igneous and sedimentary rocks, are almost always the geological formations in which veins occur.
4. The vapors and solutions from intruded igneous rocks are pre-eminently favorable chemical reagents.
5. Observations in deep mines and the data from very deep wells indicate the general absence of free water in the rocks below moderate depths, except in regions of expiring vulcanism. This is a grave objection to the conception of universal groundwater.
6. Capillary attraction is largely an ascensive force and of problematic existence with increasing pressure. Artesian reservoirs of themselves are unfavorable to extended circulation. There is a strange absence of the original content of water in

deep-seated sediments. Standing water in abandoned shafts is strong evidence of the impenetrability of rocks.

7. Hot springs are necessarily connected with an abnormal rise of the isogeotherms, and this can only be explained by intruded igneous rocks or by faults and shattering. The latter do not compare with the former as an efficient cause.

8. The distribution of the groundwater is far less uniform than has been supposed. The groundwater may entirely fail in arid regions.

9. The distribution of mining districts can only be satisfactorily explained by the corresponding distribution of igneous rocks, which have been intruded under circumstances favorable to vein-formation. Under any other view veins should be much more common.

In conclusion, I cannot forbear reference to the subject of the classification of ore-deposits. In November, 1892, I published in the *School of Mines Quarterly* a paper on the " Classification of Ore-Deposits, a Review, and a Proposed Scheme Based on Origin." The same has been subsequently printed, with one or two minor modifications, in the " Ore-Deposits of the United States." After a review of all the known schemes up to that time, and an analysis of their special features, a scheme was developed which sought more consistently than had been done up to that time to bring the ore-deposits under well-recognized geological phenomena. Aside from the ores of igneous origin, and the placers of various kinds, this involved a classification of those phenomena which would give rise to cavities, not of themselves necessarily great, but sufficient to furnish a water-way. These are the determining factors in the location of ore-deposits; they admit of the least possible difference of theoretical views or of interpretation, and they are the common ground upon which observers can best meet in harmony. They therefore furnish much the best basis of classification. I do not believe that any other line of attack of this problem furnishes equal advantages. Therefore, while the conceptions of ascending and descending waters cited by Professor Van Hise in closing his essay give new and significant points of view, yet the interpretation of the phenomena in accordance with them is inevitably destined to raise such well-grounded differences of opinion as to make the scheme impracticable for general use.

The Caliche of Southern Arizona: An Example of Deposition by the Vadose Circulation.

BY WILLIAM P. BLAKE, F.G.S.,
Director Arizona School of Mines, Tucson, Ariz.

(Richmond Meeting, February, 1901.)

In southern Arizona and in Mexico the word *caliche* is in general use to denote a calcareous formation of considerable thickness and volume found a few inches, or a few feet, beneath the surface-soil, upon the broad, dry, gravelly plains and mesas.

In western South America the same name is applied to the beds of crude soda-niter (Chili saltpeter). While these deposits of South America and of Arizona are totally different in composition, and have nothing in common, except that both occur in layers in the strata near the surface, it is probable that an explanation of the origin of the calcareous beds may equally apply to the accumulation of soda-niter and other deposits of easily soluble minerals. But the name, taken from the Latin, *Calx*, is more appropriate to the calcareous beds than to those of niter.

Caliche has a wide distribution in the arid regions of Arizona and Mexico. It is usually hidden from view by a slight covering of soil; but it is easily found by digging, and is often revealed by a flow of water during heavy rains. It is practically a continuous sheet, from three to fifteen feet thick, of earthy limestone or travertine, through which the smaller plant-roots find their way with difficulty. The presence of this comparatively impervious layer of cemented earth may account for the absence of trees, or of the larger shrubs, over wide areas. The shrubs which gain a foothold are those whose roots do not extend far downwards, and which do not require much water, such as *Larrea Mexicana* and the *Cactaceæ*. If trees are planted, it is necessary to break up the *caliche* by blasting, or at least to crack the upper layers. The top of the *caliche* is more dense and solid than the lower portions. The surface of this top crust, or layer, is comparatively smooth, though undulating, while the lower portions, under the crust, are irregular, cavernous, earthy and very porous, blending gradually with the materials of the sandy and gravelly beds, from which they are divided by no sharply defined plane of stratification or separation. The *caliche* invests, surrounds and includes sand-grains, gravel, and more or less earthy material, but seems to have had the power, especially in its upper crust, of extruding the coarse materials of the soil to a great extent.

The deposit does not form a regular horizontal bed conformable with the rude stratification of the gravels and sands, but conforms roughly with the general surface, rising and falling with the undulations of the mesa. There are, in places, repetitions of the compact layers, separated by a few inches of the amorphous and more earthy deposit.

In cross-fracture, this upper crust of the *caliche* exhibits distinct, fine lines of successive layers, in thin sheets, along which the rock splits with some ease, while there is a rude columnar fibrous structure transverse to these layers, sometimes in divergent lines from below upward.* Close observation detects in some places small perforations, like pin-holes at the top, which enlarge gradually below and penetrate the entire compact crust, becoming lost in the irregular amorphous granular mass. These holes are often occupied by rootlets of plants; but this is not regarded as evidence of any connection between the deposition of the *caliche* and plant-life—a cause of deposition to which great importance is attached by some authorities.† The *caliche* is an example of deposition independently of the influence of organic agencies.

In chemical composition the *caliche* is essentially a lime

---

* "Sorby has shown that in the calcareous deposits from fresh water there is a constant tendency towards the production of calcite crystals with the principal axis perpendicular to the surface of deposit. When that surface is curved, there is a radiation or convergence of the fibre-like crystals, well seen in sections of stalactites and of some calcareous tufas." Cited by Geikie, *Text-Book Geology*, 3d Edit., p. 150.

† Dana, for example, citing from W. H. Weed, says: "Some of the travertine deposits of Gardiners River and elsewhere are a result of the growth and secretions of conferva-like plants." (*Geology*, 4th Edit., p. 133.) Geikie says: "But besides giving rise to new formations by the mere accumulation of their remains, plants do so also both directly and indirectly by originating or precipitating chemical solutions," etc. . . . "Some observers have even maintained that this is the normal mode of production of calc-sinter in large masses, like those of Tivoli." (*Geology* 3d Edit., p. 482.)

carbonate, but contains some calcium, magnesium and aluminum silicates, as more fully shown by the result of an analysis made by my assistant, Mr. J. S. Mann, in the laboratory of the Arizona School of Mines:

Calcium carbonate ($CaCO_3$),	78.28
Magnesium carbonate ($MgCO_3$),	2.13
Calcium silicate ($CaSiO_3$),	5.57
Aluminum silicate (Al_2SiO_5),	7.37
Ferric oxide (Fe_2O_3),	1.88
Moisture (H_2O),	1.20
	96.43

This *caliche*, unlike the deposits of travertine formed in the open air, is not sufficiently compact and solid to be useful in construction, as was the travertine of ancient Rome. When calcined, it yields good caustic lime, which, tempered with sand, makes a strong, quick-setting mortar or cement. It is quarried and used for this purpose in some places. Occurring, as it does, in mixture with gravel and sand, it has the appearance of an artificial mixture, and as such was once supposed to have been laid down as a foundation by the builders of the Casa Grande in Arizona. On the line of the Phœnix and Prescott railway, it has been found that railway ties last longer when laid in the *caliche* then in ordinary soil. Analysis of this *caliche* showed that it did not differ essentially from the *caliche* of other places.

The great plain or mesa of Tucson affords one of the best examples of the occurrence of the *caliche*. This mesa, which appears like a great plain, is in reality a combination of gentle slopes from the surrounding mountains. The area within which the phenomena of the *caliche* are shown is probably not less than 400 square miles, and lies between the Santa Catalina Mts. on the north, the Rincon and Rillito mountains and the Santa Rita ranges on the east, and the Tucson Mts. on the west. Toward the south and northwest the country is open in the direction of the valley of the Santa Cruz. The Santa Cruz and the Rillito are the visible channels of drainage; but there is, in addition, an extensive underground flow of water as widely spread, possibly, as the area mentioned, but probably strongest in volume under and near the river channels draining to the northwest. The general altitude of the mesa above the sea is from 2400 ft. at Tucson to 3000 or 3400 ft. about 20 miles eastward. These declining slopes are formed, for the greater part, of the *débris* of the surrounding granitic and gneissic mountains—the "wash" or gravel and sand which has been washed out from the cañons through ages of erosion. As a rule, these materials are rudely stratified, the coarsest, heavier gravels lying nearest to the mouths of the cañons. In a well 90 ft. deep, near the University, on the mesa about five miles from the channel of the Rillito, the following beds were passed through, but the strata were not sharply defined:

Section of the Mesa, to Water-Level.

	Feet.
Soil, sandy and porous,	1
Caliche,	6
Sand and gravel,	12
Argillaceous earth (red),	2
Sand (red),	2
Caliche, soft and amorphous,	2
Sand, hard,	6
Sand and gravel ("cemented"),	3
Sand cemented and aggregated in lumps,	11
Argillaceous earth, red,	3
Argillaceous earth and sand, red,	30
Sand and boulders mixed,	8
Water in sandy bed,	4

Most of the sand and gravel not enveloped in *caliche* was found well filled with small sparkling crystals of calcspar, which appears to be the cementing substance holding the grains of sand together.

Wherever these gravels have been pierced by wells in the vicinity of Tucson, an abundance of water has been found at a depth of from 80 to 90 ft., or even less, depending upon the altitude of the surface. This water seems to be inexhaustible; at least it is in such quantity, and flows so freely, that the pumping-plant at the University can be run continuously, discharging a 6-inch stream, without exhausting the supply in the well.

The general composition of this underground water is shown in the annexed table, compiled from the records of the chemical laboratory of the University of Arizona.

Analyses of Well-Waters of Tucson and Vicinity—Parts Per 100,000.

	Two Miles N. of University.	R. R. Well.	Irrigating Well.	Tucson City Water.	Hoff's Well.	Oracle.	Tucson Water Works.
Total Soluble Salt..........	24.5	42.0	26.0	65.0	45.0	39.0	42.8
NaCl............	1.4	3.0	3.0	4.4	4.5	3.4	3.95
$(Na, K)_2SO_4$..	3.1	15.2	6.5	26.8	13.5	10.6	16.92
Na_2CO_3........	2.0	1.3	1.0	1.8	1.5	2.0	......
$(Ca, Mg) CO_3$.	9.0	15.5	9.5	22.0	16.5	14.5	18.56
$CaSO_4$..........	1.0	trace	0.5	0.0	0.5	0.5	1.74
SiO_2............	3.0	2.0	2.0	2.0	2.0	2.0	3.10

It is probable that, in the course of the underground flow of the water from the higher levels towards the Santa Cruz, there are considerable areas of basin-shaped depressions in the bed-rocks, where water accumulates and is more sluggish in its movement. So, also, there may be ancient channels, determining a more rapid flow than in other places; in each case there may be a difference in the amounts of solid matters held in solution.

There has been much speculation in regard to the origin of the *caliche.* It has been generally assumed to be a deposition from some ancient lake, or body of water, once covering the area in which it is found. But such a theory is untenable when all the phenomena are considered. The formation is clearly the result of the upward capillary flow of calcareous water, induced by constant and rapid evaporation at the surface in a comparatively rainless region.

With a constant supply of phreatic* calcareous water, the second great essential factor in the formation of *caliche* is the continued desiccating atmosphere—a condition which prevails, with only short and temporary exceptions, throughout the year. The desert and semi-desert regions of Arizona are characterized meteorologically by the unusual dryness of the air and its capacity for the absorption of moisture, and the maintenance of continued evaporation from the soil, which determines a constant upward movement of the phreatic water. The occasional rains in midsummer and midwinter do not penetrate to great depths, but are sufficient to leach out the soil to the depth of a few inches or feet, turning the calcareous solution back

---

* *Eaux phréatiques,* Daubrée, *Les Eaux Souterraines à l' époque actuelle,* i., 19.

and downwards, and producing the denser upper crust, where it meets the upward flow.

Such I conceive to be the origin of the *caliche*. It may be called a subterranean deposit of travertine; but it is not the result of a flow from springs, or from any source at the surface, or by the lateral movement of water. Unlike ordinary travertine, it is the result not of descending but of ascending currents. The ordinary conditions of vadose circulation are reversed. The *caliche* is a fine example of the formation of extensive calcareous strata in the midst of pre-existent beds, not by metasomatic processes, but by precipitation from sources below.

This explanation may apply equally well to some other subterranean deposits in arid regions, where the upward flow is maintained in excess of any downward percolation. It may apply, possibly, to the origin of soda-niter, of some beds of gypsum, and of some of the metallic sulphides. In fact, the phenomena of deposition of ores in mineral veins are here repeated in kind, though not in form, over broad and approximately horizontal areas, so as to make bedded deposits instead of fillings of fissures.

Surface-deposits of soluble salts, such as the chlorides, sulphates and carbonates of the alkalies, are familiar to all residents of arid regions. The "black-alkali" of the Salt River valley in Arizona, so injurious to vegetation, is an example of the concentration, by evaporation at the surface, of solutions of carbonate of soda. The white efflorescences on the soil in the dry season, known to the Mexicans as *tequisquita*, are familiar examples. These deposits become snow-white in a dry time, and quickly disappear into the soil during a rain-storm.

The presence of *caliche* in the soil over extended areas in the arid regions I regard as good evidence of the existence of subterranean water. The possibility of a change of conditions *since* the deposit of the *caliche* should, however, be considered.

I have elsewhere directed attention to the possible enrichment of the upper portions or croppings of mineral veins by the upward flow of solutions formed by the decomposition of the ores above the permanent water-level in arid regions, and, conversely, the impoverishment of the croppings of lodes in regions of abundant precipitation, where downward circulation predominates. The copper-deposits at Ducktown, Tennessee, afford striking illustrations of the latter process.

The Character and Genesis of Certain Contact-Deposits.*

BY WALDEMAR LINDGREN, WASHINGTON, D. C.

(Richmond Meeting, February, 1901.)

CONTENTS.

I.—Character of the Deposits.

1. *Principal Features.*

In many schemes of classification and description the term *contact-deposit* has been somewhat loosely applied to all accumulations of useful minerals (other than those of unquestioned sedimentary origin) which are enclosed between two different rocks. As thus used, the term may include deposits of widely differing origin, and, unless qualified, is not in place in a genetic classification. The present paper deals with a special class of contact-deposits.

In many geological provinces, granular igneous rocks, such as granite, diorite and syenite, have broken through and invaded sedimentary rocks. The molten magma may in part have reached the surface and there solidified with relative rapidity as a lava. The largest masses of it, however, did not reach the surface, but cooled very slowly at considerable depth under great pressure, and eventually consolidated into a rock of granitic texture. Uplifts and extensive erosion may have followed; and at the present day, in many places, thousands of feet of material have been removed, bringing to the surface the intrusive granular rocks and their once deep-seated contacts with the sedimentaries which they shattered at the time of in-

---

* Published by permission of the Director of the U. S. Geological Survey.

trusion. Along these contacts, bodies of useful minerals are often found, most commonly where the sedimentary rock is limestone, or, at least, calcareous.

All the world over, this group presents certain characteristics, the more essential of which are the following:

Form.—The deposits generally follow the contact, but are extremely irregular in detail, and almost always very bunchy. No regular law has been recognized as governing the form of the ore-bodies, which are sometimes lenticular masses.

Position.—The minerals generally occur in the limestone or calcareous rock, immediately on the contact, from which they rarely extend more (usually much less) than a hundred feet.

Constituent Minerals.—The gangue contains garnet, wollastonite, epidote, ilvaite (lievrite), amphibole, pyroxene, zoisite, vesuvianite, quartz and calcite, rarely fluorite and barite. The ore-minerals are specularite, magnetite, bornite, chalcopyrite, pyrite, pyrrhotite, and, more rarely, galena and zincblende. The sulphides may carry some gold and silver, usually more of the latter than of the former, but are rarely rich. Tellurides are unknown. The characteristic feature is the association of the oxides of iron with sulphides, a combination practically unknown in fissure-veins,* and further the presence of various silicates of lime, magnesia, and iron. The deposits are throughout metasomatic, having been formed by the replacement of limestone; and the filling of open spaces is almost entirely absent. On account of the great solubility of the limestone, well-developed crystals of the gangue minerals are very common.

Exceptions.—There are some classes of deposits which, though presenting a certain similarity to this type, must be strictly separated from it. Among these are contact-deposits between limestone and igneous rocks which carry as metasomatic products (besides galena and zincblende) sericite, dolomite, siderite and quartz, and which, upon close investigation, are usually found to be related to fissures and faults. Further, certain deposits of iron-ores, associated with limestone and with garnet-pyroxene-amphibole gangue, but without any apparent

---

* Specularite and arsenopyrite are both known from cassiterite-veins, which, however, in origin, stand close to pegmatite-veins and certain contact-deposits.

close relation to intrusive rocks. This kind will be referred to again in this paper in the discussion of the genesis of the deposits.

2. *Literature.*

Though the contact-deposits here described are not very abundant, and rarely of great economic importance, they could not long escape the notice of mining geologists. In 1865 B. v. Cotta* described the celebrated mines of the Banat, in Austria, and expressed the opinion that all of them were due to the action of intrusive rocks on a probably Mesozoic limestone. Regarding some of these deposits, this view has lately been opposed by H. Sjögren,† who, however, admits that others in the same vicinity may stand in causal relation to the intrusion.

To v. Groddeck belongs the credit of having recognized these deposits as a separate class,‡ which he calls the *Kristiania type*, and characterizes as follows:

> "Siderite, magnetite, chalcopyrite, bornite, pyrite, galena, zincblende, etc., accompanied by garnet, amphibole, wollastonite, axinite, etc., mingled in very different proportions, forming nests and stocks at the contact of eruptive rocks with granular limestone, or often wholly within the latter. These deposits thus belong in the sphere of contact-metamorphism, and may be briefly characterized as 'contact-deposits.'"

Among the examples are mentioned the contact-deposits of the vicinity of Kristiania and those in the Urals (Bogoslowsk). Several others are also included which are more doubtful (Pyrenees, Rodna, Rezbanya, Offenbanya, the Banat and Schwarzenberg), and part of which seem to be due to regional metamorphism, or to the action of ascending thermal waters at the contact of lavas and limestone. V. Groddeck apparently fails to recognize that the presence of *intrusive* igneous rocks is necessary to develop this type of deposits. Siderite, mentioned in his definition as one of the characteristic minerals, does not occur in the typical examples, and seems to be neither common nor essential.

De Launay§ also describes similar deposits, but includes

---

* *Erzlagerstätten im Banat und in Serbien,* 1865.

† *Jahrbuch d. K. K. Geol. Reichsanstalt,* 1886, xxxvi., pp. 607–668.

‡ *Die Lehre von den Lagerstätten der Erze,* 1879, p. 260.

§ *Traité des gîtes métallifères,* Paris, vol. ii., pp. 245–258.

under the heading several other deposits not so clearly belonging to the same category, and hardly recognizes the importance of the presence of intrusive rocks. In addition to the well-established examples from v. Groddeck, de Launay adds excellent descriptions of the mines of Mednorudjansk and Ekaterinenbourg in the Urals, which leave little doubt that these, also, should be enrolled under the Kristiania type.

In Prof. Kemp's classification,* the following division is found: "Contact-Deposits. Igneous rocks always form one wall. Fumaroles (Greisen)." This is evidently to include several different things under one heading. On p. 222, however, Prof. Kemp recognizes the importance of the type outlined in this paper, one example of which is mentioned, namely, that of the Seven Devils district, Idaho. Relating to the same subject we find (p. 69) the following direct utterance:

> "In the more characteristic 'contact-deposits' the igneous rock has apparently been a strong promoter of ore-bearing solutions, and has often been the source of the metals themselves. This form of deposit becomes, then, an attendant phenomenon of, or even a variety of, contact-metamorphism."

Prof. Vogt describes contact metamorphic desposits in several of his recent papers.† In that of 1894 the contact-deposits near Kristiania are described on the basis of his own investigations and of the previous work of Kjerulf.‡ These deposits, which are small and do not have much economical importance, occur in the majority of cases exactly on, or very close to, the contact of syenitic rocks and Silurian limestone and slates, along which they are found in great numbers and of irregular form. The mineral aggregates sometimes show a banding parallel to the stratification, and are only found in the sedimentary rock, not in the syenite. The gangue-minerals are garnet, amphibole, pyroxene, mica, epidote, vesuvianite, scapolite, chiastolite, quartz, calcite, also fluorite and axinite. As ore-minerals appear magnetite, hematite, chalcopyrite, galena, zincblende, and, more rarely, minerals containing bismuth, arsenic and antimony. Besides this locality are mentioned

---

* *Ore-Deposits of the United States and Canada*, J. F. Kemp, 3d ed., p. 58.

† J. H. L. Vogt. *Die Kieslagerstätten Röros-Sulitelma und Rammelsberg*, *Z. f. prakt. Geol.*, 1894, p. 177. *Zur Classification der Erzvorkommen*, *Z. f. prakt. Geol.*, 1895, p. 154. *Concentration des Metallgehaltes zu Erzlagerstätten*, *Z. f. prakt. Geol.*, 1898, p. 416.

‡ *Udsigt over det sydlige Norges Geologi*, Kristiania, 1879.

others from the Pyrenees, Banat, Pitkäranda (Finland) and Queensland.

In the treatise of Phillips–Louis* we find in the preliminary part no mention of this type of contact-deposits; and, in the second part, giving detailed descriptions, such "contact-deposits" as Leadville, Rodna and the Banat are treated together without genetic distinctions.

3. *Geographic Distribution.*

Deposits of this type are fairly common in America, though little attention has been directed to them, probably because of their smaller economic importance. As might be expected, most of them are found in the regions of the Pacific Cordilleras, where great intrusions have been followed by uplifts and enormous erosion. They are generally found at the contacts of quartz-monzonites, granodiorites, quartz-diorites and diorites with limestone. Besides the gangue-minerals mentioned above, the characteristic ore-minerals are specularite or magnetite with bornite or chalcopyrite. A smaller group is distinguished by the additional appearance of galena and zincblende which, in places, may overshadow the copper minerals in economic importance.

California.—The great area of granodiorite in the Sierra Nevada, accompanied by smaller areas of quartz-diorite, breaks through the Paleozoic and Mesozoic sedimentary rocks. Along the contacts thus presented, ore-deposits of the type here described are rarely met with, perhaps because limestones and calcareous rocks are not very abundant. However, on the area of the Colfax Folio of the U. S. Geol. Survey, about 10 miles north of the railroad station of Emigrant Gap, Nevada co., a mass of probably carboniferous limestone has been greatly contact-metamorphosed and filled with garnets, etc., but no sulphides appear in it. Along the contacts of the smaller intrusive areas of granodiorite down on the western slope of the Sierra Nevada small copper-deposits are occasionally found. Near Fairplay, Eldorado co., at the contact of granodiorite and limestone in the cañon of the Cosumnes river, garnets and epidote occur, and, intergrown with these, small masses of bornite and chalcopyrite.

---

* *A Treatise on Ore-Deposits*, London, 1896.

In Alpine co., 12 miles due south of the southern end of Lake Tahoe, an area of sedimentary calcareous rocks of uncertain (probably Triassic) age, about 1.5 mile long and 0.5 mile wide, occurs embedded in granodiorite, which is the prevailing rock in that vicinity. The locality is in the upper part of Hope valley. At several places along the contacts, mineralization has taken place. The prospects were visited by Mr. H. W. Turner in 1888, and by myself in 1895. At Rodgers' mine* the strata consist of alternating thin beds of quartzite and limestone, the latter carrying the principal value. The ore-bearing strata are in places 100 ft. thick. About $100,000 worth of ore is said to have been extracted from this place some three or four decades ago. The ore-minerals consist of pyrrhotite, chalcopyrite and bornite, and contain gold as well as some silver. The principal gangue-mineral is garnet.

On the east slope of Stevens Peak, in the same area, a stratum of limestone near the contact is very crystalline, and contains garnets and zincblende.

At Barnes' prospect, in the same area, a wedge of limestone, projecting into the surrounding mass of granodiorite, is highly crystalline and filled with garnets, amphibole, and other contact-minerals. Of ore-minerals, magnetite and chalcopyrite as well as bornite were found; these are reported to contain some gold and silver.

Idaho.—A number of deposits of the Kristiania type are believed to occur in this State, though their true nature has rarely been recognized. Position and mineral association indicate that the lead-zinc deposits at South Mountain, Owyhee co., are true contact-deposits, though when visited by Mr. F. C. Schrader† the developments did not permit any exact study of structural relations. The ores occur on the contact of limestone and diorite or granite; the ore-minerals are argentiferous galena, zincblende, and a little chalcopyrite and magnetite; the gangue being garnet, quartz, actinolite and the typical contact-mineral ilvaite or lievrite. According to the description of Mr. G. H. Eldridge,‡ certain deposits on Sheep Mountain in central Idaho very likely belong to this type.

---

* MS. notes by Mr. H. W. Turner.

† W. Lindgren, *Silver City and DeLamar*, 20*th Ann. Rep. U. S. Geol. Sur.*, Part III., pp. 187–189.

‡ 16*th Ann. Rep. U. S. Geol. Sur.*, Part II., p. 258.

Most characteristic are the contact-deposits of the Seven Devils, briefly described in a recent report.*

In the Seven Devils district, and in the adjacent Snake River cañon, copper-deposits are very abundant. There is, in that vicinity, an extensive series of Triassic basic lavas, with intercalated layers of slate and limestone. There are also diorites, intrusive in these beds. All of these igneous rocks apparently contain copper which was easily concentrated into deposits of various kinds; some, fissure-veins; others, zones of impregnation; others, contact-deposits. In the locality of the original discovery in the Seven Devils, the copper occurs in typical contact-deposits. Small masses of limestones are embedded in a later, intrusive diorite; at the contact, and usually in the limestone, are found irregular bodies and bunches of bornite, chalcocite, and a little chalcopyrite, containing, say, 10 oz. of silver and a little gold per ton. The limestone at the contact is very crystalline and contains, associated with the ores, abundant garnet, epidote, quartz, calcite and specularite. The copper sulphides, as shown by their intergrowth, were certainly formed at the same time as the gangue-minerals. The epidote, specularite and garnet, as described by Dr. Palache,† present clear evidence of simultaneous crystallization. At the Peacock mine a large body of medium-grade ore of this character was embedded in diorite. No limestone showed here; but I am informed that a lower tunnel has lately encountered limestone below the croppings.

Other claims in which the ore occurs on the contact of limestone and diorite are the White Monument, Alaska, Blue Jacket, Helena and Decorah. Considerable masses of ore have been exposed at some contacts, though the distribution is extremely irregular. In the Blue Jacket, a rich body of bornite and chalcocite was lately found; and it is reported that 500 tons of 40-per cent. ore has been shipped from this mine during the past summer. During 1900, the Boston and Seven Devils Copper Co. shipped from the Peacock and other claims 260 tons, containing 23 per cent. of copper, besides 8 oz. of silver and 0.04 oz. of gold per ton.

Still another copper deposit in Idaho which appears to be-

---

* W. Lindgren, *20th Ann. Rep. U. S. Geol. Sur.*, Part III., p. 249.

† *Am. Jour. Sci.*, 3d Ser., vol. viii., p. 299, Oct., 1899.

long to this type is the White Knob mine, near Houston, in Lost River valley. Mr. W. Darlington, the general manager of the company, has kindly furnished the following information. The ore occurs as a deposit between granite and limestone; the trend of the contact is N. and S., the limestone lying to the E. and the granite to the W. On the surface the ore-bearing zone is 1200 ft. in length, and (as a maximum) 400 ft. in width. The minerals are hematite, magnetite, chalcopyrite, pyrite and a little galena, in a gangue of garnet and coarsely crystalline calcite. A porphyry dike also occurs on the contact, complicating the geological relations. The oxidized zone is very deep, water not having been encountered until the depth of 600 ft. was reached in the shaft.

Arizona.—It is well known that many and very important copper-deposits occur associated with limestone and igneous rocks in Arizona. The descriptions published seem to indicate that few of them, if any, are contact-deposits of the Kristiania type. In most of them, also, the zone of oxidation is very deep and their original character has been greatly altered.

British Columbia.—Recent literature describing the copper-deposits of Vancouver and Texada islands points without doubt to the existence of numerous and important contact-deposits in those localities. Already indicated by Mr. Carlyle,* this is confirmed by Mr. Wm. M. Brewer†. The deposits always occur in or very near the contacts between limestone and gabbro or diorite. The mineral association is magnetite, chalcopyrite, hornblende and garnet. In some places the magnetite predominates, almost to the exclusion of the chalcopyrite.

Northwest Territory.—Mr. R. H. Stretch has recently described‡ interesting deposits on the Upper Yukon, which, to judge from the excellently presented data, are contact-deposits of the Kristiania type. Mr. Stretch, however, it is fair to say, does not consider them as due to contact-metamorphic origin, but as a result of later mineralization. The locality is a few miles west of White Horse Rapids, lat. 60° 40′, long. 135°.

The prospects are found along a narrow strip at the base of

---

* *Report of the Provincial Mineralogist*, 1897.

† The Copper-Deposits of Vancouver Island. *Trans.*, xxix., 483. *Eng. & Min. Jour.*, 1900, Apr. 21, May 5, July 14.

‡ *Eng. & Min. Jour.*, Sept. 8, 1900. *Notes on the White Horse Copper-Belt.*

a mountain range, consisting chiefly of limestone. This base is a granite plateau which Mr. Stretch thinks underlies limestone; in fact, a few patches of limestone remain on the plateau. The ores occur at the contact of the two rocks, or in seams of varying size in the granite. Two classes of ores are found: (1) large masses of specularite or magnetite, carrying a moderate amount of copper; (2) outcrops of smaller dimensions, in which the ore is bornite with a little chalcopyrite. Many of these prove to be connected with E.–W. seams penetrating the granite, but nowhere show evidence of massive vein-structure.

At all the localities, epidote and lime-garnets are present. The bornite contains some gold and silver; and a little molybdenite is also found. Dikes of granite occasionally cut the limestone.

Mexico.—From a perusal of recent geological literature of Mexico, it is clear that contact-deposits of the Kristiania type are very abundant there—more so than in other parts of North America. In a review of the gold-deposits of the republic, Mr. Ordoñez* says:

> "Examples of another type of ore-deposits are found in regions where sedimentary Mesozoic rocks appear, that is, on the eastern slopes of the Sierra Madre, towards the Gulf of Mexico. These consist of contact-veins between generally Cretaceous limestones and eruptive granitic rocks, nearly always diorite. The limestones are metamorphosed at the contact, and the copper minerals containing gold occur irregularly distributed in contact-metamorphic silicates, such as garnet and epidote.
>
> "Such deposits exist at Encarnacion, district of Zimapan, also in the vicinity of San José del Oro; further, at San José, Central district, State of Tamaulipas, as well as at many other places."

Aguilera and Ordoñez, mentioning several localities in their sketch of the Geology of Mexico,† write as follows:

> "In the region of Mazapil, Zacatecas, an extensive formation of Cretaceous limestone is cut by dioritic rocks. Near the contact extend very important deposits, worked during many years. The contact is marked by a conversion of the limestone to marble."
>
> "Chalcopyrite, always accompanied by grossularite (garnet), and usually by hematite, occurs in Cretaceous limestone, and its appearance is due to the eruption of igneous rocks, as may be seen at San José in the Sierra San Carlos, in Tamaulipas, in which copper-minerals, accompanied by magnetite, appear at the contact of the andesitic diorite."

---

* *Note sur les gisements d'or du Mexique,* Mexico, 1898, p. 233.

† *Bosquejo geológico de México,* Mexico, 1897, pp. 68, 222. *Boletin del Instituto geol. de México,* Nos. 4, 5, 6.

A similar deposit from the State of Chiapas is interestingly described by Mr. E. T. McCarty.* Here limestone of unknown age is invaded from below by rocks called trap, syenite or dolerite. At the contacts the limestone is largely converted into wollastonite and garnet, besides a little quartz, chalcedony, calcite and aragonite. This contact-metamorphosed limestone contains, partly scattered through it, partly in more concentrated but very irregular "ore-channels," auriferous and argentiferous bornite, as well as some chalcopyrite, enargite, galena and linnæite. The average ore consists of 90 per cent. of garnet with 10 per cent. of quartz and chalcedony, carrying from 3 to 4 per cent. of copper and from 6 to 8 oz. silver, and from $6 to $20 in gold, per ton. The gold is in part free and visible. Regarded as a whole, the ores appear in curved planes, which probably follow the outline of the underlying intrusive. The total width of the ore-bearing limestone is about 30 ft., and within this distance are two ore-bearing streaks. Very often the ore lies directly on the contact.

Other Countries.—In the foregoing brief notes I have attempted to call attention to the occurrences of this type in America only. But short and incomplete descriptions, found here and there in the literature of the subject, make it more than likely that such contact-deposits occur in West Australia, Queensland, South Africa and China. From the latter country, for instance, F. L. Garrison† describes lead- and zinc-deposits in contact-metamorphic limestone, near granite.

II.—Origin of the Deposits.

The deposits of the Kristiania type may be separated into several subdivisions, according to the prevalence of certain metallic minerals. Thus we have iron-deposits, carrying chiefly magnetite and specularite; copper-deposits, characterized by bornite and chalcopyrite; and finally zinc-lead deposits, containing galena and zincblende. These three groups are connected by transitional examples. In all of them the metallic-

---

* "Mining in the Wollastonite Ore-Deposits of the Santa Fé Mine, Chiapas, Mexico," *Trans. Inst. Min. and Met.*, London., vol. iv., pp. 169–189 (1895-1896). See also H. F. Collins, *Id.*, Feb., 1900; and Mr. Collins's "Note on Cheap Gold Milling in Mexico," in *Trans.*, xxi., 446.

† *Mining and Metallurgy*, Feb. 15, 1891, p. 107.

minerals are intergrown with the various gangue-minerals,—garnet, epidote, wollastonite, etc.—in such a manner that they must be considered as having a simultaneous origin. The theory of a subsequent introduction of the metallic ores is decidedly untenable. Since, on the other hand, the garnets and other gangue-minerals stand in unquestionable relation to the contact-metamorphic action, a theory of the origin of these deposits certainly becomes a branch of the study of contact-metamorphism.

1. *Contact-Metamorphism.*

The peculiar action of intrusive igneous bodies upon adjacent sedimentary rocks is a well-known fact in geology and petrography. The sedimentaries usually suffer a more or less intense metasomatic alteration, termed contact-metamorphism. Surface-eruptions (lavas), as a rule, exert no such intense action, though a certain baking or partial melting of the immediately adjoining rock may sometimes be recognized. The metamorphism exerted by intrusive rocks is characterized by a gradually fading alteration of the sediments, sometimes extending over a width of several kilometers. The contact of the altered rocks with the intrusive is usually sharp, a melting of the former being rarely if ever noticed. Slates and shales in the immediate vicinity of the intrusive rock are changed to highly crystalline schists or massive crystalline rocks, containing andalusite, feldspar, cordierite, garnets, etc.; further away, slighter recrystallization results, with development of mica and accumulation of the carbon of the shales in little knots and masses. In general, there is no considerable addition or subtraction of material during the metamorphism. Limestone usually suffers a stronger contact-metamorphism and becomes a coarse-grained marble. Garnet, wollastonite, amphibole, pyroxene, epidote, etc., often well crystallized in large individuals, form in it. In this case there is usually an addition of silica and a loss of carbon dioxide. In many places the contact-zone has received an access of certain minerals containing boron and fluorine not contained in the unaltered rocks; the most common of these are tourmaline and topaz. Oxides and sulphides, such as magnetite, specularite, ilmenite, pyrite and pyrrhotite, are often contained in contact-metamorphic slates and schists.* Magnetite, pyrite and pyrrhotite have been observed in limestones (Morbihan, France);† and the Devonian limestones at Rothau, in the Vosges, are metamorphosed for a few hundred feet from the contact, and contain pyroxene, garnet, epidote and a little galena.‡

Brögger, in his studies of the contact-metamorphic rocks near Kristiania,§ remarks:

> "Pyrrhotite appears abundantly in the altered rocks, and is certainly a mineral formed during the contact-metamorphism, for it does not occur in the unaltered rocks. It is not easy to say whether an addition of material has really taken place, or the mineral represents a recrystallization of finely distributed pyrite. Strongly in favor of the hypothesis of direct addition is the fact that large accumulations of pyrrhotite exist in the contact-metamorphic rocks—so large, indeed, that mining has been attempted in places." . . . . "As already indicated by Kjerulf, we must consider the many small ore-deposits occurring along the contacts of granite and syenite with Silurian rocks as contact-formations; and they should really be included in any study of the contact-metamorphism of this region."

The same opinion is strongly held by Prof. Vogt.

Cause of Contact-Metamorphism.—Petrographers in general agree that contact-metamorphism is due to the heat of the molten magma combined with the action of the water which it contains. It is well known that during and following volcanic eruptions, water, hydrogen sulphide, sulphur dioxide and carbon dioxide, as well as compounds of chlorine, fluorine and boron, are emitted. While some of these may result from the contact of the lavas with water and other materials, which they encounter at their eruption, it is extremely probable that a large proportion of them is derived from the magmas themselves.|| This opinion is supported by excellent geological authority—for instance, by Prof. T. C. Chamberlin, who says:¶

> "It is a familiar fact that enormous quantities of gases are ejected from volcanoes. It has been assumed that these have a surface-origin, and this is true in part; but, on the other hand, there is abundant ground for the belief that another notable part is brought from the interior, and is a real contribution to the earth's atmosphere and hydrosphere."

This is confirmed by the well-known fact that deep-seated

---

* F. Zirkel, *Lehrbuch der Petrographie*, Leipzig, 1894, ii., p. 97.

† *Loc. cit.*, p. 113.

‡ *Loc. cit.*, p. 115.

§ *Die Silurischen Etagen*, 2 and 3. Kristiania, 1882, p. 369.

|| Braun's *Chemische Mineralogie*, Leipzig, 1896, pp. 283–287.

¶ *Jour. of Geol.*, vii., p. 559, 1899. (Quotation slightly condensed.)

igneous rocks contain much carbon dioxide, and also, sometimes, sulphides; while both are much less common in extrusive lavas.

No matter by what force, the igneous rocks have certainly been brought up from deeper levels. If we admit that they contained dissolved various substances, such as water, carbon dioxide, and compounds of sulphur, chlorine, boron and fluorine, with various metals, it follows that the diminution of pressure caused by the rise to higher levels will gradually result in the escape of these compounds, which are so much more volatile than the other constituents of the magma. The higher the rise of the magma, the more complete the liberation of these substances. In what form they will escape, depends on the critical temperature of the substances and the pressure at the point of issue. We may assume with great confidence that at the contacts of intrusive rocks with a sedimentary series the temperature usually exceeded 365° C. and the pressure 200 atmospheres. Under these conditions the water, and likewise most of the more or less volatile compounds mentioned, would exist as a gas; in other words, pneumatolytic conditions would prevail. The water and accompanying compounds would be released from the magma and would penetrate, more or less energetically, the adjoining rocks for a varying distance. It does not seem probable that atmospheric water could have gained access to the contacts during the period of consolidation. Both the heat of the igneous rock and the pressure of the volatile compounds, striving to free themselves from the association with the magma, would prevent this.

The escape of the gases may be facilitated by cracks and fissures, and the emanations may be gradually taken up by circulating surface-water, which then will appear as thermal springs. Among the supporters of this view may be mentioned Profs. Rosenbusch* and Chamberlin.†

Admitting the tendency of the more volatile constituents of the magma to leave it under relaxing pressure, and knowing the tendency of the "mineralizing agents" to form volatile compounds with various metals, it does not seem so very surprising that mineral-deposits of various kinds should be formed

---

* *Elemente der Gesteinslehre*, Stuttgart, 1898, p. 42.

† *Loc. cit.*, p. 559.

during the contact-metamorphism. The only thing needed is a substance causing their deposition, and thus preventing their escape to join the circulating surface-waters. Such a substance is limestone. A chemical reaction appears to take place between the substances leaving the magma and the carbonate of lime, causing the deposition of new minerals and the liberation of carbon dioxide.

To some degree, this is confirmed by the experiment of Sénarmont,* who obtained crystallized specularite by prolonged action of a solution of ferric chloride on calcium carbonate, at 300° C., in a closed tube. Further experimental tests in this direction would be most desirable. Also interesting and pertinent to this question is the experiment of Doelter,† who obtained magnetite by cooling limestone in molten basaltic rock; this magnetite was clearly derived from the basalt, and was found segregated on the contact.

The genesis of the contact-deposits of the Kristiania type thus seems to be due to aqueous gas above the critical temperature, which was more or less laden with metallic compounds, and, under heavy pressure, penetrated the limestone adjacent to the igneous intrusive body. The temperatures must have been very high, but generally below the melting-point of ordinary rocks. Carbon dioxide was evidently not an active reagent; for the principal reaction consists in its expulsion from the limestone. Under the prevailing conditions, the metals cannot reasonably be supposed to have been derived from the limestone. Everything points to the conclusion that the metallic substances were given off by the cooling magma.

This is also, in general, the conclusion of all who have carefully examined these deposits, from v. Cotta and v. Groddeck to Prof. Vogt, who has more recently written on the subject.‡

The ores were deposited during the consolidation of the magma. The larger part of them occur in the limestone; but it is not inconsistent with the theory here developed that some ore may also be occasionally found in the adjacent igneous rock. The deposits are entirely metasomatic. The ore and gangue replaced limestone; and there were, as a rule, no open cavities to be filled.

---

* Braun's *Chemische Mineralogie*, Leipzig, 1896, p. 268. † *Loc. cit.*, p. 253.

‡ *Z. f. prakt. Geol.*, 1898, p. 416.

2. *Similar Deposits of Different Origin.*

As mentioned before, there are certain deposits which owe their origin to dynamo-metamorphic or regional-metamorphic processes, and which show a considerable similarity to the Kristiania type. Indeed, the minerals of regional-metamorphism are generally identical with those of contact-metamorphism, and the agencies are evidently similar.* We may suppose that in the latter case they consisted of water under considerable pressure and at a fairly high temperature; but it does not seem at all likely that the conditions were pneumatolytic, or that the temperature approached that of the intrusive contacts. Characteristic for the regional-metamorphic deposits are (1) the association of oxides of iron with sulphides so utterly foreign to the deposits formed by ascending waters, and (2) the minerals (garnet, amphibole, epidote, etc.) which distinguish the contact-deposits. Bornite, so common in the latter, does not, however, seem to occur in regional-metamorphic deposits. In regional-metamorphism there has been but little transportation of substance; the masses of ore are rather old disseminations, or originally sedimentary deposits, concentrated and re-arranged under the influence of heat and permeating moisture. As examples of deposits of regional-metamorphic origin may be mentioned the principal iron-ore deposits of Sweden and those of Michigan.

3. *Genetic Classification.*

The form of mineral deposits is sometimes characteristic, but at no time essential. Hydrothermal deposits are usually tabular, but this is only because ascending hot waters usually find it convenient to follow the easy path of open fissures.

It seems appropriate to make a separate division into *hydrothermal deposits* caused by hot, ascending waters, and characterized by certain very diversified, but still similar, metasomatic alteration, which I have elsewhere described more in detail.† No doubt these will be found to merge gradually into the deposits caused entirely by cold surface-waters.

A second division should be made to include "*contact-metamorphic*" *deposits*, wholly differing in mineral association and

---

* See, for instance, C. R. Van Hise, *Bull. Geol. Soc. Am.*, vol. ix., p. 311.

† "*Metasomatic Processes in Fissure-Veins,*" this volume, p. 498.

metasomatic character from the first division. Between the two divisions, but more closely related to the hydrothermal class, stand the cassiterite veins. A third division may be made to include the *dynamo-metamorphic and regional-metamorphic deposits*, similar to the contact-deposits in mineral association, but chiefly consisting of concentrated old impregnations, or old sedimentary-deposits enriched by metasomatic processes, very different from those caused by the strong solutions of hydrothermal waters. Transitions are to be found, no doubt, between the hydrothermal and the dynamo-metamorphic deposits, but this does not diminish the value of these principal divisions. It is worthy of note that a very large proportion of the total production of gold and silver is derived from hydrothermal deposits.

Prof. Van Hise has recently, in a most instructive and interesting paper,* suggested a classification in which, at first glance, there would seem to be no place left for deposits of the kind here described. It is probable, however, he did not intend to limit the "igneous" deposits to those consolidated from a molten magma, as might be inferred from his paper (*Trans.*, xxx., pp. 30–177), for on page 174 is the following statement:

> "I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies and those which may be explained wholly by the work of underground water."

From other papers it is also clear that Prof. Van Hise admits that emanations from intrusive magmas may mingle with the waters of atmospheric origin, and that deposits may be formed in this way; for he says† that

> "It is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. . . . If this be so, there will be all stages of gradation between true igneous injection and aqueous cementation, and all the various phases of pegmatization may thus be fully explained."

In the succeeding paragraph in the same paper, observations in the Black Hills of Dakota are recorded, which appear to show that a regular transition exists, from pegmatitic veins to normal quartz-veins, the latter appearing furthest away from the igneous core which furnished the material for the pegmatitic veins.

---

* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., 27.

† 16*th Ann. Rept. U. S. Geol. Sur.*, Part I., p. 687.

4. *Relation of Pegmatite-Veins to Ore-Deposits.*

The pegmatite-veins contain coarse granular aggregates of quartz and feldspar usually characterized by simultaneous crystallization; associated with these are a great number of rarer minerals, such as zircon, apatite, specularite, tourmaline, topaz, beryl, and a vast number of minerals containing the rare earths. Their origin has for a long time been a subject for discussion, both consolidation from a molten magma and aqueous deposition being suggested. The modern view of their genesis, represented by Messrs. Brögger and Rosenbusch, is that, while they may be to some extent the result of consolidation from a molten state, they are very largely of pneumatolytic origin.

The pegmatite-veins are formed *after* the consolidation of the main mass of the igneous rock, and are to be considered as the last results of magmatic differentiation. That they are so much richer in the rarer minerals than the igneous rock with which they are associated, is to be explained by the concentration of the escaping volatile compounds of boron, chlorine, fluorine and sulphur into a smaller volume of residual magma.* A migration of these volatile compounds into the surrounding rock may sometimes be noted. Thus, for instance, Prof. Patton describes,† from Colorado, tourmaline impregnating schist for 2 or 3 ft. on both sides of a 10-ft. pegmatite-vein, which itself only carries a smaller percentage of that mineral.

Sulphides, as well as oxides, are sometimes found in pegmatite-veins, though I know of no instance of economically valuable masses. Among the minerals are cassiterite, wolframite, specularite, löllingite ($FeAs_2$), molybdenite, zincblende, galena and chalcopyrite. At least one of these, löllingite, Brögger regards as certainly belonging to the earliest period of pegmatite formation (magmatic consolidation, accompanied by pneumatolytic action); while others are regarded to have been formed by a combination of pneumatolytic and aqueous agencies.

It has been noted that many pegmatite-veins are exceptionally rich in quartz, and it has been suggested that normal quartz-veins may form transitions into pegmatite-veins. Occurrences apparently confirming this view have been recorded by

---

* W. C. Brögger, *Die Mineralien der Südnorwegischen Pegmatitgänge, Zschr. f. Kryst. und Min.*, Bd. xvi., p. 213.

† *Bull. Geol. Soc. Am.*, vol. x., pp. 21–26, 1899.

many reliable observers, such as G. H. Williams,* Van Hise,† Crosby,‡ Fuller and Spurr.§ Mr. Spurr explicitly declares his belief that, in the Yukon district, pegmatite-veins form transitions into gold-bearing quartz-veins; these latter, he thinks, have been "deposited from (magmatic) solutions so attenuated that they may best be described as waters highly heated and heavily charged with mineral matter in solution."

These observations are highly interesting. It is quite possible that some such relation exists between pegmatite- and quartz-veins. But it must be strongly emphasized that the descriptions of such transitions should be fully proved by series of exact assays. This has not yet been done. It is possible, of course, that the vertical distance between pegmatites and normal gold-quartz veins may be so great that transitions between them could not ordinarily be studied in any one district; or it may be that, if some of the gold in quartz-veins has been derived by exhalations from a congealing magma, it was carried off by other agencies than the pegmatite-veins. Against the suggested relationship speaks the fact that California, Idaho and Oregon gold-quartz veins show no relation whatever to pegmatitic dikes; also, the conditions observed in North Carolina, where Pratt‖ describes normal auriferous quartz-veins, occurring together with barren lenses of pegmatitic quartz. The subject is attractive, and well worthy of further investigation.

NOTE.—Since this paper was written I have had opportunity to read Prof. Vogt's most interesting contribution, "Problems in the Geology of Ore-Deposits."¶ This, to a most desirable degree, confirms and completes the necessarily abbreviated statements in these notes, while its scope is very much larger. The pyritic deposits of the type Rio Tinto, Rammelsberg and Röros, which Prof. Vogt includes under the heading of contact-metamorphic origin, I have not attempted to discuss, on account of my very limited acquaintance with them.

---

[*] 15*th Ann. Rept. U. S. Geol. Sur.*, p. 678.

[†] 16*th Ann. Rept. U. S. Geol. Sur.*, Part I., p. 687.

[‡] *Amer. Geologist*, xix., p. 147.

[§] 18*th Ann. Rept. U. S. Geol. Sur.*, Part III., p. 312.

[‖] *Mining and Metallurgy*, Feb. 15, 1901, p. 108.

[¶] See page 636 of the present volume.

The Formation of Bonanzas in the Upper Portions of Gold-Veins.

BY T. A. RICKARD, DENVER, COLORADO.

(Richmond Meeting, February, 1901.)

INTRODUCTORY.

THE presentation to the Institute, eight years ago, of the paper of Pošepny on "The Genesis of Ore-Deposits" has borne fruit in much fresh investigation, as is evidenced, for example, by the group of very valuable papers, by distinguished members of the United States Geological Survey, read at the Washington meeting—discussions of general principles particularly suggestive to those who are engaged in mining.

Pošepny, in the discussion of his famous treatise, said that the present writer seemed to look at every new conception in ore-deposition "from the sole standpoint of its immediate usefulness in mining."* Protesting mildly against "sole" and "immediate," I accept the impeachment. It calls for no defence.

THE DEVELOPMENT OF RECENT THEORIES.

Given the idea of an underground water-circulation as the chief factor in the deposition of ore, the next step in the inquiry as to the genesis of such deposits is the endeavor to determine which particular part of the general water-circulation is responsible for the results. Around this question have centered the controversies of a generation, and to these controversies we owe the gradual clarification of our ideas upon the processes of ore-formation. It is unnecessary to sketch here their progress from Werner to Le Conte, who combated in 1883 the extreme views of the lateral-secretionists, and in 1893 opposed the narrow interpretation of the ascensionist-theory. The generally accepted opinions of to-day are a well-deserved tribute to his philosophic discrimination.

Thanks to Prof. Van Hise and Mr. Slichter, whose work he utilizes, we have now arrived at a comprehensive conception

---

* *Trans.*, vol. xxiv., 966.

of the underground circulation, which emphasizes the conclusion that sulphide-ores are generally deposited by ascending waters. In estimating the importance of this conclusion, it is to be remembered that, apart from placers and iron-mines, the largest portion, by far, of the ores exploited by the miner are sulphides. Morever, it has been shown that the other, equally essential, parts of the circulation, namely, its lateral and descending portions, particularly the latter, also play their part, to which many " secondary enrichments " are due.

This approach toward an understanding of the processes ot secondary enrichment in ore-deposits is an extremely important advance in the application of geology to the exploitation of mines. For such enrichments pre-eminently constitute the ore-masses valuable to man. Chemistry and physics may unite in determining the conditions favorable to the precipitation of gold; geology may unravel the intricacies of rock-structure, but it does not come within the province of these sciences to decide whether a gold-vein will prove rich enough for profitable mining. Nature knows no ratio of sixteen to one, or any other standard of monetary value. Therefore, the determination of the particular conditions favorable to the mere occurrence of gold-ores remains but a barren discovery until it includes some suggestion as to the search for the richest portions. To the geologist, material carrying 2 dwts. of gold per ton is as truly an auriferous deposit as if it contained 12 dwts. per ton; but, under existing economic conditions, the miner may regard the former as only fit for macadam, and the latter as potential of fortune.

When the science of ore-deposits, therefore, has predicted with certainty the places where gold can be found, it has fulfilled a conclusive test of a true theory. But this means to the miner no môre than the restriction of his search for profitable gold-deposits to those places where there is any gold at all—a restriction which, after all, amounts to little, for the progress of scientific inquiry and practical exploration has rather enlarged than diminished the field of the distribution of this metal. A greater service will be the determination of the conditions which control the formation and distribution of those particular portions of the multitudinous deposits of gold which constitute the secondary enrichments of the geologist and the bonanzas of the miner.

Such a desired consummation seems now to be nearer of attainment. The practical result of the papers of Messrs. Van Hise, Emmons and Weed will be to direct attention to the one line of inquiry most useful to the miner. Unquestionably the theories of secondary enrichment have been largely suggested by the experience of the men whom the geologists have met at the mines; and the invaluable assistance thus given to mining engineers is a pleasant outcome of such an exchange of views.

THE ENRICHMENT OF GOLD-VEINS NEAR THE SURFACE.

A quartz lode carrying gold in association with pyrite is here taken as the type of deposit under discussion. In lodes of this kind, it is a common experience to find bodies of rich oxidized ores extending to a variable depth from the surface. In this general phenomenon of enrichment two processes must be separately recognized, namely, relative enrichment by a method of natural concentration and positive enrichment by the deposition of additional gold through secondary reactions.

Enrichment by Concentration.

The iron sulphide accompanying the gold is removed by weathering. Weathering is a process of chemical decomposition and mechanical disintegration in which oxidation is aided by the shattering of the rock due to the alternate expansion and contraction of the water present in its pores, seams and cavities. The depth to which these effects extend will depend upon the facilities afforded for the penetration of surface-waters carrying free oxygen; and it will be regulated by the local groundwater-level. The results observed usually cease at the groundwater-level because at that horizon the descending surface-waters become mingled with the larger body of neutralized water, and so lose their free oxygen. When, however, they can find channels permitting a relatively rapid passage, they may not become at once diffused, and may thus continue their oxidizing action even below that level. But the actual lowering of the groundwater-level, by a change of surface altitude or hydrostatic conditions, affords the chief factor in enlarging the scope of such oxidizing action on the part of the surface-waters.

The chemistry of the process is pretty well understood, and need not be discussed here.

In the case of enrichment by concentration, the evidence indicates that the leaching and removal of the pyrite has been affected without shifting the gold, which remains behind in its native state. I have specimens from Idaho and West Australia exhibiting crumbly native sulphur, within the cubic cavities vacated by the pyrite, and in those from West Australia there is also gold in fine crystals which are readily shaken loose. The removal of pyrite; the occurrence of fine particles of gold in the vacant casts produced by this removal, and the formation of a sintery honeycombed mass of iron-stained quartz are familiar aspects of the process of natural concentration.

Weathering, then, by removing the baser and more soluble constituents of the vein, decreases the weight without diminishing the volume of the ore, which thus becomes so much the richer *per ton.* Iron-stained gossan, rich in gold, is a familiar occurrence in mining, and the frequent discovery of such material has had a far-reaching effect in determining the character of the industry. Apart from the richness of such oxidized ore, its metallurgical docility greatly enhances its value. In comparison with the unaltered and relatively refractory pyritic ores, the oxidized material is not only easier to crush, but also easier to treat by amalgamation, chlorination, etc. Hence the contrast which is occasionally offered between the early successes of the discoverers of a gold-vein and the subsequent troubles of the mining company which buys their property. The gossan of the gold-vein has been the source of a large part of the world's store of the precious metal; and to it we owe the successful beginnings of many districts, which, if they had been compelled to commence operations upon refractory pyritic ore, would have waited long for their active development.

Secondary Enrichments Due to Descending Surface-Waters.

The diagnosis of the general process by which these are formed by descending waters has been stated in clear terms in the contributions of Messrs. Van Hise, Emmons and Weed.

The occurrence of restricted bodies of extraordinarily rich gold-bearing quartz has been a startling feature of gold-mining in all countries. From them fortunes have been made with picturesque suddenness; and by means of them the inexperienced have been led into sanguine expectations, the failure of which has brought disasters not less romantic, though much less welcome to their victims. Such instances have furnished matter for proverbs concerning the uncertainty of mining; but they are soon forgotten. Nevertheless, the uncertain occurrences of rich ore on which they are based present an important feature of the ore-deposits in all gold-mining districts, though they are more particularly characteristic of desert regions, such as the area of the Great Basin, stretching between the Rocky Mountains and the Sierra Nevada, and also those arid parts of Australia which have yielded so much of the wealth of the colonies.

The outcrop of a gold-vein is not always the richest portion. The sintery gossan formed at the immediate surface may be poor in gold, and yet may be succeeded near, or even below, the water-level, by extremely rich masses of half-decomposed pyritic ore. In such cases it would appear that the gold had been leached out of the oxidized portion of the lode, and had migrated in the wake of the iron until precipitated, so as to form the secondary enrichment now under discussion.

In considering the formation of these bonanzas, one of the first problems presented is the question of the mode of occurrence of the gold in the pyritic quartz of the lode. The evidence as yet available indicates that the gold does not exist in chemical combination with the iron sulphide of the pyrite, but usually occurs in minute filaments or crystal aggregates distributed through the substance, and especially along the structural planes, of the pyrite. In my collection I have a handful of fragments of pyrite obtained from the Orphan Boy mine, in Boulder county, Colo. This mine was the beginning and end of a mining excitement which happened, in the spring of 1892, in connection with a locality named Copper Rock. Under a magnifying-glass the specimens exhibit little crystals of gold, which, by the rounding of their edges, appear in places as globules distributed over the facets and in the crevices of the pyrite.

The behavior of such gold-ore under metallurgical treatment also suggests strongly that its usual mode of occurrence is analogous to the above example. When gold-bearing pyrite is treated by cyanidation, the gold may be leached out without deformation of the pyrite or any other change in its appearance except the acquisition by its facets of a pitted surface suggesting cavities left by the removal of a soluble constituent. Moreover, there are many mining districts yielding gold from pyritic veins in which the native metal is rarely seen. The ores of Gilpin county, in Colorado, for example, contain an average of from 10 to 15 per cent. of iron and copper pyrites; and I know from frequent trial that when crushed and washed in a pan, such material, even though very rich, will not yield a "color," that is, a speck of visible metallic gold. Nevertheless, in the stamp-mill these ores yield their gold to amalgamation, indicating by their behavior in this respect that the gold is in a condition of such freedom as to permit its separation by a crude mechanical process, and its subsequent ready combination with mercury so as to form an amalgam.

The gold which occurs thus in the pyrite of the quartz-vein is soluble in many natural reagents, some of which are formed in the very process of weathering which leaches the pyrite, while others are known to be present in the surface-waters which circulate through the lode-fractures under observation at the present day. By whatever means it is dissolved, the gold is then supposed to be carried by the surface-waters in their descent toward the groundwater-level, where it is precipitated under conditions to be discussed in due course.

Solvents.

In the process of weathering, the pyrite yields many subordinate compounds, such as sulphuretted hydrogen, sulphurous and sulphuric acid, and proto- and sesqui-sulphates of iron. Of the latter, the sesqui-sulphate, $Fe_2(SO_4)_3$, is a solvent for gold, and has been cited by Wurtz and Le Conte in early discussions concerning the origin of masses of native gold in oxidized ores. Dr. Richard Pearce, in later years, has frequently drawn attention to the probability that this sesqui-sulphate is a factor in the process of gold-deposition.*

The gold-deposits in the cavernous quartzite of Battle Mt.,

---

* Presidential Address, *Proc. Colo. Sci. Soc.*, vol. iii., part ii. (1889), p. 244.

Colo.,* have characteristics which appear to confirm this view. In these ores large pieces of native gold, of a nuggety appearance, but really crystalline in structure, have been found associated with horn-silver and the sesqui-sulphate of iron. The latter occurs in lumps, mixed with clay; and although these are very rich in gold, the gold occurs in a form not to be detected by careful panning. Analyses of several large lots of ore showed the presence of 12 per cent. of the hydrated sesqui-sulphate of iron.†

But other solvents, capable of doing this work, also occur in nature, and, although the amount of any one of them to be detected in existing surface-waters may be minute, we have to remember that the processes of nature are permitted so much more time than those of the laboratory that the dilution of the solution is compensated by the quantity of it.

Most writers refer to chlorine as a possible reagent. Such a reference is suggested not only because it is a prominent reagent in the metallurgical practice of to-day, but also by the fact that it has a wide distribution throughout nature in the form of common salt. This is most apparent in arid regions where evaporation causes concentrated solutions to be formed. Thus, in the deserts of West Australia the water encountered in the mines is always brackish, and frequently contains more salt than the sea.‡ The water of the Great Boulder Proprietary mine, at Kalgoorlie, in 1897, contained 6402 grains of common salt per gallon.§ A considerable amount of magnesium chloride was also present. In some of the water used in the stamp-mills, and obtained from temporary "lakes,"‖ the salts were present up to the point of saturation and the liquid carried further salts in suspension, so that the amount reached as high as 30 per cent., rendering the term "brine" more suitable than "water." This liquid contained 17 per cent. of salts in solution even when most diluted by recent rains, and it therefore afforded a parallel to the Dead Sea, the waters of

---

* F. Guiterman, "Gold Deposits in the Quartzite Formation of Battle Mountain, Colorado," *Proc. Colo. Sci. Soc.*, vol. iii., part iii. (1890), pp. 264–268.

† *Ibid.*, p. 266.

‡ Sea-water contains 3½ per cent. of salts, three-quarters of which is common salt, the chloride of sodium.

§ This is equivalent to 9 per cent.

‖ "Sinks" or salt-marshes. They form an important feature of the physiography of West Australia.

which contain from 20 to 26 per cent. of salts, of which 10 per cent. is common salt. These excessive percentages are not due to the presence of deposits of salt in the rocks of the district, but simply to the concentration brought about by the excessive evaporation* which takes place in a hot, arid climate.

Mine-waters frequently contain a noteworthy quantity of chlorine, as chloride of sodium. At the Mammoth mine, in Pinal county, Arizona, the water carries five grains of salt per gallon, while the well-water, used in the stamp-mill, situated in the valley below the mine, contains twice as much.† This would be equivalent to six grains of free chlorine per gallon. The larger amount contained in the water from the well, as compared with that in the drainage of the mine, suggests the results of surface-leaching. Even in mountainous districts, such as Cripple Creek, Colo., the mine-waters carry chloride of sodium to a noteworthy extent. The water of the Independence mine contains three grains per gallon.

Another suggestive feature is offered by the abundance of horn-silver or cerargyrite, the chloride of silver, throughout the dry tracts of Arizona, New Mexico and Nevada.‡ Prof. Penrose emphasizes this interesting fact, and connects it with the bodies of salt water which still survive in places as "sinks" and "lakes."§ Furthermore, the oxy-chloride of copper, atacamite (which derives its name from the Atacama desert, between Chili and Peru), is frequent in these regions. Another and more uncommon mineral may also be mentioned in this connection. In the Mammoth mine, already cited, and in the well-known Vulture mine, both in Arizona, the precious metals are associated with vanadinite, which contains chlorine as a chloro-vanadate of lead, $3Pb_3(VO_4)_2; PbCl_2$.|| Thus the chlorides of copper, lead and silver are found in the oxidized ores of these regions, while the corresponding combination of gold is

---

* The rate of evaporation, in the region mentioned, has been estimated to be as much as 7 ft. per annum.

† As I am informed by Mr. T. G. Davey.

‡ The general occurrence of horn-silver in the outcrops of lodes throughout the southern parts of Arizona and New Mexico has originated the term "chloriding" which the miners employ as a synonym for "prospecting," which, by the way, the Australian calls "fossicking."

§ R. A. F. Penrose, Jr., "The Superficial Alteration of Ore-Deposits," *The Journal of Geology*, vol. ii., p. 288, 1894.

|| Dana.

absent. The explanation is obvious. The chloride of gold is an unstable and readily soluble compound, while the minerals formed by the corresponding combination with the baser metals are comparatively insoluble in water, especially the chloride of silver, for the abundance of which there is therefore a good reason. It remains but to add that, in several Arizona mines which I have sampled, the ores above the water-level carried a notable proportion of silver with very little gold, while in depth the silver contents have diminished and the gold has increased, especially in the vicinity of the water-level.*

Of the many reagents which would liberate the chlorine from salt, it is only necessary to mention ferric sulphate and sulphuric acid, both derived from the ordinary oxidation of pyrite. The hydrochloric acid thus formed would yield free chlorine in the presence of manganese oxides,† which are very prevalent in the upper portion of gold-lodes, in the form of the black earthy mineral, psilomelane.

There are other possible solvents which need not be discussed here.

Precipitants.

Whatever the solvents which leach out the gold from the superficial portions of the vein, there is assuredly no lack of precipitants. It is probable that the gold does not migrate far before encountering conditions which compel deposition. Even when it is eventually carried to a considerable distance it is most likely that such removal is effected by alternating stages of precipitation and solution.

Organic matter is a probable precipitant for the gold in such surface-waters. It exists deeper than hasty observation would suggest. At the Great Boulder Main Reef mine, at Kalgoorlie, I saw the roots of trees which, in their energetic search for moisture, had attained a depth of 85 ft. below the surface; and at the Sugar Loaf mine, near Kunanalling (also in West Australia), I saw a similar occurrence at a depth of 74 ft.‡

---

* I may instance two well-known mines, the Mammoth and the Commonwealth.

† See the experiments made by Dr. Don, to test this matter, *Trans.*, xxvii., p. 599.

‡ Since writing the above I have read Professor Vogt's very valuable contribution, and I note that he mentions having seen, among the mineral exhibits at

Another agency which, under certain chemical conditions, is a probable factor in reducing the gold from surface-waters, is pyrite itself. Thus, the gold dissolved from the decomposed pyrite at the surface may be precipitated upon the unoxidized pyrite deeper down. Among the exhibits belonging to the Colorado Scientific · Society is a bottle containing cubes of pyrite, on the faces of which crystals of gold are to be seen. They are the result of one of Dr. Pearce's experiments. The gold of a Cripple Creek ore was dissolved by using common salt, sulphuric acid and psilomelane as reagents, the chlorine being thus obtained in a manner analogous to conditions which probably occur in nature. This solution was placed in a small bottle, and to it were added a few large pure crystals of pyrite from the St. Louis mine, at Leadville. After several months the gold became precipitated in the manner described. In this connection the story of Daintree's experiment, which I have quoted before,* is worth repeating. In 1871, Daintree commenced a series of experiments at Dr. Percy's laboratory at the Royal School of Mines, London. In a number of small bottles he placed a solution of chloride of gold, and to each he added a crystal of one of the common metallic sulphides, such as pyrite, blende, galena, etc. At the time when Daintree died, a few years later, no results could be discerned; but one of the bottles, containing the gold solution and a crystal of common pyrite, was removed to Dr. Percy's private laboratory, in Gloucester Crescent, and there, in 1886, the experiment was completed by the discovery of a cluster of minute crystals of gold upon the smooth surface of the pyrite. The experiment had occupied fifteen years; and on account of its very length it may be said to have more nearly approached the actual conditions occurring in nature.

In a case like that of the "Indicator," at Ballarat, which I have lately described again,† it may be questioned whether it is the pyrite in the thin seam of graphitic slate or the carbonaceous matter of the latter which causes the precipitation of the gold.

Paris, specimens of such roots, from the Great Boulder Main Reef mine, on which gold had actually been precipitated. "Problems in the Geology of Ore-Deposits," this volume, p. 678.

* *Trans.*, xxii., 313.

† "The Indicator Vein, Ballarat, Australia," *Trans.*, xxx., 1004.

Even if the pyrite was the decisive factor, it must be remembered that it, in turn, probably owed its previous deposition to the action of the carbonaceous precipitant in the Indicator seam. This would apply also to the beds of black slate which have had so marked an influence on the occurrence of gold in the Gympie district,* Queensland, but it would not, I think, be applicable to the Rico deposits,† where pyrite is not an especial constituent of the black shales, as compared with the sandstone beds of the same stratified series.

Solution and Precipitation.

It is to be noted that in the two examples of ore-forming processes which have been considered, the gold in the superficial part of the vein is supposed, in one case, to remain in the gossan after the pyrite has been removed, while in the other instance the gold also is dissolved and carried elsewhere. This may appear contradictory. It is a good illustration of the perplexities arising from the application of chemical hypotheses to the theory of ore-deposition.

Nature knows no interval of inaction; solution is going on at one time, precipitation at another. The gold is constantly the object of one or the other activity. After the pyrite is removed, or while it is still undergoing leaching, the gold is being dissolved, but more slowly than the baser metals. That which remains to enrich the gossan may well be supposed to be the survival from a larger quantity of gold which has been undergoing slow solution. The gold which was deposited deeper down, from the surface-waters, may, as erosion takes away the upper part of the vein, eventually find itself close to the surface and undergo re-solution. It is a question whether the mining of to-day breaks in upon the gold-deposits at one stage or another of a continuous process. The miner finds the balance of gold left on deposit from a current account in Nature's bank. Solution and precipitation are everywhere in action; it is the excess of one or the other which determines the formation of ores.

---

* J. R. Don, "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 577–580.

† "The Enterprise Mine, Rico, Colorado," *Trans.*, xxvi., 906.

The Distribution of Ore-Bonanzas.

The shifting of the zone of oxidation is a principal factor in determining the distribution of rich ores. By the erosion of the superficial portions of the vein, in common with the enclosing rock, the further downward penetration of the oxidizing agencies is facilitated. The depression of the groundwater-level lowers the zone at which precipitation of gold, from descending surface-waters, takes place, while, on the other hand, when a change in the hydrostatic level causes the groundwater to rise, the zone of deposition moves up. In both cases the tendency is to give vertical extension to the rich mass of secondary gold-ore, and thus to produce the occurrence which miners term a "shoot."

Erosion is followed by another result, in itself of great importance to gold-mining. The steady removal of the superficial part of the vein causes the lower portion, which has been enriched at or below the groundwater-level, to undergo a relative elevation by being brought nearer to the surface. In this way the bonanza-zone, in process of time, may become the outcrop. This appears to me to explain the occurrence of the extraordinarily rich bunches of specimen-quartz, such as made West Australia famous in 1894 and 1895, and started the mining stampedes of other days elsewhere. In many instances fortunes have been gathered almost at the grass-roots from veins which, on systematic development, have proved unprofitable. The gold-quartz veins of West Australia traverse rocks of great geological antiquity which have not, during late geological periods, undergone any notable disturbance. We do not know at what period the veins were formed; but, even though their formation dates no further back than the beginning of the Tertiary, they have since been continuously exposed to the same quiet forces of erosion which have leveled the region until it appears as an arid table-land strewn with the wreckage of geological time.

Whatever the alternations of slow depression and elevation which have affected this region, as part of a continental area, it is certain that erosion has been long at work with patient constancy. Throughout this period chemical agencies have been active in the zone of weathering, near the surface, removing the gold to the zone of precipitation, near the groundwater.

Whatever the slight changes which have marked the level of the groundwater from time to time, erosion has continued uninterruptedly, and therefore it has steadily gained, with the result that the enriched portion of the vein has been brought nearer and nearer to the actual surface, until it finally appears as the outcrop which rewards the search of the prospector.

The Localization of Ore-Shoots.

To the miner the localization of these richer portions of the vein is of more immediate practical interest than the theory of their origin. A gold-vein is not a homogeneous mass of auriferous quartz, of tabular form, penetrating the rocks like a sheet of paper, but rather as an irregular occurrence of ore, the composition and shape of which are very variable, because they are the result of chemical agencies and structural conditions of great complexity. While the traces of the agencies which precipitated the ore are obscure, because they have been largely obliterated by subsequent chemical action, the relation between the vein and its encasing rock can often be traced by observation. In this direction the miner obtains great aid from the geologist. The transactions of this Institute and the publications of the U. S. Geological Survey contain numerous clear expositions of such structural relations. The monographs on the Leadville and Eureka mining districts may be especially instanced as affording striking examples of the direct application of geology to underground work.

Australia.—One of the best examples of the localization of rich ore came under my notice in 1890 in the Bright mining district. Bright is geographically in the Australian Alps, and geologically in the Upper Silurian slates and sandstones. Though these rocks have undergone metamorphism, and exhibit a well-developed cleavage, yet their bedding has not been obliterated. The veins cross the bedding-planes of the enclosing country both in strike and dip. When investigating the distribution of the ore in the mines of this district, I found that the ore-shoots had a pitch corresponding with the line of intersection between vein and country. This was well illustrated at the Shouldn't Wonder mine, 7 miles from the town of Bright. The lode was a simple quartz vein from 15 to 24 in. wide, carrying a small percentage of pyrite. It had a strike of N.

28° W. and a dip to the NE. of about 75°, while the country dipped SW. 79° and had a strike of N. 55° W. The plane of the vein cut across the beds of the country and the intersections thus produced were to be seen along the foot-wall of the lode as lines, pitching 42° to 46° southward. While the foot-wall was more regular than the hanging, and therefore exhibited this feature best, yet the hanging also carried lines corresponding with those observed on the opposite wall.

The boundaries of the ore-shoots in the mine followed these lines; and the longitudinal section of the workings, as seen on the mine-maps, proved also that these lines of intersection had an inclination which coincided with the trend of the ore-bodies, as stoped out between the four successive upper levels of the property.

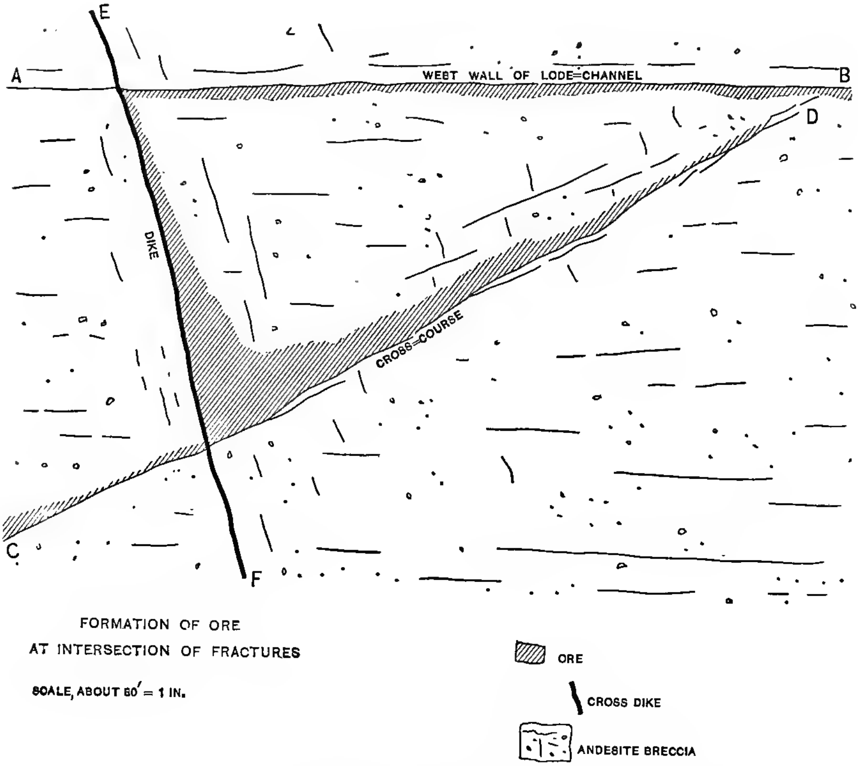
At the Myrtle mine, in the same district, there was the same correlation between the pitch of the ore-bodies and the line of intersection of the wall of the lode with the bedding-planes of the enclosing country. The stratification was distinct, the rocks consisting of altered, silicified slates of a gray to gray-blue tint. In the stopes above the 700-ft. level the pay-ore was separated from the normal valueless quartz of the lode by a small step, due to the irregular fracture of the vein in crossing two beds of unequal hardness. It marked the line of intersection between lode-plane and country bedding, and also proved to be the boundary of the pay-shoot. In the different portions of the mine the variation in the dip of the country produced variations in the angle of the lines of intersection, and also in the pitch of the ore-shoots.

It is not often that the formation traversed by a vein has such a simple structure as was presented by these Silurian sedimentary rocks; but it is probable that in other districts also the pitch of the ore-bodies may have been determined by structural conditions of a similar kind, which have been obscured, however, by metamorphism.

Colorado.—Experience has shown that the intersection of fractures favors the occurrence of rich ore-bodies. An interesting example was afforded by the Moon-Anchor mine, at Cripple Creek, in 1899. This is illustrated in Fig. 1. The ore in the mine occurs in a lode-channel marked by a band of fractured andesite breccia. At the 400-ft. level a small dike

(EF) of granite, 2 to 6 in. thick, intersects the lode-channel at a place where a counter-fracture (CD) also traverses it. A triangle is produced by these intersections, and the ore is proved to surround a block of ground which is also mineralized, but not sufficiently so to be regarded in its entirety as pay-ore.

Fig. 1.



MOON ANCHOR MINE, CRIPPLE CREEK.

Bormay & Co., N.Y.

At the crossing of the dike and cross-fractures a very rich body of telluride-ore was encountered.

This reminds me of the Yankee Girl ore-body, mentioned by Emmons.* This body of ore was of phenomenal richness, many ten-ton lots being shipped which carried 7 or 8 ounces of gold and 3000 to 4000 ounces of silver per ton. The ore was also rendered remarkable by carrying the rare mineral stromeyerite, a sulphide of silver and copper. Mr. Emmons speaks

---

* "The Secondary Enrichment of Ore-Deposits," this volume, p. 451.

of the bonanza turning into low-grade pyritic ore as depth was attained. I may add* that this change was not gradual, but sudden, and coincident with certain structural relations. At the surface, the vein consisted of comparatively low-grade ore, which led to the finding of a nearly vertical "chimney," averaging only 25 to 30 ft. in diam., of extraordinarily rich ore, consisting of the copper sulphides, bornite and erubescite, with stromeyerite and barite. The gold in the ore was associated with the barite. From the second to the sixth level, at about 500 ft. below the surface, this bonanza proved immensely productive; then, suddenly, a flat floor, dipping W. and accompanied by clay, crossed the deposit. This flat vein was worked for 90 ft., from the south drift at the No. 6 level, and contained ore similar to that of the Yankee Girl chimney. The latter was found again deeper down, and out of its former line of descent, but it was much diminished in richness, and appeared to merge into the general body of low-grade copper and iron pyrites† which characterized the lode at the tenth level. This mine and its neighbors, the Robinson and Guston, are idle now. They are in the andesite breccia of the San Juan region. The Yankee Girl chimney was situated, I believe, at the crossing of three lode-fractures, appearing as breaks in the andesite, which was bleached and mineralized where they traversed it. It was a curious feature of this mine, and of the Guston also, that the short, very rich bonanzas of the upper levels gradually lost their definition, that is to say, they became no richer than the intervening portions of the lode. This was interpreted as a "lengthening" of the ore-shoots, which may be true, viewed in one way; but I think that it should be more properly regarded as an impoverishment of the lode, marked by a disappearance of the bonanzas. The surface-waters of these mines are very acid, as Mr. Emmons remarks. At the Yankee Girl mine it became necessary to encase the pipes in redwood, brought from California. I found that the water issuing from a shallow adit (73 ft. below the collar of the shaft) readily precipitated copper on scrap iron. Ore-forming agencies were evidently still at work.

California.—In California, especially in that mining region which follows the foothills of the Sierra Nevada and traverses

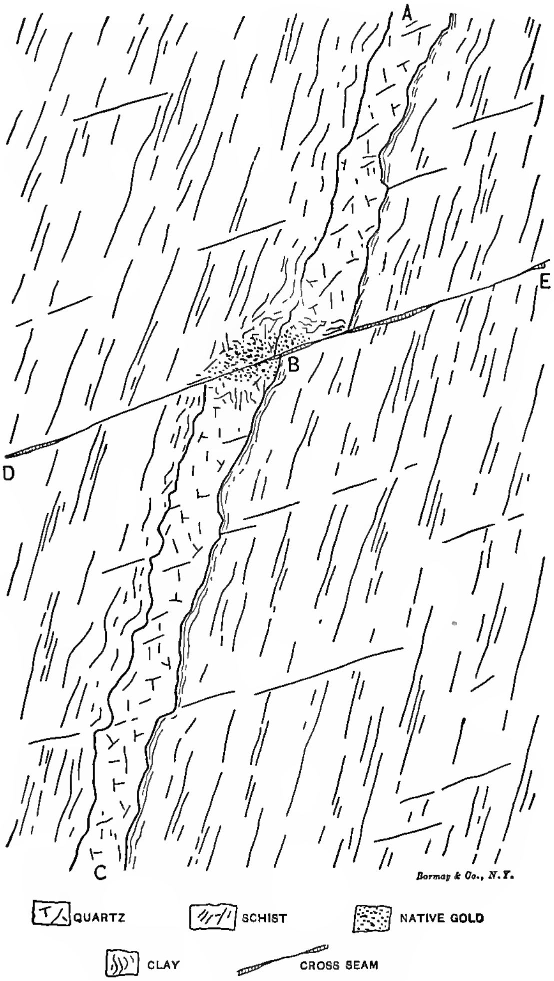
---

* From notes made during an examination of the mine in January, 1892.

† Assaying 20 to 60 ozs. silver, 1 to 4 dwts. gold, 5 to 15 per cent. copper.

the counties of Amador, Calaveras and Tuolumne, the occurrence of pockets of rich ore, full of native gold, is a notable feature of the superficial parts of the quartz-veins. These pockets appear to be confined to the zone between the surface and the water-level, and to be dependent upon the results produced by the small cross-veins which encounter the main lodes. In 1887 I had the pleasure of extracting, in two hours, a little over 170 ounces of gold, worth about $3000, from one of these pockets. It was at the Rathgeb mine, near San Andreas, in Calaveras county. The main lode consisted of 5 to 8 ft. of massive "hungry-looking" quartz, the foot-wall of which was a beautiful augite-schist and the hanging a hard diabase. The water-level was 160 ft. below the surface. Down to this point, the country was oxidized, the hanging-wall exhibiting only slight alteration, while the schist of the foot-wall was softened and decomposed almost to a clay. This was traversed by numerous small veins, which appeared to act as "feeders," forming bunches of rich ore where they encountered the main lode. At the 120-ft. level, south from the shaft, there were some old workings; and the examination of these led to the discovery of a small seam, about one-sixteenth of an inch thick, filled with red clay which carried a good deal of native gold, as was proved by washing it in a pan. An experienced miner was put to work, with instructions to follow this small streak. It varied in thickness, and occasionally opened out into small lenticular cavities, containing a clay in which the gold was distributed like the raisins in a pudding. Each of these "pockets" yielded several hundred dollars' worth of gold. At length the streak widened to 6 or 8 inches of quartz, lined with clay. The amount of red clay commenced to increase; coarse gold became more frequent; and a big discovery was hourly expected. It was finally made. The vein suddenly became faulted, and at the place of faulting there was a soft, spongy, wiry mass of gold and clay—more gold than clay. The first handful I broke, while yet the stope was thick with powder-smoke, contained three ounces of gold. Within the next two hours this pocket gave us $3000, and during the following week it yielded over $20,000, an amount which was obtained at a total cost of less than $200. When it had been worked out, it was easy to observe the conditions which determined its occurrence at this place, as Fig. 2 will explain. The vein, AC, had been faulted about its own width, namely, 10 inches, by a small cross-seam, DE, and at this intersection, B, the pocket lay. The gold was

Fig. 2.



OCCURRENCE OF A 'POCKET.'

spongy and was intermixed with quartz. The clay which penetrated the whole mass was partly red and ochreous, and partly a gray gelatinous material. In the quartz, and associated with the gold, there were acicular black crystals of pitch-blende (uraninite), together with uranium ochre. This association of gold with uranium is uncommon.

New Zealand.—Intersections which coincide with enrichments form a notable characteristic of the Hauraki gold-field* in the north island of New Zealand. In this district the occurrence of patches of native gold is an important feature of the regular mining operations. When I was there, in 1891, each stamp-mill had its "specimen-stamp," a single stamp working in a separate mortar, and employed solely for the treatment of specimen-ore. These rich patches occur at the places where the "reefs" or lodes cross bands of flinty quartz. The latter are known among the miners as "flinties." They vary in thickness from a few inches to mere threads of chalcedonic quartz. They are barren in themselves, but have a favorable effect on the gold-veins. The latter are also intersected by cross-veins, producing an enrichment similar to that caused by the "flinties." Fig. 3 is a sketch of one of these intersections, as seen by me in the Moanataeri mine. The lode, AB, consists of a series of small seams of quartz, conforming to the structural lines of the enclosing country, which is hornblende-andesite. The cross-vein, CD, is a band of soft gray decomposed rock, which also carries a number of small quartz-seams, but only near its crossing with the main lode, AB. The line of CD is parallel to a large fault, to be seen elsewhere in the mine-workings. The "leaders," or quartz-seams, in AB are gold-bearing, and exhibit marked enrichment at the intersection with CD.

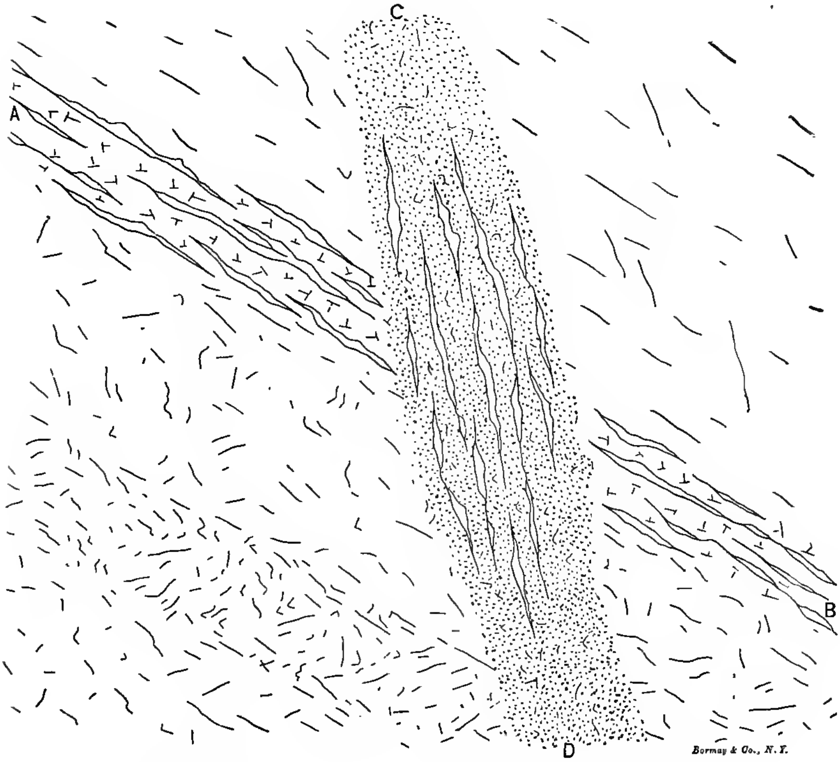
The prevailing formation of this mining district is an andesite, which is traversed by soft bands of decomposition, called "sandstone" by the miners. The latter, when penetrated by quartz-seams, are favorable to the finding of ore. The gold-occurrence is essentially sporadic and dependent upon local enrichments, such as have been described. The district is surrounded by thermal springs, and is near the well-known volcanic region of Tarawera, which was active in 1884. The mine-waters are heavily mineralized and very acid, so that the metal screens used in the mills are quickly corroded. Tellurides and selenides of gold have been detected in the ores; but the pre-

---

* It is also known as the Thames district.

cious metal is usually found native and in coarse particles, which are frequently coated with native arsenic. The district is one which, I think, if thoroughly examined, would afford many suggestions regarding ore-deposition.*

Fig. 3.



ENRICHMENT AT INTERSECTION MOANATAERI MINE, NEW ZEALAND.

Concluding Remarks.

It is to be hoped that the recent recognition of the agencies which bring about the formation of enrichments by surface-waters will not cause too violent a swing in the direction of a sweeping advocacy of the general efficiency of descending

---

* The best description which has come under my notice is "The Geology of the Thames Goldfield," by James Park, read before the Auckland Institute, 1894. See also "On the Rocks of the Hauraki Goldfields," by F. W. Hutton, *Proc. Austral. Assn. Adv. Sci.*, 1888; and J. R. Don, "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 584–589.

solutions to form ore-bodies. The study of the problems of ore-occurrence has been hindered in the past by such reactions from one extreme view to its opposite. Therefore, in concluding this contribution to the discussion of the results produced by descending surface-waters, I would emphasize the wider agency of ascending solutions in forming the ore-masses amid which such secondary enrichments are occasionally found. It is agreed that the sulphide-ores are primarily deposited from ascending waters; it is also likely that such a result is repeated. A region once subjected to fracturing, which has permitted the subsequent passage of mineral-bearing solutions, is likely, at a later period, to be subjected to a repetition of these activities. The geological history of many mining regions gives clear evidence of a repeated disturbance of structure. This is indicated by the existence of several systems of fractures crossing each other, the later ones dislocating the earlier. It is probable that each period was marked by mineralization, the character of which may have varied. The banded arrangement of the lodes of certain districts, such as Freiberg, Rico and Butte, suggests this. Enrichment may have been caused by mere addition; the introduction of other metals may have changed the average composition of the ore in the lode so that it is now extremely valuable, whereas before it may have had no economic importance; a silver-ingredient may have been added to the gold-contents, or the addition of copper may have made a deposit doubly valuable by improving its metallurgical character. I hope the present discussion on ore-deposition will prove as inspiring to further investigation as did Pošepny's paper of 1893, and that data concerning the possible secondary enrichment of sulphide-ores by the repetition of ascending solutions will be sought for. There is nothing like a working theory to sharpen the observation. Theories do not alter facts, but they often lead us to find new ones.

In cordially welcoming the splendid treatise of Professor Van Hise I need make no reservation. When Pošepny made clear the essential character of the upper or "vadose" water-circulation, he did us a great service; and when he combated "lateral secretion" he overthrew a very narrow interpretation of ore-formation, which was calculated to hinder seriously our progress toward the understanding of these difficult problems.

But Pošepny was carried so far by his controversy with Sandberger as to over-emphasize the sole agency of ascending currents. At that time, in 1893, I demurred to this extreme view and said, " the word circulation is the key to the whole matter."* By this I meant that the entire underground water-circulation played a part in the formation of ore, and that to swing from one portion of that circulation to another, restricting oneself to the agency of either, would not (so it seemed to me from experience in the mines) solve the problem.

It does not appear to me that Professor Van Hise has erred by exaggerating any particular view of the subject. His elucidation of the water-circulation as a complete system is based on a broad conception of the whole matter. Of course, in indicating the work done by an agency hitherto largely overlooked, he was compelled to place some emphasis on certain neglected features of the descending portion of the water-circulation, and thus to give it some prominence in his masterly analysis. This makes the consideration of the question of secondary enrichments by surface-waters one of the most valuable parts of his treatise.

Regarding this question of secondary enrichment, it is to be pointed out that all ore-deposits are " secondary," the ore as found by the miner being merely the last term of a series of solutions and precipitations through which its substance has passed in a constant shifting due to the underground water-circulation. However, the last stage of the journey is the only one of immediate importance to the miner; and the determination of the causes which brought it there is, to him, far the most interesting aspect of the general inquiry. That Mr. Emmons should also have investigated and illuminated the problem is matter of much pleasure to a great many, engaged in mining throughout the West, to whom his geological contributions have seemed to possess a practical bearing and value unfortunately not always found in scientific descriptions of geological phenomena.

---

* *Trans.*, xxiv., 950.

DISCUSSION.

(Presented at the Richmond Meeting, February, 1901.)

S. F. Emmons, Washington, D. C.: *Papers of Collins, Vogt, DeLaunay, etc.*—Mr. Collins tells us about facts in the veins of Cornwall that suggest secondary sulphide-enrichment is highly interesting; and I am free to confess that I have not studied the literature of that region as fully as I should have done. Nevertheless, even if it had been as familiar to me as it is to Mr. Collins, I should probably have hesitated to draw theoretical conclusions without having seen the mines myself; for the personal equation and the point of view of the observer play, perhaps, a larger part in the study of ore-deposits than in that of any other natural phenomena. One important purpose of my paper, and its publication at the time of the Washington meeting, was to call forth remarks from other geologists upon deposits with which they were personally familiar, or to lead them to re-examine such deposits with the idea of secondary enrichment in mind.

Mr. Collins's remarks on Rio Tinto, which he has the advantage of personally knowing, are also interesting. With regard, however, to his suggestion—advanced as an apparent argument against our theory—that the re-precipitation of copper from cupric sulphate solution by pyrite can hardly take place there, since it would upset the commercial process, I would remark that, while he is undoubtedly right as to the fact, it does not militate against the reduction and re-precipitation of cupric sulphate in veins; since on the surface, as at Rio Tinto, there is free access of air, and consequently an excess of ferric sulphate, whereas in depth the ferric sulphate would have been mostly reduced to ferrous sulphate, and (there being no excess of acid to hold it in solution) the small amount of copper in the presence of an excess of iron sulphide would be precipitated either as sulphide or as native copper.

To Professor Vogt's analogous remarks, that in his experience sulphuric acid is formed only in subordinate amount in the attack of sulphides by ferric sulphate, I would say that Dr.

Stokes's experiments, made in the laboratory of the U. S. Geological Survey expressly with a view to determining the effects of the attack of ferric sulphate on various sulphides, have conclusively demonstrated that sulphuric acid is formed in all such attacks in very considerable amount; much more than he had thought possible *a priori.*

It is highly gratifying that Professor Vogt has been willing to give us so fully his views on the relation between eruptive processes and ore-deposition, a subject of which he has made a most profound study. His views and those of Prof. Van Hise may be considered to express the opposite poles of geologic opinion; the extreme views of the European and American geologists respectively on this subject—though, among the latter, Prof. Kemp leans more to the European side. To me it seems that a distinction may be drawn between the working geologists, to which class most of the Americans belong, and the professors in universities, which include most of our European *confrères.* The former are more apt to work out theories by practical testing in the mines themselves, while the latter are more dependent upon the literature of the subject, and therefore upon the study of phenomena at second-hand, from the description given by others. Thus, Prof. Vogt instances the copper-mines of Butte and of Cornwall as attributable to magmatic* extraction. In the former case he very likely based his views on my early suggestion (1886) of a genetic connection between ore-deposition and the rhyolitic eruption of the "Big Butte"; but the more detailed studies which I have made since† have shown that the deposits are earlier than the rhyolitic eruption, and that the observed facts are such as to preclude pneumatolitic action as the source of the ore in its present condition.

As regards Cornwall, Prof. Vogt's process of reasoning is that, inasmuch as many tin-deposits have proved to be the result of magmatic (pneumatolitic) processes, and as observations in Cornwall, as well as in the *Erzgebirge*, seem to show "that there can have been no absolutely essential difference between the

---

* I think the use of the term "magmatic" in this connection very unfortunate. I presume he refers to the pneumatolitic method of extracting the metallic minerals from igneous magmas.

† *U. S. Geol. Surv.*, Folio 38, 1897.

genesis of the cassiterite and that of the silver-lead veins," the latter are to be attributed to magmatic extraction rather than to the work of underground water. From my point of view, the reverse reasoning, namely, that underground water must have had some part in both kinds of deposition, is at least equally admissible, and more closely fits the facts of nature.

Both Prof. Vogt and Prof. Beck quote in support of the magmatic theory Hussak's studies of the gold-quartz vein of Passagem in Brazil, which the latter conceives to be an ultra-acid granitic apophyse. But both Mr. Lindgren* and myself, from a careful consideration of the facts presented by Hussak, consider that he has proved it to be a normal fissure-vein, due to the action of underground waters.

With regard to the probable pneumatolitic origin of contact-deposits, there is an essential agreement between Professor Vogt and Mr. Lindgren, as shown in the paper presented by the latter at the present meeting.†

On the other hand, I have failed to recognize the distinction upon which both Prof. Vogt and Prof. DeLaunay lay so much stress, namely, between older and younger gold-silver veins.

There can be no doubt of the great value of such interchanges of opinion as this discussion has called forth; and it now remains for each of us, in the cases of difference of views, to put such views to the critical test of further field-studies and see how far the respective theories are applicable to the phenomena of nature.

It seems to me that the remarks ot Prof. DeLaunay, at the beginning of his contribution to this discussion, may lead to misconception with regard to his views upon what we consider the essential part of the "secondary-enrichment" idea, viz.: that secondary enrichment has undoubtedly, and indeed, in many cases demonstrably taken place below the groundwater-level. For that reason I take this opportunity to quote from his last article in the *Revue Générale des Sciences*, entitled "The Variations of Metalliferous Veins in Depth," in which he expresses himself in more definite terms. Under the caption, "Secondary Changes of Veins in Depth," after describing the

---

* "Metasomatic Processes in Fissure-Veins," this volume, pp. 498–610.

† "The Character and Genesis of Certain Contact-Deposits," by W. Lindgren, Richmond Meeting, February, 1901, this volume, pp. 716–733.

two zones, *above* and *below* the groundwater-level, and the reactions that may go on there, he summarizes as follows:

" A body situated in this zone of permanent waters below this hydrostatic surface (which may have a very complicated form) finds itself in the condition of a wooden pile, which, remaining always immersed in water, suffers no change. On the other hand, above the hydrostatic surface (the groundwater-level) there is a perpetual movement of the waters, a bringing in of oxygen and carbonic acid, alternations of humidity and dryness, etc.; it is there only that are produced the secondary reactions of which there is question here, and by which all the upper parts of metalliferous deposits are thoroughly modified."

Paper of Lindgren on "Contact-Deposits."—Mr. Lindgren's paper constitutes a very valuable and very practical contribution to the literature of ore-deposits. It has long been my opinion that the usage which prevails among miners, of calling so great a variety of deposits "*contact-deposits*" is bad, because the term, as thus applied, is illogical and incapable of definition; and I have advocated its restriction to such deposits as occur along the contact of eruptive and sedimentary rocks. Mr. Lindgren's usage restricts it still further, but has the great advantage that it rests on a distinctly genetic basis. During the past summer I have had opportunities of observing, though not of studying thoroughly, several deposits which, in many respects, fall within his definition, though I should have hesitated in some cases to call them contact-deposits.

Most of these deposits were seen in the Boundary district of British Columbia, in mines lying on either side of Boundary creek, near the town of Greenwood. They constitute the workable ore-bodies of many of the most important mines of the district, such as the B. C., the Knob Hill and Ironsides, the Mother Lode, and others. The ores of these mines are of very low grade, carrying on the average from 2 to 5 per cent. of copper, with a few dollars in gold per ton. They occur, however, in large bodies, and contain much lime, iron and other bases, with little sulphur, so that they can be mined and smelted at an extremely low cost. By reason of the liberal policy which the Canadian Pacific Railroad has adopted, of building spurs to all the important mines, so as to connect them with the smelting-works, it is estimated that the total cost of mining and smelting will be not over $5 or $6 per ton.

The region in which the mines occur is very well covered, either by a luxuriant forest growth or by glacial drift, often with both, so that outcrops are comparatively rare and the geological structure is correspondingly difficult to decipher. Hence, in my short visit, I was only able to determine certain very broad general outlines.

The immediate valley in which the town of Greenwood lies is carved out of a mass of light grey, coarsely crystalline granitic diorite, the longer axis of which apparently runs N. and S. with the valley. As one ascends the tributary ravines on either side, E. or W., one passes into a zone of much altered greenish rock, called by the miners "diorite," beyond which are porphyries, forming, in general, the crests of the bounding ridges. At various points within this zone are outcrops of white crystalline limestone; and it was soon found that the greater part of the so-called "diorite" is simply altered limestone, being largely composed of various normal contact-minerals, the most prominent of which, in the few specimens gathered, was actinolite. Very likely some of these altered rocks may be of eruptive origin; as interbedded tuffs and breccias were observed at the Ironsides mine, and dikes are frequently found crossing the ore-bodies. Such of the porphyries as were examined under the microscope were found to be of the syenitic lamprophyre type. They are distinctly later than the limestone, cutting it in dikes and sending apophyses into it. The general impression derived in going through the country was that they are also later than the diorite; but no contacts were found which would afford absolute proof of their relative age in this respect.

Compared with Mr. Lindgren's type of "contact-deposits," the ore-occurrences of this region show the following striking resemblances:

1. The association with typical contact-minerals, such as the amphiboles, garnet, vesuvianite, zoisite, etc., and the evidence that the ore-minerals were of nearly contemporaneous formation. Mr. Lindgren, who has kindly examined for me, under the microscope, thin sections of ore from the Mother Lode,

states that "they show pretty clearly that a metasomatic replacement has occurred, during which a granular limestone has been converted into amphibolitic rock, and that simultaneously, or almost simultaneously, magnetite and sulphides have been developed."

2. The association of magnetic oxide of iron, in considerable amount, and of contemporaneous formation, with sulphides of iron and copper (more particularly the latter). This peculiar association I had never had occasion to observe until last summer.

3. The irregular manner of occurrence of the ore-bodies. Not only does the material grade off insensibly in every direction, inwards as well as outwards, from the so-called "ore" into low-grade rock, but there are no fracture-planes or walls enclosing the ore-shoots, or even defining their direction. This constitutes a very serious element of uncertainty in the mining of such deposits.

4. The ore-bodies are cut by eruptive dikes which apparently do not disturb or exert any metamorphic influence on the ore, and yet are not at all mineralized themselves; so that one is puzzled to say whether the dikes are later than the ore, or the ore later than the dikes. In the B. C. mine, for instance, three such dikes lying in a nearly horizontal position, and aggregating some 90 ft. in thickness, have been cut in sinking a vertical shaft 250 ft. through the ore-shoot.

On the other hand, the definition of a contact-deposit as involving a close proximity with an eruptive body cannot be regarded at present as strictly applicable to these ore-bodies. The belts of metamorphosed limestone appear to be from one to two or more miles wide; and it is not proved, as yet, that there are considerable eruptive bodies in close proximity with the respective ore-shoots. The final settlement of this question must, however, await a detailed geological survey of the region.

Another probable instance of contact-deposits is seen on the west slope of the Grampian hills, opposite the Horn-Silver mine, in Utah. Here a monzonite intrusion has broken through the dolomitic limestone; and, along the contact, there is a zone from a quarter- to a half-mile wide on the surface (the actual thickness may of course be very much less, dependent on the slope of the contact), of a reddish-brown rock, made up largely of garnet, in which, associated with veins of remarkably beautiful fibrous white tremolite, are deposits of copper-, lead- and zinc-ores, the following of which has been found by the miners to be a very difficult and discouraging matter. I was unable to enter any of the mines, and therefore cannot speak of the manner of occurrence of the ore further than to say that it presents the peculiar association of magnetite and contact-minerals with sulphides, mentioned above.

Some Principles Controlling the Deposition of Ores

BY C. R. VAN HISE, MADISON, WIS.

[Concluding Contribution of Prof. Van Hise to the Discussion of his Paper, and Others on the Same General Subject, presented at the Washington Meeting, February, 1900 (see *Trans.*, xxx., 27, 177, 323, 424, 578); also of the contributions of Vogt, De Launay, Beck, Lindgren, Kemp, Rickard, Bain, Keyes, Collins and Adams, presented at the Richmond Meeting, February, 1901, and printed in the present volume.]

In June, 1900, shortly after my paper was published in the *Transactions*, I made a briefer statement* before the Western Society of Engineers covering the same ground, which, in certain respects, is somewhat of an improvement. For instance, instead of using the terms *descending* and *ascending* with reference to the waters resulting in the two concentrations, my modified statement is as follows:

> "The first concentration of many ore-deposits is the work of a relatively deep water-circulation, while the reconcentration is the result of reactions upon an earlier concentration through the agency of a relatively shallow water-circulation. Commonly the deep water circulation is lacking in free oxygen, and contains reducing agents, and the shallow water contains free oxygen. The deep water is therefore a reducing, and the shallow water an oxidizing agent."†

Of the papers upon ore-deposits which, in vol. xxx. of the *Transactions*, follow my own, or which were presented at the Richmond meeting, a considerable number are wholly confirmatory of the conclusions which I have presented. Among these are the Washington paper of Emmons upon the Secondary Enrichment of Ore-Deposits‡ and his discussion at Richmond of other papers,§ that of Weed upon the Enrichment of Gold and Silver Veins,|| the discussion of Emmons', and at Richmond of Weed's paper by Collins† and Prof. De Launay,† the paper of Lindgren on Metasomatic Processes in Fissure Veins,¶ that of Rickard upon the Formation of Bonanzas in the Upper Portions of Gold Veins,** and the remarks of Bain upon the Mississippi Valley lead- and zinc-deposits.†† It is therefore un-

---

* *Jour. of Geol.*, vol. viii., 1900, pp. 730–770.

† *Ibid.*, p. 765.

‡ This volume, p. 433.

§ See under "Discussions" in this volume.

|| This volume, p. 473.

¶ This volume, p. 498.

** This volume, p. 734.

†† See under "Discussions" in this volume.

necessary to discuss these papers; but in this connection those of Messrs. Emmons and Weed are of interest, since their main purpose is to emphasize and illustrate one of the principles stated by me, which they have independently worked out and used; namely, the principle of secondary concentration by descending waters, not only in the belt above the level of groundwater, but in the sulphide belt below that level. This principle, as well as many of the others stated in my paper, I have been presenting to my students for a number of years. Messrs. Emmons and Weed working at Washington, and I at Madison, were wholly unaware that similar work was being done elsewhere, and that identical conclusions had been reached. If independent investigation by different men leading to the same results be evidence of the truth of a conclusion, the principle of secondary enrichment by descending waters has such confirmation.

A second class of papers, and especially the admirable papers of Vogt upon the Geology of Ore-Deposits,* of Lindgren upon the Character and Genesis of Certain Contact Deposits,† and a part of the discussion by Prof. Beck,‡ have apparently been interpreted by some as presenting views radically different from mine. Two fundamental points which Lindgren, Vogt and Beck emphasize are that the main source of the metallic ores is the igneous rocks, and that the heat of the igneous rocks has been instrumental in their production. With these positions I not only agree, but definitely advocate the same ideas in my paper, as is shown by the following quotations:

> "The original source of much of the material for the metalliferous deposits may, indeed, be largely the centrosphere or the lower part of the lithosphere; for from these sources vast masses of volcanic rocks are injected into the zone of fracture or brought to the surface. This is especially true during great periods of vulcanism. Furthermore, it is well known that in regions of volcanic rocks many ore-deposits are found. Also it is believed that all the rocks of the lithosphere were originally igneous, and that from these igneous rocks the sedimentary rocks have been derived by the epigene forces, *i.e.*, the forces working through the agencies of atmosphere and hydrosphere. It follows, therefore, that the metals of ore-deposits, either directly or indirectly, are derived from igneous rocks. However, the ores are directly derived from rocks in the zone of fracture by circulating underground waters. The rocks which furnish the metallic compounds may be intruded igneous rocks; they may be extruded igneous rocks; they may be the original rocks of the earth's crust; they may be sedimentary rocks de-

---

* This volume, p. 636. † This volume, p. 716.

‡ See under "Discussions" in this volume.

> rived by any of the processes of erosion from primary rocks; they may be the altered equivalents of any of these classes."*
>
> * * * * * * *
>
> "The nature of the rocks which contribute the metallic salts has been much discussed. With Sandberger, I have little doubt that the metallic constituents of ores are in large part derived from the igneous rocks which have been intruded or extruded into the lithosphere; and especially is this true of the basic rocks. Le Conte points out that the undoubted frequent occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the igneous rocks, this promoting the work of underground solutions. That the heat furnished by the igneous rocks is a very important factor in the production of ore-deposits, I have no doubt. Since it is very difficult to prove that the metallic content of an igneous rock is original, it is impossible to make any general statement as to whether the metallic content or the heat furnished by the igneous rocks is the more important in the production of ore-deposits. It seems to me clear that both are important; and equally clear, in many cases, that both work together. That is to say, an igneous rock may furnish all or a part of the metal which appears in an ore-deposit, and the heat of the same igneous rock may greatly assist its concentration by the underground waters.
>
> "While the massive igneous rocks are the undoubted source of a large portion of metallic deposits, it is also equally certain that another large part is derived from the sedimentary rocks and the metamorphosed, or partly metamorphosed, igneous and sedimentary rocks. Lastly, it is also certain that many ore-deposits derive their metalliferous content in part from igneous rocks and in part from sedimentary rocks. Probably this is the most frequent of all cases. To give any estimate of the relative amounts of metalliferous materials derived from the original igneous rocks and from the secondary rocks is quite impossible."†

Prof. Vogt holds that ore-deposits may be formed by magmatic segregation, but that such "differentiation"-ores are "confessedly infrequent."‡ With this conclusion I concur in every particular, and in my classification made a place for ores of this kind: "(A) Ores of Igneous Origin."§ Although agreeing that this class exists, I do not concur in the conclusion that all of the ores specifically mentioned by Vogt as belonging to it are produced by magmatic segregation alone, without modification by the underground water-circulation. Prof. Vogt holds, however, that the ore-deposits formed by so-called eruptive after-actions are much more important than those directly produced by magmatic segregation. In this class of deposits he places cassiterite-veins, apatite-veins, and pegmatite-veins. Only the first of these groups yields a metallic product; and to the metallic ores my paper is confined. There is nothing in it which can be interpreted as dis-

---

* "Some Principles," etc., *Trans.*, xxx., 45–46; this volume, p. 300.

† This volume, pp. 346, 347.

‡ This volume, p. 642.

§ This volume, pp. 284, 285, 428.

agreeing with these conclusions of Prof. Vogt, since I refer to no tin-deposits whatever as the product of underground water, and have maintained, as will be seen just below, that the pegmatite veins are connected with igneous action.

But the main contention of Prof. Vogt, and one of the principal ones of Dr. Lindgren, is that there is a large class of ore-deposits of contact-metamorphic origin. The existence of this class I have also distinctly recognized. I say:

> "In another place I have explained that there are gradations between different classes of rocks, and this statement applies equally well to ore-deposits. I even hold that there are gradations between ore-deposits which may be explained wholly by igneous agencies, and those which may be explained wholly by the work of underground water, or by processes of sedimentation."*

Also, in my article in the *Journal of Geology* I say:

> "I have elsewhere held that there is complete gradation between waters containing rock in solution and rock containing water in solution. If there be no sharp separation between water solutions and magma, it is probable that this is also true in reference to ore-deposits of direct igneous origin and those produced by underground water."†

The fact that I clearly recognize this class of deposits is fully appreciated by Dr. Lindgren, who quotes one of the statements above given, and also the following from my paper upon North American pre-Cambrian Geology:

> "It is thought highly probable that under sufficient pressure and at a high temperature there are all gradations between heated waters containing mineral material in solution and a magma containing water in solution. If this be so, then there will be all stages of gradation between true igneous injection and aqueous cementation, and all the various phases of pegmatization may thus be fully explained."‡

It therefore appears that, so far as the classes of ore-deposits are concerned, there is no difference of opinion between myself and Prof. Vogt and Dr. Lindgren. We all agree that the class of contact-deposits exists; that the source of the ores of such deposits is largely the igneous rocks; and that during the concentration of the ores a high temperature prevailed. The difference of opinion occurs in the interpretation of particular cases. Prof. Vogt and Dr. Lindgren, but more especially the

---

* This volume, p. 429.

† *Jour. of Geol.*, vol. viii., 1900, p. 768.

‡ "Principles of North American Pre-Cambrian Geology," by C. R. Van Hise. 16*th Ann. Rept. U. S. Geol. Surv.*, Part I., p. 687 (1895).

former, hold that many ore-deposits, including sulphides, are more closely allied to the igneous rocks than to water-deposits; while I hold that the majority of ores, and especially those included under "Other Contact-Deposits" by Vogt,* as shown by their character and relations, are deposited by underground waters. However, I have distinctly recognized that there may be deposits in which it is difficult to say which of these two agencies predominate. For instance, in the *Journal of Geology* I say:

> "There may be ore-deposits in which water-action and magmatic differentiation have been so closely associated that one cannot say whether the resultant ore-deposit is mainly a water-deposit or mainly a magmatic deposit."†

But in the vast majority of cases I hold that there is little difficulty in discriminating between veins and dikes—the first representing crystallizations from water-solutions; the second, crystallization from magma. There are few cases where the discrimination with reference to ore-deposits is not easy. While gradations between water-deposited ores and igneous ores are uncommon, gradations between the different classes of ore-deposits formed by underground water are common.

Concerning pneumatolytic action as an auxiliary in the formation of ores, as held by Vogt, Lindgren, Beck and Kemp, I do not deny the existence of ores of this class, but simply say that, while ore-deposits produced by this process are theoretically possible, and very likely exist, I do not know of any instance in which it has been shown that pneumatolytic action has actually been a dominating factor in the production of a workable ore-deposit. However, I think it not unlikely that pneumatolytic action (in the sense of water-gas under very high pressure, above the critical temperature of water) may have helped in the segregation of the metals by transporting them to the main channels of water-circulation. This condition of the water I distinctly recognize‡ as producible not only by igneous rocks, but also by dynamic action. But discrimination should be made between what may be true and what has been shown to be true. The presence of such so-called contact-minerals as tourmaline and fluorite, holding such elements

---

* This volume, pp. 650, 651, 652, 653.

† *Jour. of Geol.*, vol. viii., 1900, p. 768.

‡ This volume, p. 293.

as boron and fluorine, is not proof that they and the other minerals in the veins containing them were not deposited by heated circulating waters.

From the proposition that igneous rocks are an important source of the ores, and that the ores are extracted from them by circulating waters, it by no means necessarily follows that this work is chiefly done while the rock is a fused liquid mass. After the rocks crystallize and become partly cooled, deformation, and the cooling itself, may produce many fractures in them, thus furnishing channels through which the hot waters course while they are collecting the metals. In this manner is largely explained the difficulty under which Prof. Kemp labors in understanding how circulating waters may work upon hot igneous rocks.* So far as igneous rocks are deep-seated intrusives, they may retain after crystallization a very large part of the water which they previously held. This is evidenced by the innumerable liquid inclusions in many such rocks.

In this connection I may say that, among the papers presented in this discussion, Lindgren's admirable paper upon metasomatic processes in fissure-veins seems to me wholly to confirm the view that the deposition of most metallic deposits is effected by underground water. The metasomatic changes in the rocks which Dr. Lindgren describes occur not only in the veins themselves, but in the walls of the veins. Moreover, in many cases the amount of change decreases in passing from the walls into the veins. During the metasomatic changes, metals were added and subtracted. Lindgren declares that, in the great majority of these cases, the chief agents through which the metasomatic changes were accomplished were circulating waters. He says:

> "The processes observed are such as can only be explained by aqueous agencies. Possible exceptions are the forms of alteration connected with cassiterite, apatite, and tourmaline veins, in which pneumatolytic conditions may have partly obtained."†

He concludes, further,‡ that the waters were probably hot; that those which originally deposited the sulphide constituents were probably ascending; but that the ascending waters are chiefly of surface-origin. Therefore, in all these matters, by

---

* This volume, pp. 687, 688, etc.

† This volume, p. 610.

‡ This volume, p. 610.

his exhaustive study of the metasomatic processes in the veins, Dr. Lindgren fully confirms my most fundamental contentions.

It is noteworthy that Prof. Vogt and Dr. Lindgren, with admirable scientific restraint, notwithstanding the beliefs which they hold, discriminate clearly between the few cases in which they have shown a probability that the ores are the products of igneous action and the far more numerous cases in which the evidence of such origin is very scanty or wanting altogether. Says Prof. Vogt:

> "That the ore-deposits first mentioned above, viz., the titanic iron-ores in gabbro, the chromite-occurrences in peridotites, the nickel-pyrrhotite deposits in gabbro, etc., were formed by magmatic extraction, I think I have scientifically proved beyond doubt; and I believe that the magmatic-extraction theory advanced for the cassiterite- and apatite-veins is in its main proposition correct. For the ore-deposits subsequently considered,—the contact-deposits, the pyritic deposits, the gold-veins, silver-lead veins, copper-ore veins, etc.,—the views here offered become confessedly more and more hypothetical. But they have much in their favor; and even if, following in particular the French observers, I have here ascribed to magmatic-extraction too great a significance, I believe, nevertheless, that the hypothesis is worthy of thorough scientific discussion."*

Thus Prof. Vogt recognizes clearly that the attribution of the larger class of these ores to igneous action is purely hypothetical. He fully appreciates that, of the great majority of ore-deposits, he has wholly failed to show that igneous agencies have separated the ores from the original rocks and placed them in their present positions. This connection must be made before the hypothesis advanced by Prof. Vogt can hope for acceptance. Since the majority of the ore-deposits thought by Prof. Vogt to be possibly due to "contact after-action" in some other sense than segregation by underground water differ in no essential particulars as to their character, the minerals they contain, the relations of these minerals to one another, the relations of the ores and minerals to the surrounding rocks, the presence of crustification, and other features, from ore-deposits which many authorities, including Prof. Vogt, recognize as deposited by underground water, I shall hold to the old view that they are the results of water-deposition until evidence is presented showing the contrary. To attempt to prove the proposition that these ores are deposited by water would require the

---

* This volume, p. 658.

repetition throughout of the arguments for such an origin which have been presented during the past half-century by nearly all of the famous men who have discussed ore-deposits. If these arguments are not adequate to convince the reader, I cannot, in closing this discussion, present the case more fully, but must defer the matter until the publication of my treatise upon Metamorphism, in which I consider much more fully the circulation and work of underground water, and the character of the deposits produced by that agent.

If it be recognized that, in the majority of the cases cited by Vogt and Lindgren, the materials of the ores were transported and deposited in their present positions by underground waters, it makes no difference to me whether such ore-deposits be called contact-deposits, hydro-thermal deposits, dynamo-metamorphic deposits, or regional metamorphic deposits, as proposed by Lindgren.*

As I have pointed out,† dynamic action may increase the temperature of the underground waters, and make the conditions much more favorable for the deposition of ores. If in the first part of my paper, discussing general principles, I have not made clear my belief in the extreme efficiency of hot water, as compared with that of cold water, in the segregation of ores, I have failed altogether to convey my ideas. I fully recognize the remarkable relative potency of hot water in all classes of alterations of rocks, including the deposition of ores. I emphasize especially the effect of high temperature, (1) in producing a deeper circulation,‡ (2) in producing a more rapid circulation,§ and (3) in very greatly increasing the power of water to do chemical work of all kinds. For instance, I say:

> "But pure water at a high temperature is a potent solvent. Barus has shown that water at temperatures above 185° C. attacks the silicates composing soft glass with astonishing rapidity. At 180° C. various zeolites can be dissolved in pure water, the material crystallizing out on cooling. Lemberg shows that water at 210° C. slowly dissolved anhydrous powdered silicates. It is therefore apparent that water in the lower part of the zone of fracture is a most potent chemical agent."||

With this conclusion the following quotation shows that Prof. Vogt agrees:

---

* This volume, pp. 730, 731.

† This volume, 304.

‡ *Ibid.*, 298.

§ *Ibid.*, 303–306.

|| *Ibid.*, 308.

> "As is well known, the ionization of water increases rapidly with its temperature. This explains the activity of water at high temperatures. Thus, for example, Barus has shown that water heated above 185° C. attacks the silicates composing soft glass with astonishing rapidity; and an experiment by Lemberg has proved that water at 210° C. slowly dissolves anhydrous powdered silicates."*

Further, I strongly make the point that both the speed of solution and the amount of material which may be taken into solution are greatly increased by high temperature;† and in proof of the efficacy of hot water in the production of ore-deposits, I cite the Cordilleran region of the West‡ as one in which the temperature of the water is higher than normal, and in which ore-deposits are common.

In conclusion as to this portion of the discussion, I would say that, while I think I have given adequate weight to igneous rocks as a source of the ores, and to the resultant hot waters as an agency in their concentration, I have not elaborated that branch of the subject. The reason is, that these ideas are not new, but have been generally accepted for decades by all who have written upon ore-deposits. A complete treatise upon ore-deposits should, of course, give proportional representation to all parts of the subject; but a paper on the subject necessarily covers the new ground most fully; and if, in addition to this, it puts new material in its proper relations and proportions to old material, that is all that can be fairly expected.

I have reserved for separate consideration most of the points raised in Prof. Kemp's paper upon "The Rôle of the Igneous Rocks in the Formation of Veins,"§ with the arguments and conclusions of which I am not in such general agreement as with those of the other papers named. I shall state the points both of agreement and of difference between us; and, I need hardly say, with entire personal esteem and respect for Prof. Kemp. But my position is rendered somewhat embarrassing by the circumstance that this contribution closes the discussion, so far as it is to be published by the Institute in the special volume now in press.

1. From the frequent occurrence of ore-bodies in regions of vulcanism, it does not follow, as held by Prof. Kemp,|| that the

---

* This volume, p. 643. † *Ibid.*, 320, 321. ‡ *Ibid.*, 304, 305.

§ This volume, pp. 681–709. || This volume, pp. 686, 708, 709.

igneous rocks are the sole source, or, in some cases, even an important source of the ores. As pointed out by Prof. Le Conte many years ago, and as shown by me in my paper (*Trans.*, xxx., 91, 92), "the undoubted occurrence of workable ore-deposits in regions of vulcanism may be explained by the heat furnished by the igneous rocks, this promoting the work of the underground solutions." I have already emphasized the enormously increased activity of solutions with rise of temperature. In the neighborhood of igneous rocks the underground solutions are hot, and these hot solutions may, and in many cases, I believe, undoubtedly do, derive a large part of their metallic material from the sedimentary or metamorphosed rocks, although, as indicated in my original paper,* I maintain that probably the ultimate source of all the ores, and very frequently the chief or sole immediate source, has been the igneous rocks.

2. While Prof. Kemp would derive the majority of ores from igneous rocks, he declares† that surface-flows of such rocks are unfavorable to vein-formation. But, to give an instance to the contrary, the Lake Superior copper-deposits were shown by Pumpelly, years ago, to occur in or associated with surface volcanic rocks. I think the true statement is, that in most districts very recent volcanic flows have not had time enough for the development of contained or connected ore-deposits; or else, they have not been eroded deeply enough to expose such deposits, if they exist. But in the San Juan region of Colorado, where denudation has taken place on a vast scale in very late geological time, great ore-deposits do occur in Tertiary volcanic rocks; and it would be rash to say that ore-deposits are not even now forming in the middle and lower parts of the great lava-flows of the plateaus of the West. Indeed, I think it highly probable that such formations are going on, and that at some future period the resulting ore-deposits will be at the surface.

3. In asserting the existence of gradations between pegmatite and quartz-veins, I am glad to find Prof. Kemp in full accord with me. I pointed out such gradations some years ago, and, as already explained, advanced as the explanation that

---

* This volume, pp. 300, 301.

† This volume, p. 695.

water and rock, at sufficiently high temperatures and pressures, are miscible in all proportions.

4. From Prof. Kemp's statement* that "practically all students of volcanic phenomena are agreed that steam and its dissociated representatives in the molten rock are the chief, if not the only, cause of eruption," I must wholly dissent, holding with Dutton and Gilbert† that, in areas of regional vulcanism (which are those containing the most extensive ore-deposits), gravitative stress is the dominant force producing eruption, although it is agreed that steam plays a subordinate part, and an important part in local vulcanism.

5. Perhaps I do not fully appreciate Prof. Kemp's arguments‡ concerning capillary attraction as connected with the movements of underground water. Prof. Kemp says that the imperviousness of strata is partly due to the "feebleness or disappearance of capillary attraction with increase of pressure." On later pages he says: "Whenever, for example, capillary transmission occurs, the previously acquired head is lost, and the emerging water proceeds on its way only under a newly accumulating head." Further, he says that "capillary attraction is largely an ascensive force." I am uncertain whether or not Prof. Kemp intends to imply that I have advocated the view that capillarity is an important force which accounts for the circulation of groundwater in the belt of saturation. As a matter of fact, I have not appealed to the force of capillarity in any way whatever to explain the circulation in this belt. It seems to me that Prof. Kemp has wholly failed to recognize the great difference in the nature and forces which control the circulation of water in the belt of weathering, above the level of groundwater, and the belt of cementation, below that level.§ Above the level of groundwater the force of capillarity is important in the movement of groundwater. This matter I shall discuss fully in my treatise on Metamorphism, but cannot take up

---

* This volume, p. 687.

† "Geology of the High Plateaus of Utah," by C. E. Dutton, *Rept. of U. S. Geogr. and Geol. Surv. of the Rocky Mt. Region,* Washington, 1880, pp. 113–142.

"Geology of the Henry Mts.," by G. K. Gilbert; *Id.*, pp. 66–74.

"Earth-Movements," by C. R. Van Hise. *Trans. Wis. Acad. Sci. Arts and Letters,* vol. xi., 1898, pp. 495–502.

‡ This volume, pp. 699, 701–2, 705, 708. § See my remarks, this volume, p. 327.

here, as it is a complicated one. Below the level of ground-water, the size of the openings, as I have fully explained,* is of very great importance in the movement of the underground water, because friction runs up very rapidly with subdivision of the openings; but how capillarity is a "descensive" or "ascensive" force in this belt, I am at a loss to understand.

6. Prof. Kemp does me an unintentional injustice when he cites me as supporting "the view that hot springs are the result of normal terrestrial circulations, without accessions of heat other than those which would be received through the ordinary increase of temperature with depth."† I refer the increase of temperature of the underground waters to the normal increase of temperature with depth, to *vulcanism, and to dynamic action.*‡ Regional vulcanism and orogenic movements I mention twice as producing high temperature.

7. But I held, and still hold, that difference in temperature of the ascending and descending columns is a cause which works in the promotion of circulation as an adjunct to the main cause, head. Prof. Kemp§ argues against this conclusion in the following way:

> "(3) That water under great load or pressure does not expand according to the 4 per cent. rate named (*i.e.*, 4 per cent. for 100° C.). On the contrary, it may be held by the pressure at fixed volume, despite the added heat. If, for example, we roughly assume a column of water 1 sq. in. in cross-section and 2 ft. high (it is really about 2 ft. 3½ in.) as equal to a pressure of a pound to the square inch, in 10,000 ft. we would have a pressure of something near 5000 lbs., or over 2 tons to the square inch; and in the face of this, the expansion of water from an added temperature of 100° C. practically becomes a negligible quantity as contributing to hydrostatic head."

This argument seems to me to be unsound for the following reasons:

a. Since I emphasize vulcanism and orogenic movements as chief causes of high temperature in underground water, the depth, and therefore the pressure, may be but a small fraction of that assumed by Prof. Kemp.

b. The only experiments which I have found upon the compressibility of water at high temperature are those of Barus,||

---

* See my remarks, *Trans.*, xxx., 40–45.

† This volume, p. 704.

‡ *Trans.*, xxx., 49.

§ This volume, p. 704.

|| "The Compressibility of Colloids," by C. Barus; *Am. Journ. of Sci.*, 4th ser., vol. vi., 1898, pp. 287–289.

in which he finds that the compression resulting from the pressure cited by Kemp is much less than would be necessary to neutralize the expansion due to the heat mentioned.

c. Admitting for the moment that the pressure does neutralize the expansion due to heat, since the pressure is nearly the same upon both the ascending and descending columns, and inasmuch as, under the hypothesis, there is a difference in temperature between the two columns, there would be a difference in density, and therefore a cause for flowage.

8. Upon another point connected with the circulation of underground water, Prof. Kemp says:

> "(4) We must bear in mind also that the standing body of cold groundwater fills the interstices of all rocks near the surface, except those in very arid regions, and exerts a retarding influence on uprising currents."*

I am entirely at a loss to understand how the coldness of the water prevents circulation due to difference in head and difference in temperature of the two columns, except as to an effect which I have emphasized,† namely, that due to varying viscosity.

After the arguments above mentioned, Prof. Kemp says:

> "I regard it as extremely improbable that the water of any natural spring whose flow is due simply to hydrostatic head, has ever reached more than a very limited depth below the point of emergence."‡

We have already found that difference in temperature of the descending and ascending columns are excluded by Prof. Kemp as an effective cause of deep circulation. The force to which he appeals to explain the deep circulation is that which proceeds from the igneous rocks. He says:

> "I will even go so far as to say that it is in the highest degree improbable that any waters which have reached depths even approximating 10,000 ft. can ever again reach the surface and yield flowing springs, except through the propulsion of stores of energy contributed by still heated masses of igneous rock."§

I, of course, maintain that the heat-energy of the igneous rocks passes into and thereby expands the water, thus causing a difference in density between the ascending and descending columns,|| and thereby promoting circulation. But

---

* This volume, p. 704.

† *Trans.*, xxx., 43.

‡ This volume, p. 705.

§ This volume, p. 705.

|| *Trans.*, xxx., 47–49.

Prof. Kemp has just thrown this use of the energy of the igneous rocks out of consideration; and how this energy acts in producing a circulation, unless it be by heating and thereby expanding the water, he does not explain.

9. Prof. Kemp says that "standing water in abandoned shafts is strong evidence of the impenetrability of rocks."* This seems to me untenable. Such standing water has come in either from the surface, or through the "impenetrable rocks." The latter hypothesis Prof. Kemp rejects. But if the former be true, why does not the water rise with periodic additions? According to my view, standing water in shafts, exactly as in wells, indicates the upper limit of the belt of saturation. But the standing water maintains its uniform level (in the absence of pumping) by flowage through the rocks, compensating the local additions or subtractions. Certainly the water standing in the wells of the drift-covered regions of North America does not prove that there is no active underground circulation in the drift.

Passing from specific points concerning the circulation of underground water, I, of course, largely dissent from Prof. Kemp's general view upon this subject, and can only refer to the argument already given in my paper.† If the evidence there presented, showing that the main source of the underground water depositing the ores is meteoric, and not derived from the igneous rocks, as held by Prof. Kemp (but without giving adequate evidence), does not prove the point, it is useless further to discuss the matter here. In my treatise on Metamorphism I shall cover this part of the subject much more exhaustively. While I hold that the main source of the water depositing ores is meteoric, I recognize that another source of such water is the igneous rocks. I say:

> "Also, through the agency of vulcanism, water occluded in magma is transferred from the zone of rock flowage, or even possibly from the centrosphere, to the zone of rock-fracture."‡

Nor am I able to accept Prof. Kemp's statements as to the small amount and local deficiency of groundwater. He says, "In regions when the rainfall is small," . . . . "if the rocks

---

* This volume, p. 709.

† *Ibid.*, pp. 282–334.

‡ *Ibid.*, p. 302.

are shattered, standing groundwater may be entirely lacking."* And again, "The groundwater may entirely fail in arid regions."† I know of no region in the United States which justifies these statements.

While I have never advocated a universal uniform underground circulation, as implied by Prof. Kemp, I have held, and still hold, that the amount of underground water and its circulation is much more general than he believes. This problem may be considered, first, from the point of view of the amount of underground water now present; and second, and more important, the amount of work which has been done by underground water.

Upon the first point, it is contended by Prof. Kemp that the amount of underground water in the belt of saturation is usually small; but in opposition to this view we have the general experience of mining men and of those who by wells seek underground water. While there are notable exceptions, it is in general a difficult and expensive process to lower artificially the level of groundwater which is generally found in both humid and arid regions, though at greater depth in the latter. In the lead- and zinc-districts of Missouri, this operation, called by the miners "beating the water," is usually attempted only by a number of companies, acting jointly, and constitutes the most formidable part of mining-work.

. In Wisconsin, it is a grave hindrance to mining below water-level. The lowering of the groundwater by, say, 50 ft., is an exceedingly difficult task, involving enormous expenses for pumping. The subsequent holding of the water at a given level is much easier, as Prof. Kemp has noted. But my conclusions from these facts are that, in the belt of saturation, the openings are large and the quantity of water is great, but the circulation is, in most cases, not too rapid to be controlled by pumps of moderate capacity—although, in some cases, to hold the water at a given level involves the handling of vast quantities of underground water.

In this connection Prof. Kemp remarks‡ that the circulation at smaller depths than 1500 or 2000 ft. has no bearing on the question of ore-deposition. While a few ore-deposits have

---

* This volume, p. 706. † This volume, p. 709. ‡ This volume, p. 699.

been profitably worked to a greater depth than this, it is well known that probably more than 90 per cent. of the metallic wealth of the earth yet mined has come from above the 2000-ft. level; and therefore there is no warrant for the statement that the circulation above this level is not of vital importance in the production of ore-deposits.

In this matter of depth, Prof. Kemp asserts,* of the general circulation of underground water, that "something like 2000 ft. appears to be its limit;" but the only evidence which he presents upon this point is that in some cases this is the fact. The local instances cited are not, to my mind, proof of such a law. On the other hand, the evidence which I have presented to the contrary is reinforced by the arguments of Prof. Vogt,† which, combining the facts of observed depth of denudation of veins with the likeness of their deeper parts to those parts nearer the surface plainly produced by underground waters, clearly lead to the conclusion that, in many cases, the underground circulation must have been efficient to a depth several times greater than 2000 ft.

On the second point, the work of underground water, Prof. Kemp declares that veins are the exceptional, not the general, work of this agency. He says that while veins occur locally in mining districts, there is a "general absence of veins."‡ If Prof. Kemp means *mineral* veins, this is of course true; but if he means literally what he says (and it is only with this meaning that any argument can be made as to the circulation of underground water), I wholly dissent from the conclusion. In my field-work throughout the United States and considerable areas of Canada I have yet to find a district in which a series of rocks has been in the belt of saturation for a long time geologically in which there are not extensive, metasomatic changes in the rocks, and many veins. For instance, in the Appalachian region, almost innumerable veins, the work of underground water, may be seen from Maine to Alabama; but only very rarely and locally are there important ore-deposits. Therefore the localization of mineral (*i. e.*, ore-bearing) veins gives no information as to the general circulation of underground water.

While I repeat that I have never advocated a universal, uni-

---

* This volume, p. 699.

† This volume, p. 669 *et seq.*

‡ This volume, p. 707.

form, vigorous underground circulation, as implied by Prof. Kemp, I have held and still hold that, almost universally, in those places where ore-deposits occur, a vigorous circulation was going on during the time the ores were deposited; and at the only places of which I know where ore-deposits are now forming, such a circulation is going on. The fact that some areas in which ore-deposits are now worked do not now show a vigorous circulation has no bearing upon the question of the deposition of these ores by underground water. The very process of vigorous circulation by underground water results in the cementation of the openings, as I have fully explained.* In so far as the innumerable openings are filled, and during the process here and there ore-deposits are formed, just to that extent the openings are closed. When the openings have been filled to such an extent that they become subcapillary, circulation practically ceases for the time. But subsequent earth-movements or igneous intrusions may again produce openings in the rocks, and thus a new circulation may be set up. Of course it is well known that in the deep copper-deposits of the Lake Superior region, and at various other localities, as at Przibram, there is not now a vigorous underground circulation. I cannot believe that Prof. Kemp therefore dissents from the conclusion of Pumpelly, Irving, and others, that in the Lake Superior region the deposits of copper in the openings of the conglomerates and amygdaloids, extending to a depth of 5000 ft. or more, are the cementation-result of circulating underground waters. Posepny realized full well that when the ore-deposits were formed at Przibram, there was a vigorous circulation of underground waters at a depth below 1100 meters. With regard to the formation of the deep deposits of Lake Superior, Przibram, and many other localities in all parts of the world, cited by Posepny, in some of which there is now but a feeble circulation, I am but a follower of Sandberger and Posepny and nearly all the eminent geologists who have written upon ore-deposits, in the belief that these ores were put in place by underground waters. In whatever respects I may differ from Sandberger or Posepny, there is absolute identity in our fundamental contention that the great majority of the metallic ores,

---

* This volume, pp. 326–334.

to the greatest depth penetrated by man, were deposited in the places where they now exist by circulating underground waters. Probably Prof. Kemp does not intend to argue, although his reasoning could be so interpreted, that because there is not at present a vigorous circulation where ore-deposits exist, such ores were not deposited by the circulation of underground water.

While it is clear that the underground circulation is much more vigorous and widespread than is believed by Prof. Kemp, and while I first discuss the circulation which would take place in a homogeneous medium,* I follow with what I regard as one of the most essential points of my paper, viz., the elaborate evidence presented of the very unequal and variable character of the underground water-circulation, due to unequal temperature caused by normal increase, vulcanism and dynamic action; the preferential use by water of large channels;† the variation of the rocks in porosity and structure; the complexity and irregular distribution of the openings; the intersections of fractures; the successions of fractures; the impervious strata at various depths; the pitching troughs and arches; etc.‡ Prof. Kemp speaks§ also of the importance of impervious strata in influencing the circulation of groundwater. I have strongly emphasized|| the very profound influence of impervious strata upon the deposition of ores, and have explained that the difference between pervious and impervious strata is that pervious strata have openings of capillary or supercapillary size, while the openings of impervious strata are subcapillary.

The localization of ore-deposits, of which Prof. Kemp speaks,¶ I have shown to be due to the fact that each case of the formation of a deposit "requires the fortunate combination of many favorable factors working harmoniously together, the absence of any one of which may prevent the concentration of the ore-deposit."** Only here and there have existed the remarkable combination of circumstances necessary to form an ore-deposit, and thus once in a million times, or once in ten million times, a vein formed carries a sufficient amount of the valuable metals to be an ore.††

---

* This volume, pp. 306–315. † *Ibid.*, 315–317. ‡ *Ibid.*, 393–427.

§ This volume, p. 699. || *Ibid.*, 396–416.

¶ This volume, p. 708. ** This volume, p. 421.

†† See my article, *Jour. of Geol.*, vol. viii., 1900, p. 753.

Therefore, notwithstanding the contrary belief of Prof. Kemp, I again assert that the deposition of the great majority of ore-deposits—namely, those produced by underground water—is a special case of the general work of underground water, which can only be adequately explained by a profound knowledge of the facts and principles controlling the circulation and work of underground water, and a detailed knowledge of the special modifications necessary to explain the localization and relations of the ores.

In closing this discussion I must express deep gratification for the kindly and appreciative manner in which my attempt to solve some of the problems of ore-deposition has been received by the men who have discussed it. Indeed, the papers of Lindgren, Vogt, Beck and Rickard speak of the paper in a more complimentary way than I could have hoped. When I published it, I anticipated that it would be regarded as too theoretical by geologists who are at work in the field upon the fascinating problem of ore-deposition, and especially by the practical men who are in charge of the development of large mining properties. In this respect, however, I have been wholly mistaken; for the most hearty appreciation which has come to me has been from these two classes of men.

In conclusion, I can only say that I find in the various papers following my own so much which confirms my conclusions (and no reason which appears to me to be sound, advanced against any of them) that, after a careful consideration of all that has been said, I find it unnecessary to modify my paper (beyond the changes in the *Journal of Geology* to which I have referred) either as to statements of facts and conclusions, or as to their proportional importance.

APPENDIX.

SECRETARY'S NOTE.—The amount, variety and value of the contributions made to the science of ore-deposits by the American Institute of Mining Engineers, since its organization in 1871, may be inferred from the list, given below, of papers in its *Transactions* bearing upon that subject. This list does not include the numerous papers on coal, or other non-metallic deposits, such as those of clay, apatite, bauxite, etc. On the other hand, it comprises, besides many treatises directly treating of the formation of ore-deposits, and many generalizations of great suggestiveness as to parts of that field, a large number of studies of single mines or districts, in which geological and mineralogical facts of importance are incidentally reported, though greater space is often given to methods of mining, etc. As a whole, I venture to say, this list presents a mass of careful observations and intelligent deductions which no student of this science can afford to disregard.

Papers in the Transactions of the American Institute of Mining Engineers, Bearing Directly or Indirectly upon the Science of Ore-Deposits.

TITLE.	VOL.	PAGE
The Geographical Distribution of Mining Districts in the United States. By R. W. Raymond,	I.	33
The Origin of Metalliferous Deposits. By T. Sterry Hunt,	I.	413
The Ore Knob Copper-Mine and some Related Deposits. By T. Sterry Hunt,	II.	123
The Formation of Fissures and the Origin of their Mineral Contents. By A. J. Brown,	II.	215
The Magnetic Iron-Ores of New Jersey; their Geographical Distribution and Geological Occurrence. By J. C. Smock,	II.	314
The Ores of Iron; their Geographical Distribution and Relation to the Great Centers of the World's Iron Industries. By Henry Newton,	III.	380
On the Occurrence of the Brown Hematite Deposits of the Great Valley. By Frederick Prime, Jr.,	III.	410
The Cornwall Iron-Mine and some Related Deposits in Pennsylvania. By T. Sterry Hunt,	IV.	319
The Southeastern Missouri Lead-District. By G. C. Broadhead,	V.	100

TITLE.	VOL.	PAGE
A Study of the Specular and Magnetic Iron-Ores of the New Red Sandstone in York County, Pa. By Persifor Frazer, Jr.,	V.	132
The Nickel-Ores of Orford, Quebec, Canada. By W. E. C. Eustis,	VI.	209
The Mesozoic Formation in Virginia. By Oswald J. Heinrich,	VI.	227
The Eureka Lode of Eureka, Eastern Nevada. By W. S. Keyes,	VI.	344
What is a Pipe-Vein? By R. W. Raymond,	VI.	393
Missing Ores of Iron. By Persifor Frazer, Jr.,	VI.	531
The Ore Deposits of Eureka District, Eastern Nevada. By William P. Blake,	VI.	554
The Antimony-Deposits of Arkansas. By Charles E. Wait,	VIII.	42
Silver Islet. By Thomas Macfarlane,	VIII.	226
The Gold-Gravels of North Carolina. By W. C. Kerr,	VIII.	462
The Silver Sandstone District of Utah. By Charles M. Rolker,	IX.	21
Some Copper-Deposits of Carroll County, Maryland. By Persifor Frazer,	IX.	33
The Whopper Lode, Gunnison County, Colorado. By Persifor Frazer,	IX.	249
Auriferous Slate-Deposits of the Southern Mining Region. By P. H. Mell, Jr.,	IX.	399
The Gold-Bearing Mispickel-Veins of Marmora, Ontario, Canada. By R. P. Rothwell,	IX.	409
The Formation of Gold Nuggets and Placer-Deposits. By T. Egleston,	IX.	633
On the Occurrence of Lustrous Coal with Native Silver in a Vein in Porphyry in Ouray County, Colorado. By G. A. Koenig and Moritz Stockder,	IX.	650
Note on Black-Band Iron-Ore in West Virginia. By S. P. Sharpless,	X.	80
The Geology and Veins of Tombstone, Arizona. By William P. Blake,	X.	334
The Gold-Fields of the Southern Portion of the Island of San Domingo. By R. P. Rothwell,	X.	345
The Mines and Mills of Gilpin County, Colorado. By A. N. Rogers,	XI.	29
On the Peculiar Features of the Bassick Mine. By L. R. Grabill,	XI.	110
Notes on the Geology and Mineralogy of San Juan County, Colorado. By Theodore B. Comstock,	XI.	165
The Iron-Ores of the Middle James River. By Persifor Frazer,	XI.	201
Coal and Iron in Alabama. By T. Sterry Hunt,	XI.	236
The Iron-Ores of the Valley of Virginia. By A. S. McCreath,	XII.	17
The Copper-Deposits of the South Mountain. By C. Hanford Henderson,	XII.	85
Geologico-Geographical Distribution of the Iron-Ores of the Eastern United States. By John C. Smock,	XII.	130
Some Canadian Iron-Ores. By Frederick P. Dewey,	XII.	192

TITLE.	VOL.	PAGE
The Pyrites-Deposits of Louisa County, Virginia. By W. H. Adams,	XII.	527
Note on Tantalite and other Minerals, Accompanying the Tin-Ore in the Black Hills. By Charles A. Schaeffer,	XIII.	231
The Vallecillo Mines, Mexico. By Richard E. Chism,	XIII.	351
Geology and Mineral Resources of the Rio Grande Region in Texas and Coahuila. By E. J. Schmitz,	XIII.	388
The Electrical Activity of Ore-Bodies. By Carl Barus,	XIII.	417
The Iron-Mines of Putnam County, N. Y. By Arthur F. Wendt,	XIII.	478
The Iron-Ores of Pictou County, Nova Scotia. By E. Gilpin, Jr.,	XIV.	54
The Geology and Mineral Resources of Sequatchee Valley, Tennessee. By W. M. Bowron,	XIV.	172
The Sulphide Deposit of South Iron Hill, Leadville, Colorado. By Francis T. Freeland,	XIV.	181
The "Centennial" and "Lotta" Gold Properties, Coahuila, Mexico. By Persifor Frazer,	XIV.	196
Note on an Exhibition of Banded Structure in a Gold-Vein. By Charles M. Rolker,	XIV.	265
Notes on Certain Iron-Ore-Deposits in Colorado. By Charles M. Rolker,	XIV.	266
Notes on the Leadville Ore-Deposits. By Charles M. Rolker. (See correction, p. 948),	XIV.	273
Note on the Apatite Region of Canada. By Dr. T. Sterry Hunt,	XIV.	495
The Nova Scotia Gold-Mines. By E. Gilpin, Jr.,	XIV.	674
Geology of the Low-Moor, Virginia, Iron-Ores. By Benjamin Smith Lyman,	XIV.	801
Iron-Ore Deposits of Southern Utah. By William P. Blake,	XIV.	809
The Cornwall Iron-Ore Mines, Lebanon County, Pennsylvania. By E. V. D'Invilliers,	XIV.	873
The Copper-Ores of the Southwest. By Arthur F. Wendt,	XV.	25
Notes on the Geology of the Tilly Foster Ore-Body, Putnam County, N. Y. By Ferdinand S. Ruttmann,	XV.	79
The Genesis of Certain Ore-Deposits. By S. F. Emmons,	XV.	125
The Diamond Mines of South Africa. By Gardiner F. Williams,	XV.	392
Sierra Mojada, Mexico. By Richard E. Chism,	XV.	542
Indicative Plants. By R. W. Raymond,	XV.	645
Mining Developments on the Northwestern Pacific Coast and their Wider Bearing. By Amos Bowman,	XV.	707
The Silver-Mines of Calico, California. By Waldemar Lindgren,	XV.	717
Gold and Silver Mining in Utah. By O. J. Hollister,	XVI.	3
The Old Telegraph Mine, Utah. By G. Lavagnino,	XVI.	25
Notes on the Geology of Butte, Mont. By S. F. Emmons,	XVI.	49
The Association of Minerals in the Gagnon Vein, Butte City, Montana. By Richard Pearce,	XVI.	62
The Rainbow Lode, Butte City, Montana. By William P. Blake,	XVI.	65

TITLE.	VOL.	PAGE
The Chapin Iron-Mine, Lake Superior. By Per Larsson, . .	XVI.	119
Mode of Deposition of the Iron-Ores of the Menominee Range, Michigan. By John Fulton, ...	XVI.	525
The Bedded Ore-Deposits of Red Mountain Mining District, Ouray County, Colorado. By G. E. Kedzie, . . .	XVI.	570
Notes on the Topography and Geology of the Cerro de Pasco, Peru. By A. D. Hodges, Jr., ...	XVI.	729
Notes on the Topography and Geology of Western North Carolina.—The Hiawassee Valley. By Henry E. Colton, .	XVI.	839
Hot Springs Formation in Red Mountain District, Colorado: A Reply to the Criticism of Mr. Emmons. By Theodore B. Comstock, ...	XVII.	261
Notes on the Rosario Mine at San Juancito, Honduras, C. A. By Thomas H. Leggett, ...	XVII.	432
The Copper-Deposits of Copper Basin, Arizona, and their Origin. By William P. Blake, ...	XVII.	479
Ore-Deposits of the Black Hills of Dakota. By Franklin B. Carpenter, ...	XVII.	570
The Distribution of Phosphorus in the Ludington Mine, Iron Mountain, Michigan: A Study in Isochemic Lines. By David H. Browne, ...	XVII.	616
The Ore-Deposits of Red Mountain, Ouray County, Colorado. By T. E. Schwarz, ...	XVIII.	139
The Geology and Ore-Deposits of Iron Hill, Leadville, Colorado. By A. A. Blow, ...	XVIII.	145
The Geological Relations of the Principal Nova Scotia Minerals. By E. Gilpin, Jr., ...	XVIII.	198
Notes on the Geology of the DeKaap Gold-Fields in the Transvaal. By W. H. Furlonge, ...	XVIII.	334
The Association of Gold with Other Metals in the West. By Richard Pearce, ...	XVIII.	447
Gold-Quartz. By W. M. Courtis, ...	XVIII.	639
The Iron-Ores of the United States. By T. Sterry Hunt, . .	XIX.	3
Geological Notes on the Manganese Ore-Deposit of Crimora, Virginia. By Charles E. Hall, ...	XX.	46
The Mount Morgan Mine, Queensland. By T. A. Rickard, .	XX.	133
Notes on the Iron-Ores of Danville, Pennsylvania, with a Description of the Long-Wall Method of Mining Used in Working Them. By H. H. Stoek, ...	XX.	369
The Bendigo Gold-Field. By T. A. Rickard, ...	XX.	463
Zinc-Blende Mines and Mining near Webb City, Mo. By Carl Henrich, ...	XXI.	3
La Gardette: The History of a French Gold-Mine. By T. A. Rickard, ...	XXI.	79
Association of Apatite with Beds of Magnetite. By William P. Blake, ...	XXI.	159
A New Tin Mineral in the Black Hills. By Titus Ulke, . .	XXI.	240
The Late Discovery of Large Quantities of Magnetic and Non-Magnetic Pyrites in the Croton Magnetic Iron-Mines. By W. H. Hoffman, ...	XXI.	513
The Mesabi Iron-Range. By Horace V. Winchell, . . .	XXI.	644

TITLE.	VOL.	PAGE
The Bendigo Gold-Field (Second Paper): Ore-Deposits Other than Saddles. By T. A. Rickard,	XXI.	686
The Cause of Faulting. By John A. Church,	XXI.	782
Notes on the Geology of the Half-Moon Mine, Pioche, Nevada. By Ernest Wiltsee,	XXI.	867
The Biwabik Mine. By H. V. Winchell and J. T. Jones,	XXI.	951
Geological Distribution of the Useful Metals in the United States. By S. F. Emmons. (See Discussion, p. 732),	XXII.	53
The Lead- and Zinc-Deposits of the Mississippi Valley. By Walter P. Jenney. (See Discussion, p. 621),	XXII.	171
On a Remarkable Deposit of Wolfram-Ore in the United States. By Adolf Gurlt,	XXII.	236
The Origin of the Gold-Bearing Quartz of the Bendigo Reefs, Australia. By T. A. Rickard. (See Discussion, p. 738),	XXII.	289
The Bertha Zinc-Mines at Bertha, Va. By William H. Case. (See Discussion, p. 696),	XXII.	511
The Mineral Deposits of Southwest Wisconsin. By William P. Blake,	XXII.	558
The Genesis of Ore-Deposits. By F. Posepny. (See Discussion, p. 587),	XXIII.	197
The Silver-Mines of Lake Valley, New Mexico. By Ellis Clark,	XXIV.	138
The Allotropism of Gold. By Henry Louis,	XXIV.	182
The Zinc Ore-Deposits of Southwestern New Mexico. By William P. Blake,	XXIV.	187
Iron-Ores of East Texas. By W. Kennedy. (See Postscript, p. 862),	XXIV.	258
The Geological Structure of the Ringwood Iron Mines, New Jersey. By Frank L. Nason,	XXIV.	505
Notes on the Structure of the Franklinite- and Zinc-Ore Beds of Sussex County, New Jersey. By William P. Blake,	XXIV.	521
The Ore-Deposits of Butte City. By R. G. Brown,	XXIV.	543
The Nickel-Mine at Lancaster Gap, Pennsylvania, and the Pyrrhotite-Deposits at Anthony's Nose, on the Hudson. By J. F. Kemp. (See Discussion, p. 883),	XXIV.	620
Lead- and Zinc-Deposits of Missouri. By Arthur Winslow. (See Discussion, p. 931),	XXIV.	634
The Mines of the Chalanches, France. By T. A. Rickard,	XXIV.	689
Cinnabar in Texas. By William P. Blake,	XXV.	68
The Tin-Deposits of Durango, Mexico. By Walter Renton Ingalls. (See Discussion, p. 997),	XXV.	146
The Ducktown Ore-Deposits, and the Treatment of the Ducktown Copper-Ores. By Carl Henrich,	XXV.	173
Hysteromorphous Auriferous Deposits of the Tertiary and Cretaceous Periods in New Zealand. By Henry A. Gordon,	XXV.	292
The Form of Fissure-Walls, as Affected by Sub-Fissuring and by the Flow of Rocks. By William Glenn,	XXV.	499
The Gold-Regions of Georgia and Alabama. By William M. Brewer,	XXV.	569
The Geological Structure of the Western Part of the Vermillion Range, Minnesota. By Henry Lloyd Smyth and J. Ralph Finlay,	XXV.	595

TITLE.	VOL.	PAGE
The Present Condition of Gold-Mining in the Southern Appalachian States. By H. B. C. Nitze and H. A. J. Wilkens. (See Discussion, p. 1016),	XXV.	661
The Ore-Deposits of the Australian Broken Hill Consols Mine, Broken Hill, New South Wales. By George Smith,	XXVI.	69
Copper-Ores in the Permian of Texas. By W. J. Schmitz. (See Discussion, p. 1051),	XXVI.	97
Vein-Walls. By T. A. Rickard. (See Discussion, p. 1053),	XXVI.	193
Gold in Granite and Plutonic Rocks. By William P. Blake,	XXVI.	290
Sketch of a Portion of the Gunnison Gold-Belt, including the Vulcan and Mammoth Chimney-Mines. By Arthur Lakes,	XXVI.	440
The Smuggler-Union Mines, Telluride, Colorado. By J. A. Porter,	XXVI.	449
Gold in the Guyanas. By Henry G. Granger,	XXVI.	516
The Ore-Shoots of Cripple Creek. By Edward Skewes,	XXVI.	553
Some Mines of Rosita and Silver Cliff, Colorado. By S. F. Emmons,	XXVI.	773
The Occurrence and Treatment of Certain Gold-Ores of Park County, Colorado. By B. Sadtler,	XXVI.	848
The Occurrence of Gold-Ores in the Rainy River District, Ontario, Canada. By William Hamilton Merritt,	XXVI.	853
The Enterprise Mine, Rico, Colorado. By T. A. Rickard,	XXVI.	906
The Manganese-Deposits of the Department of Panama, Colombia. By Eduardo J. Chibas,	XXVII.	63
The Geology of the Magnetites near Port Henry, N. Y., and Especially those of Mineville. By J. F. Kemp,	XXVII.	146
The Chromite-Deposits on Port au Port Bay, Newfoundland. By George W. Maynard,	XXVII.	283
The Potsdam Gold-Ores of the Black Hills of South Dakota. By Frank Clemes Smith,	XXVII.	404
Some Dike-Features of the Gogebic Iron-Range. By C. M. Ross. (Discussion, p. 978),	XXVII.	556
The Genesis of Certain Auriferous Lodes. By John R. Don. (Discussion, p. 993),	XXVII.	564
The Origin and Mode of Occurrence of the Lake Superior Copper-Deposits. By M. E. Wadsworth,	XXVII.	669
The Kotchkar Gold-Mines, Ural Mountains, Russia. By H. B. C. Nitze and C. W. Purington. (Discussion, p. 844),	XXVIII.	24
Mining Districts of Colombia. By Henry G. Granger and Edward B. Treville. (Discussion, p. 803; see also p. 591),	XXVIII.	33
Kalgoorlie, Western Australia, and its Surroundings. By George J. Bancroft. (Discussion, p. 808),	XXVIII.	88
Notes on the Vein-Formation and Mining of Gilpin County, Colo. By Forbes Rickard,	XXVIII.	108
The Manganese-Ore Industry of the Caucasus. By Frank Drake. (Postscript, p. 841),	XXVIII.	191
Emery, Chrome-Ore and Other Minerals in the Villayet of Aidin, Asia Minor. By W. F. A. Thomae,	XXVIII.	208
Note on Limonite Pseudomorphs from Dutch Guiana. By R. W. Raymond,	XXVIII.	235
The Auriferous Deposits of Siberia. By René de Batz,	XXVIII.	452

Title.	Vol.	Page
The Alluvial Deposits of Western Australia. By T. A. Rickard,	XXVIII.	490
Notes on the Mines of the Frontino and Bolivia Company, Colombia, S. A. By Spencer Cragoe. (Discussion, p. 908; see also pp. 33, 803),	XXVIII.	591
The Superficial Alteration of Western Australian Ore-Deposits. By Herbert C. Hoover,	XXVIII.	758
The Platinum-Deposits of the Tura River-System, Ural Mountains, Russia. By C. W. Purington,	XXIX.	3
The Occurrence, Origin and Chemical Composition of Chromite, with Especial Reference to the North Carolina Deposits. By J. H. Pratt,	XXIX.	17
The Gold-Bearing Veins of Bag Bay, near Lake of the Woods. By Peter McKellar,	XXIX.	104
Notes on the Geology of Sonora, Mexico. By E. T. Dumble,	XXIX.	122
The Rich Patch Iron Tract, Virginia. By H. M. Chance,	XXIX.	210
Modern Gold-Mining in the Darien. Notes on the Reopening of the Espiritu Santo Mine at Cana. By Ernest R. Woakes,	XXIX.	249
The Liberty Bell Gold-Mine, Telluride, Colorado. By Arthur Winslow,	XXIX.	285
Iron-Ores of the Potsdam Formation in the Valley of Virginia. By Charles Catlett,	XXIX.	308
The Copper-Deposits of Vancouver Island. By William M. Brewer,	XXIX.	483
The Mines and Mill of the Atacama Mineral Company, Ltd., Taltal, Chili. By Sidney H. Loram,	XXIX.	488
The Copper Queen Mine, Arizona. By James Douglas. (Discussion, p. 1056),	XXIX.	511
The Peculiar Ore-Deposit of the East Murchison United Gold-Mine, Western Australia. By D. P. Mitchell,	XXIX.	556
The Manganese-Deposits of Bahia and Minas, Brazil. By John C. Branner,	XXIX.	756
Some Principles Controlling the Deposition of Ores. By C. R. Van Hise,	XXX.	27
The Secondary Enrichment of Ore-Deposits. By S. F. Emmons,	XXX.	177
A Peculiar Clastic Dike near Ouray, Colorado, and its Associated Deposit of Silver Ore. By F. L. Ransome,	XXX.	227
Some Notes on the Nome Gold Region of Alaska. By F. C. Schrader and Alfred H. Brooks,	XXX.	236
Notes on the Gold-Mines of Zaruma, Ecuador. By J. Ralph Finlay,	XXX.	248
Gold-Ores of the Black Hills, South Dakota. By H. M. Chance,	XXX.	278
Origin and Classification of Ore-Deposits. By Charles R. Keyes,	XXX.	323
The Clealum Iron-Ores, Washington. By George Otis Smith and Bailey Willis,	XXX.	356
The Cripple Creek Volcano. By T. A. Rickard,	XXX.	367
Geological Relations of the Iron-Ores in the Cartersville District, Georgia. By C. Willard Hayes,	XXX.	403

TITLE.	VOL.	PAGE
The Enrichment of Gold- and Silver-Veins. By Walter Harvey Weed,	XXX.	424
Types of Copper-Deposits in the Southern United States. By Walter Harvey Weed,	XXX.	449
The Oil-Bearing Shales of the Coast of Brazil. By Prof. John C. Branner,	XXX.	537
Metasomatic Processes in Fissure-Veins. By Waldemar Lindgren,	XXX.	578
Notes on the Occurrence of Platinum in North America. By David T. Day,	XXX.	702
The Telluride-Ores of Cripple Creek and Kalgoorlie. By T. A. Rickard,	XXX.	708
An Occurrence of Limburgite in the Cripple Creek District. By E. A. Stevens,	XXX.	759
The Iron-Mines of Hartville, Wyoming. By H. M. Chance,	XXX.	987
The Indicator Vein, Ballarat, Australia. By T. A. Rickard,	XXX.	1004
The Geology and Vein-Phenomena of Arizona. By Prof. Theodore B. Comstock,	XXX.	1038

INDEX.

NOTE.—The names of actual contributors to this volume are set in small capitals, preceding the references to their contributions. References to citations, whether of actual contributors or others, are preceded by the names of the authors cited in lowercase type. For mere allusions, not giving further details, the page-references are printed in brackets.