General Review of United States Bureau of Mines Stream-pollution Investigation*

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(Pittsburgh Meeting, September, 1930)

In 1924, the United States Public Health Service was requested to undertake a special study of stream pollution. The Public Health Service asked the United States Bureau of Mines to take up the study because the training and experience of the personnel of the former was considered not to be as well suited to this type of investigation as that of the Bureau of Mines. Under H. Foster Bain, then Director of the Bureau, field investigations were begun in the spring of 1925. Along with mine-drainage wastes, the problem of gas-house and coke-oven waste was investigated in the laboratory and a method of treatment by sodium hydrate and benzol was found to be promising. The idea was obtained by A. C. Fieldner, chief engineer of the Bureau Experiment Stations, on a trip to Germany in 1924. He saw a practical application of the process, but obtained no information as to definite chemical or mechanical processes. Because of the then pending American patent applications by the German firm, we made no attempt to develop our findings further. Shortly afterward, a similar method of treatment was developed in the United States,[1] and since that time we have devoted our attention entirely to mine drainage. This paper is a presentation of some general facts and information gathered during the past five years on coal-mine drainage.

Scope of Work

There was such a diversity of opinion at the time this work was begun, on the whole subject and apparently so little accurately known, that it was decided to undertake a basic study from which first, certain definite information might be evident, and second, what might be considered

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[1] H. E. Jones: Phenol Recovery Plant Avoids Waste Pollution of Streams. *Chem. & Met. Eng.* (1928) **35**, 215–218.

R. M. Crawford: Elimination and Recovery of Phenols from Crude Ammonia Liquors. *Ind. & Eng. Chem.* (1926) **18**, 313–315, and (1927) **19**, 168–169.

side issues of the original investigation would be suggested for subsequent study.

A stream in a district thought to be representative of those in low to average sulfur bituminous coal fields and another in a high-sulfur district were selected for study. A fair number of factors entered into the tentative selection of such streams, the chief ones, in addition to the presence of mine drainage, being their accessibility and freedom from other industrial or domestic pollution. Fig. 1 shows a typical stream and Fig. 2 a map of a stream that was sampled.

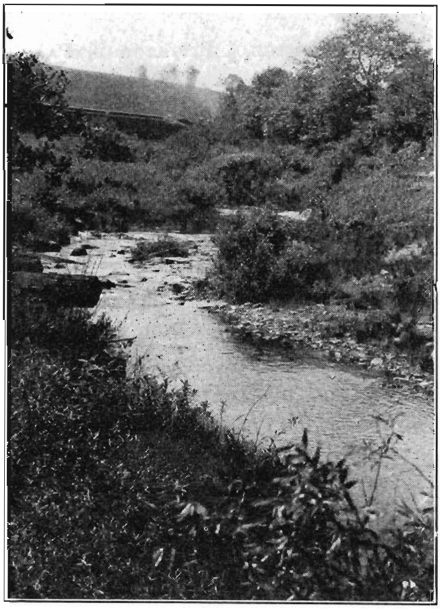


FIG. 1.—A TYPICAL STREAM IN A MINING DISTRICT.

We have attempted to determine the variations of mine-waste waters as to acidity in the two districts, in different mines in the same district, and in different parts of the same mine. We have also attempted to determine the seasonal variations in mine drainage and the resultant effect on streams. Attention was also given to the possibility of sealing abandoned or worked-out mines, or parts of mines and influence of outside "gob" piles. These data were reported[2] by the Bureau of Mines in 1926 and 1928. The apparent recovery of naturally caved mines so far as acidity of drainage is concerned has been treated in *Report of Investigations* 2895, made available in 1928. At present, the relation between the amount and occurrence of pyrite in coal, top and bottom rock and gob material is being studied, both in the field and laboratory.

NON-ACID MINES

It is commonly supposed that coal mines give off acid waste waters. Generally speaking, this appears to be true, but at least one large and important coal area has little acid drainage.[3] Some time ago it was learned that a mine in the Thick Freeport area had no acid water. The main field of the Thick Freeport bed is in Allegheny County, Pennsylvania,

[2] R. D. Leitch: Stream Pollution by Acid Mine Drainage; and Observations on Acid Mine Drainage in Western Pennsylvania. U. S. Bur. Mines *Rept. of Investigations* 2725 (1926) and 2889 (1928).

[3] Unpublished report, U. S. Bur. Mines.

an area roughly rectangular in shape and about 11 by 17 miles in extent. Detached areas are said to be in the vicinity of Argentine and Hilliards in

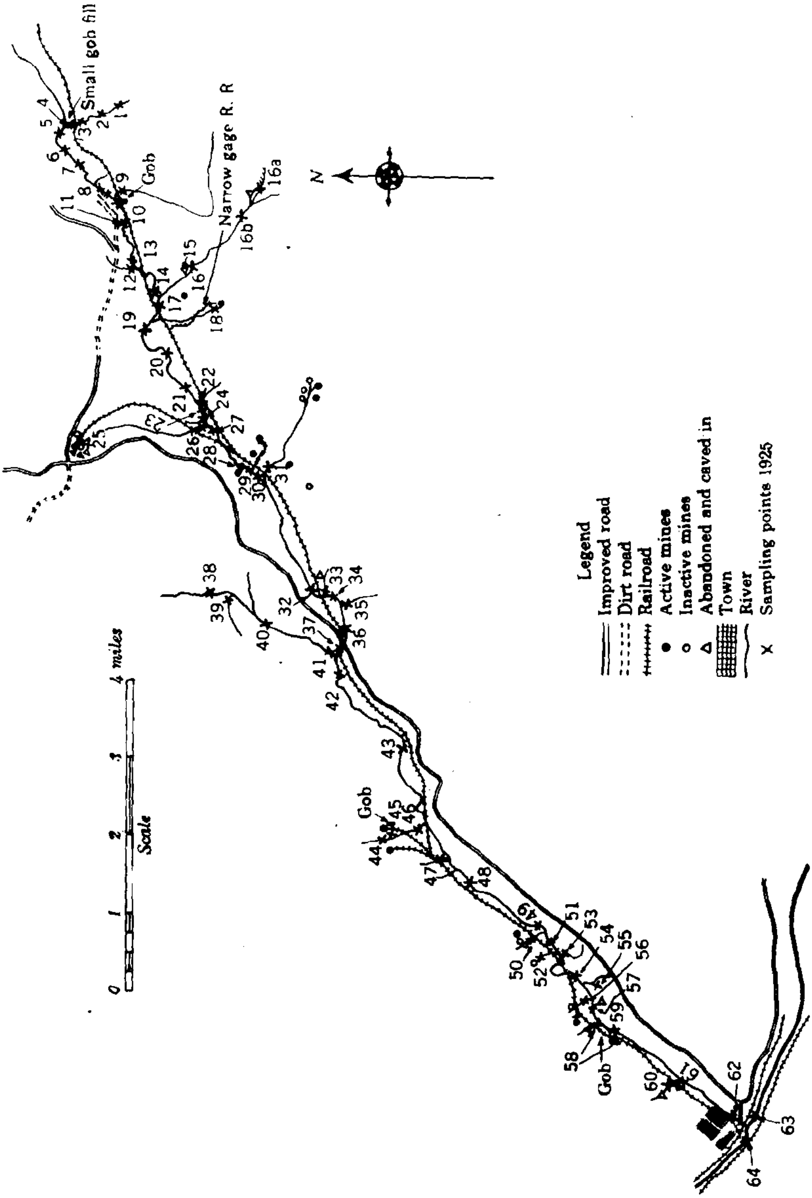


FIG. 2.—MAP OF STREAM THAT WAS SAMPLED.

Butler County, Coral and Graceton in Indiana County, and Derry and Latrobe in Westmoreland County. Most of the mines in the main area and several in detached areas were visited, and samples of coal, top and bottom rock and gob, and water were collected. Of 17 mines so visited and sampled, 6 had no acid water, 6 had both acid and alkaline water, and of those having acid water, only one was strongly so. Many samples were very highly alkaline, drippers especially had alkalinity values as high as 1200 parts per million. This is many times as high as normal surface waters and, as an example, one good stream in southwestern Pennsylvania (Indian Creek) is said to have an alkalinity of 17 to 19 p.p.m. The Thick Freeport bed is a low-sulfur coal and has about 0.6 per cent. of the total sulfur in combination as organic sulfur, which does not enter into an acid-forming reaction. Waters that enter mines in the Thick Freeport bed have an unusually high alkalinity and therefore are able to neutralize considerable amounts of acid or inhibit its formation. There must be a bed of highly alkaline material with which these entering waters have previously been in contact, but core drillings rather widely scattered over the field do not show any unusual conditions other than that the strata are irregular.

In addition to these mines in the Thick Freeport bed, others in Pennsylvania[4] and other states[5] have been found not to have any acid water. Sometimes this is due to limited development and light cover, but there are unquestionably many mines which, for other natural reasons, do not make acid water.

Sealing Mines

During other work we have observed many abandoned and caved mines or otherwise sealed, from which effluent water was either not acid at all or only slightly so. In a few cases,[6] water from such mines has been used as a source of supply for domestic and drinking purposes. Most of these have been in districts and coal beds where water from other adjacent and active or open mines has been acid. There is no proof, of course, that these sealed mines were ever acid, but evidence is strong in support of that condition. From the fact that the accepted theory of acid formation in coal mines requires the presence of water, oxygen and iron sulfide together, it would naturally follow that if any one of these three constituents is absent no acid will be formed. In the past, we have endeavored to find some nearly worked-out mines, so that observations might be made on them both before and after sealing. Such mines must have sufficient cover at all points to prevent breaks to the surface, through which "breathing" might effect a considerable interchange of

[4] R. D. Leitch and W. P. Yant: A Comparison of the Acidity of Waters from Some Active and Abandoned Coal Mines. U. S. Bur. Mines *Rept. of Investigations* 2895 (1928).

[5] R. D. Leitch, W. P. Yant and R. R. Sayers: Effect of Sealing on Acidity of Mine Drainage. U. S. Bur. Mines *Rept. of Investigations* 2994 (1930).

[6] Observation of the writers and information given by other observers.

air, even though the entrances were sealed. It has been impossible, so far, to find suitable mines. In 1928 our attention was called by W. S. Harris, superintendent of the Panhandle Coal Co. at Bicknell, Ind., to a mine in the southern part of that state. He said that water from certain sections of their mine before sealing had been highly acid, as shown by excessive corrosion and consequent replacement of acid-resisting pipe lines and pumps. Shortly after sealing these sections the water was said to have become clear and no repairs were necessary during four years to date. Mr. Harris said that no explanation of these observed facts had been apparent to them until reference was made in the magazine *Coal Mine Management* to a report of the Bureau of Mines in which sealing was advocated to decrease acidity. He was immediately interested in the probable value of the information to the coal industry and asked the Bureau to send a representative to sample water in his mine and observe reported conditions. A visit there verified his statements and a few months later seven other mines in southern Indiana were visited and sampled in a similar way. This work was reported in detail in Bureau of Mines *Report of Investigation* 2994, already cited. Briefly, the results were: (1) that no sample of water from behind seals contained free sulfuric acid and only one had sulfates of iron in solution; (2) every sample in open sections of five mines, of long standing, was acid; highly acid, as a rule. Finally, three of the eight mines visited apparently had no acid water in either open or sealed sections. As a rule, gas samples from behind seals in these mines show the presence of oxygen to be less than 1 per cent. The mines were selected at random and solely upon information from the local district mine inspector that samples of water from both open and sealed sections could be taken in these mines. Three different coal beds were being worked in the group selected. They were all shaft mines from 265 to 315 ft. in depth and had the room-and-panel system of mining.

Laboratory Tests on Iron Sulfide

Laboratory tests have been made[7] using pyrite and marcasite in specially designed and constructed apparatus, which show the marked difference in acid formation as between oxygen and inert gases. In these tests moist air, as well as moist natural gas, was repeatedly passed over the same iron pyrite. The moisture was condensed and acidity determinations were made. Condensate from the moist air tests was invariably highly acid and that from moist gas was extremely low. No particular effort was made to prevent contact with air while washing the samples and replacement in the apparatus prior to making gas tests. The amount of acid formed in the latter was therefore assumed to be due to previous

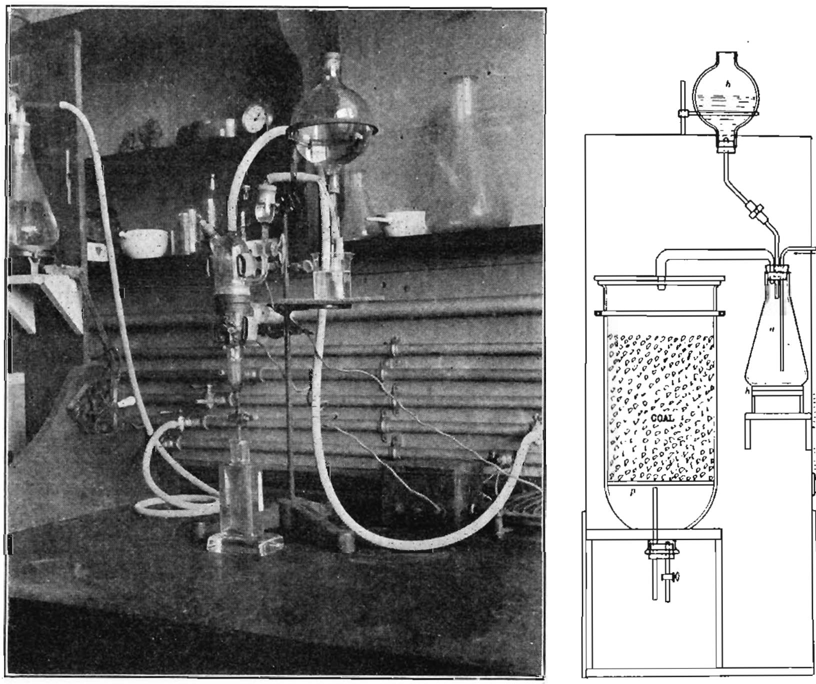
[7] Unpublished reports, U. S. Bur. Mines.

contact with air and possibly (though not probably) to very small amounts of oxygen in the gas, as no attempt was made to remove it, if present.

All of our work points to the fact that, where possible, exclusion of air from mines or parts of mines will result in preventing formation of acid. Fig. 3 shows the laboratory apparatus.

Effect of Mine Drainage on Fish

In many ways a consideration of the effect of acid mine drainage on fish has no place in this discussion; at the same time, and realizing the presence of many sportsmen in the mining industry, it has been thought



a *b*

Fig. 3.—Apparatus for oxidation of iron pyrite.

of enough interest to include references thereto. Also, various organizations of sportsmen have naturally the greatest interest in mitigating stream pollution in general and at present mine drainage in particular.

There is a general lack of knowledge as to just how fish are affected by acid drainage or how much can be tolerated by them. Communications from Fish and Game Departments of several states, the United States and Canada, are in general agreement that more than four parts per million of mineral acids will kill trout and that this fish is less resistant to pollution than any other. Carp and bullheads are most resistant, with the so-called game and pan fish occupying various places between these extremes.[8] A lack of oxygen can and does kill fish, as well as direct toxic effects of the polluting substances.

Laboratory experiments have shown that one volume of water having an acidity of 1000 parts per million caused by the addition of ferrous sulfate can reduce the dissolved oxygen saturation value of from four to five volumes of pure water to zero. Field observations[9] have shown that entry of mine drainage into a stream having an oxygen saturation value of 40 per cent. can reduce the whole to a value lower than 30 per cent. Although rapidly flowing streams can quickly build up a reduced oxygen value if uncontaminated further, the temporarily lowered value may kill fish. Our work, however, has shown[10] that fish most likely are killed by the irritating effect of acid on the gill follicles, rather than by any lack of oxygen.

It has also been shown by Wells, Forbes and Richardson[11] that deposits on the bottoms of streams as a result of previous pollution of various kinds inhibits fish propagation by disturbance in egg laying, even though the water alone may be entirely suitable. It is problematical, therefore, whether the purification of streams once polluted will make them suitable for fish life for an indefinite period.

Mines Ordered Sealed

The so-called Indian Creek case in Fayette County, Pennsylvania, has attracted wide attention and is perhaps familiar to most coal-mining men in this district. Reference to it is made, however, to illustrate the seriousness of the mine-drainage problem in certain instances at least.

In 1927, a court order was issued enjoining 29 operating companies in Indian Creek Valley from permitting mine drainage to enter the waters of Indian Creek above the Pennsylvania Railroad Company's dam. This came as a final result of about seven years of legal battles through the courts of the state, in which there was some of the best legal talent on both sides and volumes of expert testimony were introduced, both for and against the mine-drainage question. For some months prior to the final settlement, three of these companies operated chemical treatment plants, where drainage from their mines was treated with sufficient lime to neutralize the acidity of the water. Subsequently, the iron was removed by allowing the treated water to stand in shallow ponds for several

[8] M. M. Wells: Reactions and Resistance of Fishes to Carbon Dioxide and Carbon Monoxide. *Bull.* Ill. State Lab. of Natural History (1918) **11,** 557.

S. A. Forbes and R. E. Richardson: Some Recent Changes in Illinois River Biology. *Ibid.* (1919) **13,** 139.

[9] Unpublished report, U. S. Bur. Mines.

[10] B. G. H. Thomas: unpublished report, U. S. Bur. Mines.

[11] Reference of footnote 8.

hours, to settle out as iron hydrate. While satisfactory so far as producing a clear and alkaline effluent was concerned, the process was said to be expensive and caused no little trouble. By so treating the drainage, these companies hoped to have the court decide that they were not putting mine drainage into the streams. Most of the smaller companies made no attempt to keep drainage from the streams, and some months later all were cited for contempt of court. During the hearing in contempt proceedings, a combination drainage tunnel and flume for directing the

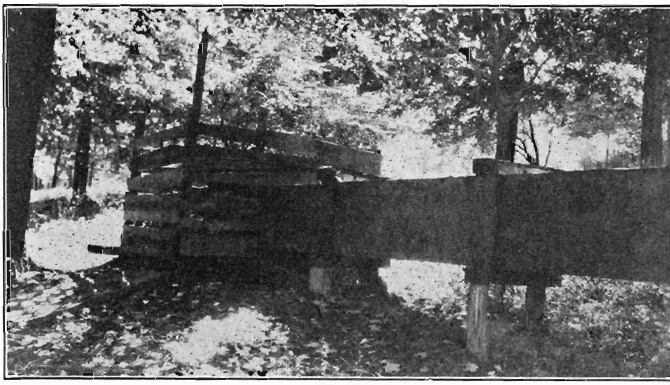


FIG. 4.—CONNECTION BETWEEN DRAINAGE FLUME AND TUNNEL NEAR INDIAN CREEK.

mine drainage into Indian Creek below the Pennsylvania Railroad dam was decided upon as the best solution of the problem. Four companies undertook the construction and financing of the drainage project and it was completed about a year later. At present, this scheme comprises tunnels that total 4 miles in length and flumes above ground of more than 2¾ miles (Fig. 4). For the tunnel, nearly 3 miles had to be driven especially for the purpose, and the remainder was mine entries previously driven in regular mine operations. Needless to say, this work was expensive and requires more or less constant attention. The writers have been told that, as compared with continued operation of chemical treatment plants already installed, the drainage tunnel was considered the more desirable of the two schemes for disposal of acid waste, even though the court had permitted the former to be used.

With the exception of four companies who were financially able to enter this disposal scheme, most of the companies in the valley had to seal their mines or submit to having sealing done by the sheriff of Fayette County. Bills for the work were submitted to the companies later. As a result, much trouble and bitter feeling were caused by the situation.

A few of these mines so sealed have been visited at intervals by one of the writers to see whether water continued to flow therefrom, and if so, whether the acidity and volume decreased. Of the eight so noted, sealing seems to have resulted in completely stopping the water after a period of four years from three of them, and in two others at least in the dry season. In the remainder, the volume of water seems to have decreased markedly and in those from which water issues from behind the seals, acidity has markedly decreased.

This litigation in Indian Creek Valley is thought to be the first and to date the only one of importance where a decision has been rendered against the mining companies. Not a few similar suits have been entered and after the decision described, the local press contained a number of notices of others entered or about to be entered. It was shown during court testimony that about 75,000 people were dependent on the reservoir of the railroad company for a domestic water supply, and this fact is generally admitted to have been the deciding factor in the court's order. Nevertheless, it has established a precedent of considerable importance in the problem as a whole.

Interest of Water-supply Companies

The whole subject of stream pollution is of paramount interest and importance to water companies. In thickly settled regions, the necessity of constant, close and intelligent supervision of treatment of waters for domestic use is a problem which most people do not realize. Water purification, both chemical and bacteriological, has so far advanced in recent years that in spite of enormously increased difficulties due to volume and variety of polluting materials, most of us receive, without interruption, a product well suited to our needs. The processes used in water purification are of necessity so delicately balanced that a relatively slight change in composition of many raw water supplies results in a great change in the method of treating it. At best, this requires some time and unless applied quickly, therefore, the change may result in entirely unsuitable water. Processes have been developed to care satisfactorily for the polluting materials that do not greatly vary in amount or composition. Acid wastes, however, are generally not of this class and fluctuations in their volumes and strength may cause great trouble in water purification, especially in streams near a point that normally is neutral. The increased cost of water purification is by no means an insignificant matter, but even that is secondary to the problem of satisfactorily handling fluctuations in composition of the raw water in many localities today. It may be well to add here that although acid water may be neutralized, a water of correspondingly increased hardness is the result. This water may next be softened, but if the original acidity is above a certain and by no means an impossibly high value, softening does not end the problem. The amount and nature of chemicals so used that remain in solution cause "foaming" or "priming" in boilers.

Therefore, it should not be assumed that chemical neutralization of mine water is a final solution of the problem, even if practicable financially and mechanically.

Sources and Variations of Acid Mine Water

The accepted theory of acid formation in coal mines is first an oxidation of iron pyrite, commonly known to miners as "sulfur." This results in iron sulfates, which are readily soluble in water as opposed to the original pyrite. Subsequent oxidation and hydration result finally in the formation of varying amounts of iron oxide, commonly known as "sulfur mud" and definite amounts of free sulfuric acid.

Pyrite occurs in widely varying forms and quantities in coal, also in top or bottom strata. As a rule, bottom coal and fireclay immediately beneath the coal have the highest percentages of pyrite. Not infrequently, top strata or coal also contain relatively large amounts of pyrite. These conditions seem to remain fairly constant for the different coal beds, but wide variations are to be noted in different sections of the same mine. As might be expected, therefore, the acidity of water may and usually does vary considerably in different mines in the same bed and even in different parts of the same mine.

Old, worked-out sections of a mine are almost invariably the sources of the most acid water and information from many mining men seems to indicate that pillar drawing generally results in increasing the acidity of water as noted by its color and corrosive effect on metals later. While the coal itself no doubt contributes to general acidity, it is by no means certain to be the deciding factor. In some mines crystals of iron sulfate have been observed on the face of coal *in situ* in considerable quantities, and in one in particular these crystals were said to work out of the ribs sufficiently to fill up rooms and entries. This extreme condition was indicated by piles of the crystals observed along ribs in the sections visited, from a few inches to 24 in. in depth. Analyses showed the material to be almost chemically pure ferrous and ferric sulfate in about equal proportions. On the other hand, as mentioned before, the most acid water is generally observed to be coming from sections long since worked out and here the acidity is certainly not due to the presence of coal. Likewise, in strip pits from which the coal has already been removed (and cleanly) we have observed the most acid water of a dark brown color.

Effect of High Pyritic Content

Recently, we have been studying mines known to be situated in areas having a high pyritic content. Previous work has shown that some of these give off highly acid waters. Theoretically, at least, all should be similar in this respect. Generally speaking, this has been found to be true in a preliminary survey and the effluent has usually been from two to five times as high in acidity as is generally considered average acidity. Three of the total of 31 mines visited had water coming from them which was not acid. No doubt later and detailed information will offer an explanation for this fact.

Effect of Outside Gob Piles

Outside gob piles are believed to be an important contributing factor in the general problem of stream pollution. Almost invariably they are composed largely of the pyrite thrown out when mining or cleaning coal. They are exposed to the most favorable conditions for acid formation so far as contact with moisture and air is concerned and thus the three factors necessary in the reaction are present. As a rule, water is trickling from these refuse piles, and when pools of water can collect around them, this water is invariably highly acid. Not infrequently they are thrown across or built out into natural streams, and in such instances samples of the stream taken immediately above and below these piles often show a marked difference in acidity.

Conclusion

We have attempted to touch briefly on many phases of the general subject of mine-drainage stream pollution in so far as the Bureau of Mines work has brought the questions to light. Almost any one of these properly requires a separate paper, but if time is available and there is particular interest in some one of these various phases of the work, perhaps it will be more profitable to emphasize this in subsequent discussion.

The authors wish to express their appreciation of the cooperation of those members of the mining industry and others who have in many ways assisted in the progress of the investigations herein reported.

DISCUSSION

(S. A. Taylor presiding)

R. D. Hall, New York, N. Y.—I note that on page 140 Mr. Leitch states that several mines are alkaline in their characteristics and that the mines mentioned are all in Pennsylvania. More numerous and more striking examples doubtless could be found by studies in certain other states. In Alabama, for instance the water that leaves the coal washery does not kill fish, and often the fish in the dams which have been erected to receive this water have multiplied to such a degree they have become a nuisance. This happened with water from the washeries of the Tennessee Coal, Iron & Railroad Company. I am told that many of the mines of West Virginia have more or less alkaline water. The water there usually does not carry sulfur mud. I am disposed to believe that Pennsylvania, Illinois, Indiana and Ohio mines produce more acid water than the mines of other states.

There are two kinds of coal, designated by the geologists "paralic" and "limnetic" coals. The limnetic type is coal produced from peat which was near the sea level. Consequently the seams or the measures interstratifying them were frequently invaded by the sea. As a rule the coal contains much pyrite as a result of that invasion.

The paralic coal is the coal laid down on higher ground. In many cases it rests on and is surmounted by arkosic sediments; that is to say, by sediments which contain many of the original materials out of which this earth was built. They were the result of the erosion of unchanged or little changed igneous materials. There are such coals all along the Allegheny front.

In the anthracite region the coals are paralic in the sense that they were too far above sea level when deposited to be invaded by the sea and in a degree also in the sense that the sediments which underlay and overlay them were composed of more arkosic material than the sediments of the bituminous region.

Nevertheless there was enough sulfatic material from the Mississippian measures to give the waters of the anthracite region an acidic, usually a strongly acidic, character, the folding in many places raising the Mississippian with its marine beds above the level of the Pennsylvanian. This folding doubtless came largely after Pennsylvanian time, nevertheless it had its effect on the coal measures, the waters from eroded Mississippian beds percolating through the cracks in the shrinking peat.

However qualified may be the arkosic character of the anthracite measures, the southern part of the Appalachian uplift did afford this material, and for that reason the waters that come from the mines in that section do not exhibit the acidity manifested by the coals in the State of Pennsylvania. People have rather exaggerated the general acidity of mine waters, because they have taken their evidence exclusively from the states mentioned—Pennsylvania, Ohio, Indiana and Illinois.

I do not believe that this acidity is a serious problem in Europe. Great Britain, I understand, is fairly, if not entirely, free of it. There is—as one authority who has made many experiments asserts—a soda complex in the roof which is more active than the lime complexes which we find in the states that I have mentioned, and therefore more capable of reducing the acidity caused by the oxidation of the pyrite. Out West also the waters are not of the same character as in the states named.

G. S. Rice, Washington, D. C.—My observation is that Great Britain and the Continent do not have the problem of acid mine water which confronts mining men in some districts of the United States, for two reasons: (1) Coal measures of the Carboniferous age generally contain a large amount of interbedded shales and clays which are practically impervious to water, as in the Illinois longwall district where in some instances the mines have had less than 100 ft. of cover under streams and water-bearing strata, yet are perfectly dry; (2) in European mines the depth is much greater, so that most of the mines of the present time are deeper than 1200 ft. Usually they are overlain by shales and also surface clays or marl deposits, therefore, except in the vicinity of geologic faults, water does not enter into the mines except as it may come down from the old mines at the outcrop.

My observation has been that mines of England and Europe are dry at the faces. A large amount of water may come in through a shaft or at a fault but this has not come in contact with pyrite or sulfides and hence is not acid.

I had occasion to make a formal inquiry and found that there have been few instances in which the acidity of the mine water has been important.

A. B. Crichton, Johnstown, Pa.—I had to do with the Indian Creek litigation referred to. At that time the Pennsylvania R. R. wondered what the situation was in Great Britain and parts of Europe, and what they did there. I made a hurried investigation in Great Britain, and found that their waters were mostly alkaline, and any that were acid were very slightly acid. It was thought that this was due to the thick chalk formation overlying the coal, which greatly increased the alkalinity of the ground waters before they reached the coal.

As Mr. Rice has said, the coal seams are very deep and less of the percolating water reaches the deeper mine workings. There is not as much mine water as in the mines of this country, and as most of the mines are near the coast, mine-drainage stream pollution would never be the problem it is in this country. Many of the mining plants use, without trouble, untreated mine water in their steam boilers.

Mr. Hall may be interested in hearing that the mine drainage of the northern West Virginia mines is highly acid, although in southern West Virginia it is less acid, due perhaps to the lower sulfur coals.

Some years ago I thought that mine-drainage stream pollution was one of the most serious problems confronting the coal industry. But since we have been discussing the economic situation through which we have lived during the past eight years or so, I would say now that it is next to the most important question, or perhaps the third most serious problem. But the thing that concerns me is that no satisfactory solution of the problem has been found.

The attempt to treat the mine water with lime in Indian Creek Valley caused so much sludge that it was impossible, or almost impossible, to handle it. It is a slimy yellow mud, too thin to shovel and too thick to pump. I think the reason the tunnel was finally decided upon as the most feasible plan for keeping the mine water out of Indian Creek was that the lime treatment was not satisfactory in method or results. This treatment was no cure, as it made a very hard water, and after this expense it was yet unfit for any use. When water contains 15 grains per gallon of acid sulfates it cannot be treated satisfactorily, and usually there is a comparatively short time between the time it begins to need treatment and the time at which it becomes unfit for treatment.

It becómes a serious problem for Pittsburgh and other cities along the Allegheny and Monongahela rivers. With increasing quantities of mine drainage being dumped into the rivers and their tributaries, because of the increasing coal development, their future water supply for domestic and industrial needs seems in danger. This year, the river waters have been acid a large part of the summer, seriously affecting river transportation. The river water has been unfit for boiler use, and is attacking the boats and barges.

Sealing abandoned mines, which we did find fairly satisfactory in Indian Creek, has been referred to here. Some of the mines that went to the dip from the openings were not so hard to seal up, and in that event only the main openings were sealed at outlets. In a mine at the upper end of Indian Creek Valley, where the coal measures went to the rise about 8 or 9 per cent. from the drift mouth, and where sealing could not be expected to shut off the water, we closed all openings around the crop, sealing off the air with fairly satisfactory results, as the acidity has been considerably reduced. The fish in Indian Creek at one time were killed for several miles below the opening, but that stream is clear now. The same thing is true in most of the other mines sealed,—the acidity has been reduced and the quantity of water flowing from the mines has been lessened, in some cases stopped entirely.

R. D. Leitch.—A short distance north of Pittsburgh, in the Thick Freeport area, out of 17 mines investigated, 6 were found not to have any acid water, 6 had both acid and alkaline waters, and of those having acid water, only one was strongly so. A partial explanation of these facts, without doubt, is that the water coming into the mines in the Thick Freeport bed is of an unusually high alkalinity. I found many samples ranging from 800 to 1200 parts per million. A normal, pure surface water, taking Indian Creek as an example, generally runs from 17 to 19 parts per million. That gives an idea of what surface waters are. There are waters coming into the Thick Freeport area having an alkalinity of at least 810 parts per million, and they are able, therefore, to neutralize considerable amounts of acid when formed or to prevent such formation. At the same time the Thick Freeport bed is low in total sulfur and considering that about 0.6 per cent. of it is organic sulfur, which cannot enter into an acid formation, there is not much pyrite left to form acid. But of course the highly alkaline water coming in is the explanation.

R. D. HALL.—What is the character of that alkali?

R. D. LEITCH.—The water is a so-called "bicarbonate" water; that is, it contains relatively large amounts of sodium and potassium bicarbonates, and carbonates as well.

A. B. CRICHTON.—I would like to add a word to what Mr. Leitch has said about the tunnel and the gob piles in Indian Creek. Even after taking that half million or million gallons of mine drainage out of Indian Creek and sealing up the mines to which reference was made, the stream water above the dam was hardly different from its condition before treatment was given, and in my opinion this can only be attributed to the natural increase of water from these gob piles in recent developments. There is no doubt that the gob piles caused a great deal of acid in the streams.

C. W. GIBBS, Pittsburgh, Pa.—I think we must be operating one of the mines that had both acid and alkaline waters. Two or three years ago we were shut down from active operation for about a year and a half during reconstruction of the tipple and bottom. Prior to that time we could put in any kind of pipe and it would last indefinitely, but since the shutdown we have had all sorts of trouble with acid condition, especially in one section.

R. D. LEITCH.—It is probable that the water in those sections had an opportunity to come in contact with air, which might have resulted in an increase in free acid content.

C. M. LINGLE, Nemacolin, Pa.—Have any of your investigations been of coal seams above which is a thin seam of low-grade iron ore?

R. D. LEITCH.—I have had no experience of that kind. In fact, I do not know where to go to find mines of that kind. I think such deposits of iron would not determine whether the drainage, or even entering waters, would be acid or alkaline.

R. D. HALL.—The water in the Van Lear mine of eastern Kentucky was relatively alkaline, yet there the roof contains large quantities of carbonate of iron. Though there are exceptions not far from the line, the mines along the Appalachian front, south of Mason and Dixon's line, rarely have any trouble from acid water. Most of them use steel pipe exclusively. Probably the presence of carbonate of iron makes little difference. It can be found in the B seam of Pennsylvania, where the worst kind of acidic water is produced.

R. D. LEITCH.—Iron is found in the form of iron carbonate or bicarbonate. If it is not present in connection with coal deposits in the form of pyrite, the sulfates of iron are not formed and subsequently sulfuric acid, although the yellow precipitate of iron oxide often is present. This often leads observers to believe that the waters from which it has been deposited are acid, but this is not always true.