UNION OF SOUTH AFRICA

DEPARTMENT OF MINES AND INDUSTRIES

GEOLOGICAL SURVEY

MEMOIR No. 12

ASBESTOS IN THE UNION OF SOUTH AFRICA

BY

A. L. HALL, B.A., F.G.S. (Assistant Director)

Printed by authority of the Honourable the Minister for Mines and Industries

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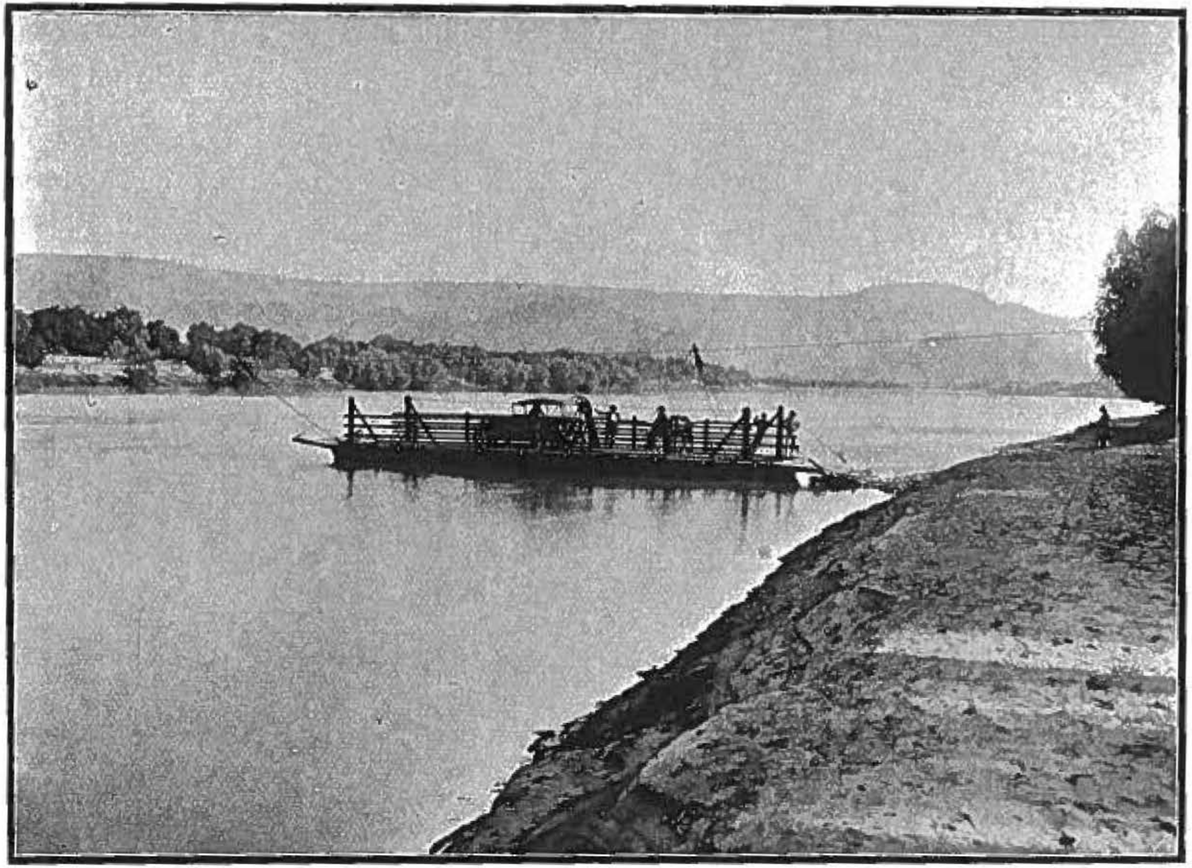

Plate I (FRONTISPIECE).—*Looking down the Orange River, near Koegas;* in the background the crocidolite carrying hills of the Lower Griqua Town Series in Griqualand West.

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Geological Survey,
Department of Mines and Industries,
Pretoria, 15th August, 1918.

THE SECRETARY,
DEPARTMENT OF MINES AND INDUSTRIES,
PRETORIA.

Sir,

I have the honour to forward the manuscript of a Memoir on the Asbestos Deposits of the Union, written by Mr. A. L. Hall.

The rapidly growing output and local use of asbestos, due chiefly to recent exploitation of the extensive deposits of the Transvaal, rendered the publication of the Memoir very desirable. The facts described in it should remove doubt as to the permanence of the supply of certain varieties and encourage manufacturers to provide machinery to deal with asbestos of a length to which they are unused.

There is also much information in the Memoir on the mode of occurrence of asbestos interbedded with sediments of peculiar character, which is of very considerable scientific interest.

I have the honour to be,
Sir,
Your obedient Servant,

ARTHUR W. ROGERS,
Director, Geological Survey.

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INTRODUCTION.

Among the numerous far-reaching effects of the present world situation, not the least important has been the increased activity in the development of the natural resources of many countries. In a young dependency like South Africa this stimulus is likely to be specially felt. The opening up of new markets, readjustments of the conditions of supply and demand, the closing of established sources, and other economic factors have directed keener attention to the resources of our sub-continent, and the notable impetus to industrial developments recently manifested in many fresh directions is a wholesome sign of the times. In the domain of mineral resources the more energetic search for new deposits of economic use and the more vigorous exploitation of known ones are bearing good results. Under these circumstances the South African asbestos industry is acquiring increased importance.

The object of the following pages is to give a connected review of the present state of our knowledge regarding the various kinds of asbestiform minerals within the Union, their mode of occurrence, distribution, and comparative value of different varieties in the industrial applications of the raw material. Recent discoveries in the Transvaal have yielded new varieties of asbestos of remarkable fibre-length and in large quantities, so that South Africa now holds the world's record in the variety and length of fibre, as well as in the proportion of spinnable deposit; very little information of these new fields has hitherto been available.

In case of the Transvaal the asbestos fields were examined in the course of the writer's general geological survey of the areas concerned during 1907, 1908, and 1913, but the more recent opening up of new fields provided the opportunity for an examination of all fibre areas during 1917.

The geology of the Cape Asbestos belt has been investigated by the late Geological Commission of Cape Colony, and, with these results as a basis, the more important workings of that Province were visited by the writer during 1917 and 1918, and in the present year the Natal occurrences were also examined, but fibre deposits of economic possibilities have not so far been recorded from the Free State.

The literature bearing on South African asbestos occurrences is very meagre. The oldest and best-known developments are those of blue asbestos of the Cape, referred to in the Annual Reports of the Geological Commission of that Province; in 1906 the Carolina chrysotile fields were examined by Dr. Humphrey without his results being published. In 1907 and 1908 the new variety of long fibre iron amphilde—described below as amosite—was located during the geological survey of the Lydenburg and Pietersburg Districts, and its existence is referred to in the Annual Reports for those years. The Carolina fibre belt formed part of the survey of the country north-east of Carolina, of which an account is given in the Annual Reports of the Geological Survey of the Union of South Africa for 1913. Mr. Frood, Inspector of Mines, Bloemfontein, in the Annual Report of the Government Mining Engineer for 1915, has contributed a valuable discussion of the economic aspects of the Cape Asbestos industry, and the *South African Journal of Industries* for November, 1917, includes an account by Dr. Wagner of the industrial features of South African asbestos.

As regards chrysotile, the extensive memoir by F. Cirkel, which contains, besides a full description of the Canadian fields, much other useful information, remains the standard work, and no apology is needed for making a full use of this publication.

The disposal in the world's market of asbestos from new fields meets with a good deal of competition, so that a general knowledge of the industrial factors governing foreign sources is very desirable ; this information is supplied in a concise form in Dr. Wagner's article referred to.

The author desires to gratefully acknowledge the valuable assistance received from Mr. T. H. B. Wayne, Mr. Olds, Mr. Grimley, and Mr. W. Macbean, while his special thanks are also due to Mr. Jones, manager of the Egnep and Amosa Mines ; Mr. Trevor, Inspector of Mines, Pretoria ; Mr. Frood, Inspector of Mines, Bloemfontein ; Mr. W. H. Addison, manager of Northern Asbestos Co. ; Mr. Campbell, Krantzkop ; Mr. Vaughan, Inspector of Mines, Maritzburg ; Dr. Wagner, Mr. S. Weingarten, Mr. A. von Dessauer, Mr. Harris, Mr. Neil MacLeod, and Mr. Hedges, Deputy-Commissioner for Mines for Natal.

A bibliography of the more important literature on asbestos is given at the end.

CHAPTER I.

VARIETIES AND PROPERTIES OF ASBESTOS.

THE natural occurrence of a substance combining the valuable property of incombustibility with a very finely developed fibrous structure has been known for a very long time. The Romans obtained a supply from the Italian Alps, and even from the Ural, under the name of "Amianthus," then regarded as of vegetable origin, and worked up into cremation cloths. In the thirteenth century another fibrous mineral resembling Italian amianthus was spun into cloth in Siberia. The property of incombustibility was also made use of for lamp wicks, according to Plutarch, but the knowledge of such a valuable deposit seems to have been lost, and its commercial applications were reserved for modern times; probably the first step in this direction was the establishment about 1760 of a factory for the manufacture of asbestos articles in Russia, which did not long flourish on account of the few uses then known and the consequent small demand.

Serious attempts at establishing the economical exploitation of asbestos began some fifty years ago, and the successful invention of mechanical devices for the adaptation of the mineral for manufacturing processes of spinning, etc., soon led to a rising industry, to which the discovery of the extensive Canadian chrysotile fields of the Quebec Province contributed in no small degree. A considerable number of localities were discovered in other parts of the world yielding chrysotile and other fibrous minerals of asbestiform characters. In the latter respect South Africa has come well to the front with its extensive belt of crocidolite asbestos of Cape Colony, while during the last three or four years enormous quantities of amosite—an ash-grey amphibole asbestos of exceptionally great fibre length—have been proved in the Transvaal and extensive deposits of chrysotile opened up in Rhodesia, so that it remains to be seen how long the predominant share of Canada in the world's output will be maintained.

VARIETIES OF ASBESTIFORM MINERALS.

The property of assuming a fibrous growth is exhibited by a large number of minerals, but there are great differences in the degree of perfection which this mode of growth may attain. In some cases a limit is soon reached in attempting to isolate thin strands from a lump of fibre; in others there appears to be no limit of fineness, so that in the case of the best chrysotile a real single fibre has never yet been isolated, since microscopic examination under the highest magnification possible still indicates compound growth. Very fine fibres are essential from a commercial point of view, and when a high degree of infusibility is also required, the possible range of minerals is still further restricted.

The term "Asbestos" may be translated as "Non-burnable," but this quality is not exhibited in all asbestiform minerals to the same degree. All these fibrous minerals belong to the two groups amphibole (hornblende) and serpentine, and, broadly speaking, the term "Asbestos" includes all fibrous varieties of these groups, but some lack of precision in nomenclature exists in practice. Strictly, the use of the term "Asbestos" should be confined to the amphibole minerals, though it is often applied to fibrous serpentine as well; the name, "Chrysotile" or "Chrysolite," is universally understood to refer to the serpentine variety only.

In the trade the terms "Blue Asbestos" or "Cape Blue" are used with reference to the pale lavender blue soda amphibole crocidolite, in the supply of which South Africa occupies the leading position, while the term "White Asbestos" covers the white chrysotile or serpentine asbestos. Though this distinction is well recognized in the industry, it does not correspond to a sharp natural division, since some of the so-called "Blue" is discoloured in yellowish or rusty brown shades and forms a separate grade of fibre, known as "Discoloured"; similarly, not all "White" is serpentine asbestos, since the same colour designation could be applied to certain varieties of amosite from the Lydenburg District.

Although the very regular and perfect fibrous structure at once distinguishes asbestos varieties from all other minerals, there are important differences in chemical composition, amphibole asbestos being a metasilicate of iron, with variable proportions of lime, magnesia, alumina, and soda, with low content of water, whereas serpentine asbestos is hydrated magnesium orthosilicate, containing a high percentage of magnesia and of water.

The following is a list of asbestiform minerals:—

I. Serpentine Group.—Hydrated magnesium silicate with the composition $2H_2O$, $3MgO$, $2SiO_2$, and characterized by high percentage of magnesia and water:—

Chrysotile.
Picrolite.

II. Rhombic Amphiboles.—Silicate of magnesia and iron with the composition $(MgFe)O$, SiO_2:—

Anthophyllite.

III. Monoclinic Amphiboles:—

Tremolite.—Silicate of calcium and magnesium of the composition CaO, $3MgO$, $4SiO_2$.

Actinolite.—Silicate of calcium, magnesium, and iron, with the composition CaO, $3(MgFe)O$, $4SiO_2$.

Crocidolite.—Silicate of iron and sodium; its composition is given by Dana as—

$$NaFe, (SiO_{3}3)_2, FeSiO_3.$$

Soda is an invariable constituent of this amphibole.

Amosite.—Chemically characterized by high percentage of iron with variable amounts of aluminium, magnesium, and calcium. Soda may or may not be present.

Single crystals of serpentine with polyhedral habit, so as to show crystal faces, are not known, and while some amphiboles show this habit to a marked degree, crocidolite has never yet been met with otherwise than in a finely fibrous condition. In the case of amosite the fibrous growth is very common, but in the Lydenburg District certain phases of the same country rock develop stellate group of an amphibole, showing in thin section the characteristic lozenge-shaped prismatic outlines of hornblende, intimately associated with slender needles and fibres of amosite.

In mineralogical literature one meets a number of other terms denoting fibrous amphiboles, etc., such as *mountain leather*, *mountain cork*, *mountain wood*, amianthus, etc., which do not possess any precise meaning and need not be considered from a commercial point of view.

The asbestiform minerals enumerated above are of very different economic importance. About 1909 or 1910 chrysotile represented 95 per cent. of the world's raw material for the asbestos industry, and although the increased activity of other fields has probably somewhat reduced this figure, the fibrous serpentine is still easily first in this respect. Furthermore, some 80 per cent. of the world's output comes from the Province of Quebec, so that Canada accounts for the bulk of the present supply.

Next in importance are crocidolite and amosite, the former being practically, and the latter wholly, restricted to South Africa. Tremolite asbestos occurs in Natal (see below).

The remaining varieties, picrolite, anthophyllite, and actinolite asbestos, are of little commercial importance and call for no further notice.

Varieties of Asbestos found within the Union of South Africa.

As far as the Union is concerned, workable asbestos deposits include *chrysotile*, *crocidolite*, *amosite*, and *tremolite*. Of these the chrysotile and tremolite workings are of negligible importance in the world's output, but for a good many years crocidolite has furnished an appreciable contribution, while amosite during the last three or four years has shown a rising output and has secured a market in America and Japan; these deposits occur, so far, in the Lydenburg and Pietersburg Districts only, and constitute a very promising field.

Amosite.—This term is new to geological literature and denotes the special variety of monoclinic iron amphibole from the Lydenburg and Pietersburg Districts, where it was first discovered and is now successfully developed. Though this species may, perhaps, turn out to be a local variety of crocidolite without the characteristic lavender blue colour, its presence in very large quantities, its establishment in the markets of Japan and America, the high proportion of very long fibre, and particular physical appearance in white, pale brown, silvery grey, ash grey, or very delicate green tints make it desirable and convenient to employ a distinctive name. The proposed term is derived from the word *Amosa*, made up of the initial letters of

"Asbestos Mines of South Africa," a concern under which several farms of the Transvaal fibre area are being exploited, thus taking cognizance of local conditions and the priority of the north-eastern Transvaal in this new variety.

Classification of Fibre Deposits.

In accordance with the arrangement of the fibres in a vein, the following distinctions are commonly recognized :—Cross fibre, slip fibre, and mass fibre.

In *cross fibre* the asbestos is made up of many delicate straight fibres, thoroughly oriented and extending at right angles across the vein from wall to wall. In many cases a truly perpendicular disposition is observed, though not infrequently there is a light departure from perpendicularity amounting to a few degrees, or the fibres may be sharply bent for a short fraction of their length along one or other or both containing walls. Nearly all asbestos occurrences in the Union are of this kind.

Slip fibre denotes an arrangement where the fibres tend to be disposed along the vein direction, a result often depending on lateral movement and slickensiding. This type is of restricted occurrence.

In *mass fibre* there is no definite orientation of the fibres, which sometimes are scattered quite irregularly, or this arrangement may be accompanied by nests of stellate groups or strings of small radiating needles. The very characteristic hard dark blue lumps of crocidolite, found as boulders in some river beds in the Cape Asbestos area, are a form of mass fibre asbestos, and a generally similar type has been recorded from the Haenertsburg goldfields.

In the Union nearly all the commercial asbestos occurrences consist of cross-fibre veins.

CHRYSOTILE.

Physical Properties.—The very perfect structure is perhaps the most striking physical property of chrysotile. A lump of this mineral can readily be separated into strands or delicate threads by the fingers ; yet the microscope shows that fibres of the finest attainable thinness do not represent a single unit of growth. Under powerful magnification chrysotile fibres appear like fine polished metal rods, without those jagged edges which characterize cotton fibre and cause them to cling together during spinning, so that the successful manufacture of asbestos yarn had to overcome great initial difficulties. According to Professor H. T. Barnes (No. 2, p. 85[*]), the smallest obtainable fibre shows the following dimensions :—

	Smallest in Millimetres.	Fibres per Linear Inch.
Canadian Chrysotile, Black Lake	·001	250,000
Grand Cañon Arizona, Chrysotile	·00075	33,325
West Griqualand Crocidolite	·009	27,775
Carolina Chrysotile	·0015	16,650

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[*] These numbers refer to the bibliography at the end.

This important property of a highly developed fibrous structure is of the greatest value in the commercial application, and spinning machines can now turn out single threads of fair strength, of which a hundred yards do not exceed one ounce in weight.

The length of chrysotile fibre is subject to great variation. In the South African Museum, Capetown, is an exhibit of chrysotile from Zoet Vlei (Prieska District), showing the remarkable length* of 24 inches, and in the Carolina District exceptional cases of 6½ inches have been observed free from stony or other partings and consisting of continuous fibres of high value; such cases are, however, very rare. Lengths varying from ¼ inch to 1 inch are the common rule, and of the total Canadian output during 1915 only 4 per cent. represented fibre exceeding ¾ inch in length, while that over 1 inch only amounted to 1·4 per cent. In the Union the Carolina chrysotile area yielded fibre averaging ·92 on one farm and a little less than this elsewhere. In the other direction there is every gradation down to the faintest fibres of asbestiform matter.

In colour chrysotile varies only slightly. Most kinds are brilliant white, but may develop pale greenish or olive greenish to faint yellowish green or yellow tints. Larger lumps of fibre with a distinct greenish coloration acquire the dead white colour and consistency of purest cotton or silk when worked up in the hands.

Fibres which have been thoroughly worked up between the fingers and hands acquire a very brilliant, soft, silky lustre, have an agreeable soft touch and a characteristic fluffy appearance.

Flexibility is another property of obviously great commercial importance in connection with asbestos yarn, and chrysotile possesses this quality to an eminent degree. This may be shown by a simple test, consisting of pulling a thin strand slowly over a smooth edge, when the fibres adapt themselves to a considerable amount of bending without breaking. It is sometimes stated that chrysotile fibres are the most flexible, but it is doubtful if crocidolite and amosite are appreciably inferior in this respect. It is probable that the flexibility is due to the presence of water of constitution, since a thin strand heated in the hottest part of a burning match will become brittle, so that it easily snaps, after being subjected to low red heat. During this process the water of constitution is driven off, but the power to withstand great heat is not lost. In certain parts of Canada, where the trees protecting some outcrops of serpentine with chrysotile veins have been subjected to bush fires, the fibre has lost its strength and become hard and brittle.

The properties of elasticity or resiliency are conspicuous in fresh chrysotile fibres which have not been worked up, but this quality is distinctly better in case of the two amphibole varieties named.

Capacity for resisting heat is of very great importance in the industrial application of chrysotile, which takes the first place in this respect. No visible affect is produced on raising serpentine

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* In the Maritzburg Museum is an example of asbestos (chrysotile ?) from Umsinga, Natal, with the extraordinary length of 43 inches; it is most probably slip fibre.

asbestos to temperatures as high as 3000° F., and in some cases even to 5000° F., which greatly exceed those at which crocidolite readily fuses. This remarkably great heat-resisting property has been regarded as depending on the high content of magnesia.

Tensile strength or toughness expresses the fact that chrysotile may undergo a considerable strain before breaking, though this property is more marked in some of the amphibole asbestos varieties.

Under the influence of weak acids, chrysotile is decomposed, so as to leave almost pure silica ; this change does not appear to affect the fibrous structure. In this acid resisting quality chrysotile is inferior to crocidolite and amosite.

Exposed to sea water or moist air, the fibres are gradually decomposed, a matter of some importance when the export of chrysotile takes the form of shipments as ballast. Crocidolite and amosite are distinctly superior in this respect. This remark probably also applies to capacity for electrical insulation.

The specific gravity is given by Dana as 2·14–2·64, as determined from a number of localities, while that of ordinary massive serpentine falls within the narrow limits of 2·50 and 2·65. For those reasons it is frequently stated that chrysotile is less dense than its country rock. In a recent paper by R. P. D. Graham (No. 14, pp. 186 to 189), this question has been subjected to accurate tests, and it was found that, after boiling in water for two hours, higher values were obtained for chrysotile, while without this precaution it was impossible to accurately weigh massive serpentine immersed in water, owing to continual increase in weight. The results show a value of 2·56 and 2·58 for picked threads of chrysotile and of 2·55 to 2·58 for massive serpentine ; the difference in density is thus negligible. The so-called massive serpentine shows in thin section a distinct fibrous structure without orientation : this rock might be referred to as mass fibre chrysotile, so that the change to chrysotile would not be accurately described as the development of crystalline from amorphous massive serpentine.

Some of the preceding physical properties, like length, colour, silkiness, flexibility, and to some extent tensile strength, can be tested by eyes and fingers, e.g. by selecting long slender strands and applying a twisting, tearing, or bending movement between the fingers or rubbing the strands between the hands. Better quality fibre will yield soft silky strands with a kind of unctuous feel, show elasticity, and stand considerable strain without breaking ; inferior asbestos will remain rough or harsh to the touch and show brittleness.

Other properties can only be determined under the practical conditions of manufacture, etc. ; this applies specially to heat-resisting qualities, spinnability, etc., as well as to exact measurements of tensile strength.

Chemical Properties.—Chrysotile is a hydrated silicate of magnesium, always showing a high percentage of magnesia and water of constitution, low percentage of iron oxides, and low but variable amount of alumina. The most complete analytical data are those available for Canadian chrysotile, and the average composition of this is given in the table below, computed from eleven separate analyses published in Cirkel's monograph (No. 2, p. 31). In these the silica percentage varies from 39·05 to 42·64 that of magnesia from 39·54 to 42·97, ferrous and ferric iron together from 0·69 to 3·66, alumina from 3·67 to nothing. The amount of water shows a remarkably slight range from 13·47 to 14·50.

COMPOSITION OF CHRYSOTILE.

	I. Canada.	II. Italy.	III. Carolina.
SiO_2	40·49	40·30	41·9
Al_2O_3	1·27	2·27	nil
Fe_2O_3 and FeO	2·53	0·87	nil
MgO	41·41	43·37	36·3
CaO	—	—	·5
Na_2O	—	—	2·71
H_2O (Const.)	14·06	13·72	18·00
TOTAL	99·76	100·53	99·41

I. Mean of 11 analyses given in Cirkel (No. 2, p. 31).
II. Given in Cirkel (No. 2, p. 31).
III. Diepgezet; Analysis by C. Gardthausen, Assistant Curator, Geological Survey.

Of the chrysotile asbestos within the Union only one analysis is so far available—from the Carolina fibre belt. This agrees in a general way with the Canadian results in the high percentage of magnesia and water, but differs in the presence of soda (2·71 per cent.). The latter result is unusual, though Hintze quotes several instances of serpentine containing that constituent, and in Graham's paper (No. 14, p. 161) an analysis of massive serpentine from near Black Lake Station gives a low percentage of alkalies. It must be borne in mind that the mode of origin of chrysotile near Carolina in an altered sedimentary rock cannot be directly compared with that in the Canadian fields, which depend directly on basic igneous rocks, and this may be reflected in differences in composition. Further analytical investigations from different points along the Carolina deposits are nevertheless desired.

The probability that the high content of water of constitution controls flexibility has been already referred to.

CROCIDOLITE.*

Physical Properties.—This variety also possesses a highly pronounced fibrous structure, but is easily distinguished from all other forms of asbestos by its very characteristic lavender blue colour.

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* Term introduced by Hausmann 1831, and built up of Greek words meaning "Flaky" or "Woolly stone." The so-called crocidolite of the jewellers trade is a brown altered variety, to which the name "Tiger eye" is here applied.

In length fibres of crocidolite also vary, but within narrower limits, and, as far as the writer is aware, such an exceptional length as 6½ inches, met with in chrysotile, is not known in crocidolite, though very common in the case of amosite. In the great fibre belt of the Cape the length rarely exceeds 3 inches, and ranges from this value down to the smallest dimensions; veins from ¾ inch to 1½ inch are common, and in the Westerberg and Koegas workings some 80 per cent. of the output during 1917 is represented by fibre under ¾ inch long. In the Pietersburg District the crocidolite fibres range from 3 inches downward in length, but values in the neighbourhood of ¾ inch are frequent. Development has not proceeded far enough to state more definitely what a reliable average would amount to in the northern Transvaal.

The tensile strength of crocidolite is distinctly greater than that of chrysotile, and experiments made with a cylinder $\frac{4}{100}$ inch in diameter show that a considerable weight can be supported. Cirkel (No. 2, p. 22) considers this remarkable tensile strength due to the large amount of iron in crocidolite.

As regards heat-resisting capacity, there is a marked difference between fibrous serpentine and crocidolite. Both forms of asbestos readily lose their flexibility even at moderate heat and become brittle, but chrysotile retains its quality of resisting high temperatures, whereas crocidolite easily fuses before the blowpipe and turns into a black magnetic glass with yellow flame colouration; these effects seem to depend upon the relatively high soda content. Cirkel states (No. 2, pp. 21 and 22) that, for purposes where fire-resisting quality is essential, its substitution for chrysotile was a complete failure, and refers to experiments made by the United Asbestos Co., London, which gave unsatisfactory results, it being stated that "the fibre was unsuitable for engineering purposes, since it would not stand much heat without disintegrating and becoming quite rotten."

Crocidolite is superior in its resistance to acids, chemical solutions, and sea water, which have very little effect, a quality now made extensive use of in several European navies and mercantile marines by the application of flexible boiler covering, protection of steam-pipe with asbestos lagging, etc. From the point of view of shipment, the sea-water resisting capacity is a further important asset.

Both as regards heat and electrical insulating qualities, special advantages are claimed for crocidolite.

Elasticity is also greater here than in the case of chrysotile fibres.

Chemical Properties.—The distinctive chemical features are the low amounts of magnesia, lime, and alumina, the high percentages of iron oxides, and relatively high soda content. In the following table analytical data are given both for the normal crocidolite of the Cape and the Pietersburg District, as well as for the more or less altered and silicified phases, known as griqualandite, tigereye, etc.:—

COMPOSITION OF CROCIDOLITE, GRIQUALANDITE AND TIGEREYE.

	CROCIDOLITE PROPER.							ALTERED CROCIDOLITE OF CAPE COLONY.							
	CAPE COLONY.								Pietersburg.	Tiger-eye.	Bluish.	Blue	Brown.	Brown.	Griqualandite.
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
SiO_2........	51·1	51·22	50·00	50·81	51·64	52·11	51·89	52·11	56·27	93·05	93·43	97·27	94·45	57·46	56·75
Al_2O_3......	—	—	—	—	—	1·01	—	—	—	·66	·23	—	—	—	—
Fe_2O_3......	—	—	—	—	—	20·62	19·22	20·26	—	4·94	2·41	—	4·50	37·56	37·64
FeO........	35·8	34·08	40·50	33·88	34·38	16·75	17·53	16·51	33·78	—	1·43	1·67	—	—	1·09
MgO.......	2·3	2·48	—	2·32	2·64	1·77	2·43	1·88	1·67	·26	·22	—	—	—	·10
CaO........	—	·03	1·50	·02	·05	—	·40	·75	1·70	·44	·13	·15	—	—	—
Na_2O.......	6·9	7·07	5·00	7·03	7·11	6·16	7·71	5·79	3·92	—	—	—	—	—	—
H_2O (Const.)	3·9	4·50	3·00	5·58	4·01	1·58	2·36	3·53	—	·76	·82	·76	·80	5·15	4·96
TOTAL...	100·00	99·48	100·00	99·81	99·85	100·00	101·69	100·83	99·84	100·11	98·67	99·85	99·75	100·17	100·54
(Including)	—	·10MO_2	—	·17Mn_2O_3	·$O_2Mn_2O_3$	—	·15K_2O	—	—	—	—	—	—	—	—
Sp. Gr.....	—	—	3·200	—	—	—	—	—	—	—	—	2·69	2·684	3·05	3·136

Analyses Nos. I and II are given in Cirkel's monograph from R. Jones "Asbestos," London, 1897, and De Lapparent, Cours de Mines respectively. Nos. III to VIII are quoted by Dana ("System of Mineralogy," 6th edition), and Hintze ("Handbook of Mineralogy," Vol. II): No. IX is blue fibre from the Malips River, east of Pietersburg, analysis by Professor Hahn, Nos. X to XV are given by Dana and Hintze.

AMOSITE.*

Physical Properties.—This amphibole asbestos is apparently a new variety, characteristic of a definite horizon in the north-eastern Transvaal, and is not, as far as the writer is aware, known from other countries. On the whole, it is related fairly closely to the crocidolite variety, but may perhaps represent a fibrous phase of the cummingtonite or grunerite group of amphiboles.

A strongly marked fibrous structure is again well developed, and in this respect there is no sensible difference as compared with crocidolite.

In colour there is a great range of greys and white, or yellowish greys. The lavender blue of crocidolite has not yet been observed. Nearer the surface pale dirty brownish tints are predominant, or sometimes pale impure olive greenish colouration in case of lumps of fibre. Fresher fibres from lower workings vary in silvery grey, ash grey, very delicate bluish grey, and pale yellowish green shades. Some occurrences, after fiberizing and working up between the fingers, assume an almost pure white appearance.

As regards length of fibre, amosite is unique and easily surpasses every other asbestiform mineral. The greatest value hitherto observed is a little over 11 inches, from which there are many gradations down to the minutest fibres. Lengths from 4 inches to 7 inches are very frequent, and no difficulty has been experienced in maintaining a continuous supply of this length, all of which is spinnable.

Smaller strands of amosite, tested by hand manipulation, show an elasticity and a tensile strength in no way inferior to crocidolite, while the inflexibility approaches that of chrysotile. A recent occurrence from the farm Streatham could be worked up into a pure white ball with the appearance of cotton wool, the material being eminently flexible and not inferior to serpentine asbestos in this respect.

Held in the hottest point of a burning match, strands of amosite soon lose their flexibility, darken, and become brittle. In the blowpipe very thin fibres, after prolonged heating, show signs of fusion, though much less readily than crocidolite. Experiments carried out in the Government Chemical Laboratory, Capetown, by Dr. Versfeld, showed that, on subjecting amosite in glazed porcelain crucibles for some hours to a bright red heat in gas muffle furnaces, the fibre does not fuse, but turns dark brown and becomes thoroughly brittle, being easily powdered between the fingers. Under similar conditions crocidolite forms a melt of black glass. In these tests amosite was represented by a white variety from Streatham, a golden yellow variety from Penge, by No. III grade from the Egnep Mine, and by the best or No. 1 quality from the fourth level of the same mine. The better heat-resisting quality of amosite probably depends on the lower soda content as compared with crocidolite.

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* This name was proposed by the writer in a paper read before the Geological Society of South Africa in 1918 (Bibliography No. 16).

Acids have very little effect on amosite. Samples of fibre from the Egnep Mine, both the poorer more brownish grade from higher and the best quality greyish variety from the fourth level, were tested by leaving them immersed in strong cold hydrochloric acid for twenty-four hours. The washed and dried fibre shows an appreciably lighter colour in case of the lower grade brownish kind, due to removal by the acid of some of the hydrated iron ore, while the best quality produced only faint colouration of the acid and assumed very slightly lighter colour. In both instances the flexibility and tensile strength were scarcely affected.

As far as present experience of shipments has gone, amosite fibre readily withstands the action of sea water and is not inferior to crocidolite in this property.

More detailed tests, e.g. to determine capacity for electrical insulation, carried out under the practical conditions of manufacture are not yet available, since amosite has only recently come into the market. (See Chapter VII.)

The identity of amosite as an amphibole rests on comparison, supported by chemical evidence, of a number of occurrences in thin section, which lead from well-developed crystals through various stages of fibrous phases up to thoroughly asbestiform habit. In the former case one finds idiomorphic crystals, pale yellowish brown and non-pleochroic, showing good typical prismatic amphibole cleavage, with an extinction up to twenty-two degrees, though the majority of the values lie between eleven degrees and seventeen degrees. In some less common varieties of country rock the same mineral occurs in scattered nests or small radiating pale yellowish or ash-grey aggregates, and can also be observed in thin veins made up of not yet oriented amphibole needles, which are seen in thin section to feather out into wisps or delicate asbestiform strands. Amosite may, therefore, be described as a non-pleochroic pale yellowish monoclinic amphibole.

Chemical Properties.—Present information on the composition of amosite is incomplete, and many more data are desirable in view of the variations in the physical appearances and character of the material in different parts of the fibre area. The following table contains four analyses representing occurrences from Penge and Streatham, the principal economic localities. The composition of cummingtonite and grunerite are added for comparison :—

	Amosite.				Cummingtonite.		Grunerite.	
	Penge.	Penge.	Penge.	Streatham.				
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	49·72	53·34	50·24	49·10	56·55	51·09	50·74	43·90
Al_2O_3	5·72	9·35	—	—	—	·95	·89	1·90
Fe_2O_3	—	—	7·80	—	—	—	—	—
FeO	37·00	34·35	32·00	43·86	21·67	32·07	33·14	52·20
MgO	3·77	·74	3·96	6·14	—	10·29	10·31	1·10
CaO	1·65	1·59	tr.	·46	—	tr.	tr.	·50
Na_2O	—	—	2·12	—	8·44	·75	3·04	—
Water (Const.)	2·29	—	—	—	3·18	3·04	—	—
Moisture	—	·616	—	—	—	—	—	—
Ignition	—	—	3·00	—	—	—	—	—
	100·15	99·986	99·12	99·56	97·64 +7·8MnO	99·69 +1·5MnO	100·43 +1·77MnO	99·60

I. Third grade brownish asbestos from near the surface; analysis by Prof. Hahn. II. Ditto. III. Best quality "white asbestos," IVth Level, B Section, Egnep Mine; analysis by C. Gardthausen. IV. Second quality: analysis by Prof. Hahn. V–VII. Cummingtonite from Massachusetts; Hintze, vol. II, 1897, p. 1242. VIII. Grunerite from France; Hintze, vol. II, 1897, p. 1236.

The results are consistent in showing a high percentage of ferrous iron, low percentage of magnesia and water, and thus are in strong contrast to chrysotile. Alumina is apparently subject to much variation, as in the case of serpentine asbestos; lime is consistently low, while the highest soda content is only a little over 2 per cent., i.e. distinctly less than for crocidolite. None of the amosite from the Lydenburg area has the appearance of that amphibole, which is characterized by a much higher amount of soda, whereas many analyses are available of amphibole containing soda, but not possessing the crocidolite appearance. Hintze classes cummingtonite and grunerite as ferrous silicates of the general formula $(Fe,Mg)SiO_3$ with low amounts of lime and magnesia, and analysis IV agrees closely with this formula. In the literature cummingtonite from Massachusetts has been described as ash-grey to brownish crystalline masses with silky lustre, and grunerite—as first described from France—appears in brown radial masses with silky appearance and feebly pleochroic, statements which recall the special form of amosite hornblende alluded to above as occurring in scattered nests; both in these foreign and in the Lydenburg amphibole soda is also a variable constituent. (See Appendix for further analyses.)

It is possible that amosite may represent a variety of crocidolite with less soda, and that the differences in colour are conditioned by variations in that constituent; on the other hand, there appears to exist some affinity to the cummingtonite or grunerite group.

TREMOLITE.

This asbestos is a calcium magnesium amphibole, often light coloured to pure white, though sometimes found in dark grey long blade-like crystals. Its commercial value and uses are more limited. The soft silky fibre possesses inferior flexibility and tensile strength, but is capable of withstanding high temperatures.

Tremolite has been used as a substitute for actinolite in the manufacture of fibrous wall powder and mineral wool. Some of the Natal deposits (slip fibre) have been employed for boiler and steam-pipe covering. Other adaptations appear to lie in asbestos millboard and in filtering mediums for acids or corrosive liquids.

Within the Union tremolite asbestos has been worked in Natal (see Chapter V). The analysis given below shows a fairly high percentage of lime and is in general agreement with those of calcium-magnesium amphiboles:—

COMPOSITION OF TREMOLITE ASBESTOS.

SiO_2	58·80
Al_2O_3 Fe_2O_3	5·32
MgO	22·75
CaO	10·65
Ignition (H_2O, etc.)	·50
TOTAL	98·02

Analysis by Professor G. H. Stanley of asbestos from the workings of the Buffalo Asbestos Co., Natal.

To the tremolite variety probably also belong the deposits found north of Mara Siding in the Zoutpansberg District, which are being used in the manufacture of boiler lagging (see Chapter VII).

CHAPTER II.

DEPOSITS OF ASBESTOS IN THE CAPE.

WITHIN the limits of the Cape Province the only variety of asbestos exploited is crocidolite, commonly referred to as "Cape Blue," which is found in interbedded cross fibre veins.

The earliest reference to the occurrence of this fibrous hornblende in South Africa is most probably that of Klaproth in 1815,* who published an analysis of material collected by Lichtenstein in the Orange River; the results of this analysis are given under I in the table of crocidolite analyses in Chapter I. The name crocidolite was proposed by Hausmann in 1831,† and means a "stone" with "woolly" appearance; Klaproth describes the material as Blau-Eisenstein (blue ironstone).

The exploitation of crocidolite began about 1893, when the Cape Asbestos Company undertook active development north of Prieska and led the way in establishing a market for this variety of fibre. Since that date many other workings have sprung into existence in Griqualand West, and, more especially during the last ten years, further developments of asbestos have arisen in the northerly extension of the fibre belt round Daniels Kuil and Kuruman.

DISTRIBUTION OF THE ASBESTOS BELT.‡

The fibre area is restricted to the northern parts of the Cape Province, and forms a very extensive belt of country belonging to one and the same formation of banded ironstones of sedimentary origin. It stretches without interruption from south of the Orange River near Prieska in a general northerly or north-north-easterly direction, certainly as far as the Mashowing River in British Bechuanaland, and most probably beyond that into the districts of Vryburg and Mafeking.

Beginning in the south, the most southerly outcrops of the asbestos-carrying formation (Lower Griqua Town Series) begin some twenty miles south-south-east of Prieska, on the farm Lovedale or Kalk Punt, whence they strike towards the north-north-west in form of a hilly belt rising as a distinct feature above the Dwyka-covered plateau of the Karroo. These hills are known as the Doornberg Range or Doornbergen, and continue past the south-west side of Prieska towards the Orange River about as far as Westerberg, along the south bank of this stream, through a total length of not less

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* Beitr. z. Chem. Kenntn. der Mineral Körper, 1815, vol. 6, p. 237.

† Gött. Geol. Anz. 1831; Mineral. 1847, pp. 743, 521.

‡ For fuller details see the following sheets published by the Geological Commission of Cape Colony: No. 32 Van Wyks Vlei, No. 33 Britstown, No. 40 Marydale, No. 41 Griquatown, No. 45 Postmasburg, No. 49 Kuruman. Compare also the sketch map at the end of this volume.

than fifty miles. The whole of the Doornberg Range is composed of banded ironstone and allied siliceous ferruginous or jaspery rocks, which form a varied group of hills and ridges with a rather complex detailed physiography. Along the higher portions the banded ferruginous rocks are naturally most conspicuous, but much of the intervening valleys or lower-lying ground generally is due to the same formation and develops a highly characteristic deep reddish brown soil, freely strewn with fragments of ironstone.

Between Prieska and Westerberg the Orange River cuts through the asbestos formation, but, although the latter is identical on both sides of the river, the name Doornbergen is restricted to the hilly tract along the southern side, while that situated north of the river forms the extreme southern end of the very extensive belt of high ground which reaches far northwards, and is known as the Asbestos Mountains.

In crossing the Orange River (see frontispiece) from its left to its right bank, one enters Griqualand West, made up of the Divisions of Hay, Hopetown, Herbert, Kimberley, and Barkly. Owing to the highly folded character of the Lower Griqua Town Series, the surface distribution of the asbestos formation, specially along the Orange River section, but also further north, is somewhat irregular, and this becomes intensified by the increased development of surface deposits (compare Sheet No. 40, Marydale).

Across the most southerly portion of Hay a little north of Prieska the Lower Griqua Town Series occupies a continuous stretch of country some forty miles wide from east to west, but owing to the repeated synclinal and anticlinal arrangement, combined with the irregular distribution of the overlying middle Griqua Town or Ongeluk Volcanic Series, in part removed by denudation, the northward extension of the lower division is along three branches of variable length and breadth.

The shortest and *most westerly branch* runs along the northern banks of the Orange River from Prieska to Stilverlaats nearly as far as Ezel Rand, with a length of about forty-five miles and an average width of eleven miles; it includes the important asbestos workings of Koegas and district. The *middle branch* extends from Prieska due northwards to a point some twenty-two miles south-west of Postmasburg (see Sheets No. 41, Griqua Town, and No. 45, Postmasburg). For the first forty-eight miles or so the outcrops are continuous, but become detached further north, owing to superficial deposits. This middle branch has a length of about seventy-five miles and averages eleven miles in width; included in it are the asbestos workings of Blackridge. The *third* and *most easterly branch* forms a continuous chain of high ground, beginning north of Prieska as the Asbestos Mountains or Jasper Hills, this name being extended northwards to the neighbourhood of Daniels Kuil, but the same feature keeps on still further north, where it is known as the Kuruman Hills, and reaches as an orographic element to Tsenin on the Mashowing River in British Bechuanaland. From Prieska to Tsenin represents a distance of not less than 180 miles, and along more or less the entire stretch the Asbestos Mountains and the Kuruman Hills rise as a distinct feature from the vast Kaap Plateau of the underlying dolomite of the Campbell Rand Series in the east. Since the Lower Griqua Town Series consists of a great succession of more thinly bedded siliceous ferruginous slates, the western limit of the Kaap Plateau is defined, not so much by a clean-cut single escarpment, as by a more irregular line of high ground rising on the whole somewhat abruptly, but with more rounded outlines. This line ascends up to about 2000 feet above the general level of the flat country on the east, and is now and then marked by more conspicuous and more elevated short ridges, e.g. Gamopedi (4264 feet above sea-level), north-west of Kuruman ; Gamohaan (5277 feet above sea-level), west of Kuruman ; Chee (5800 feet above sea-level), south of Kuruman ; Gakarusa (6070 feet above sea-level), north of Daniels Kuil. The degree of contrast between this long feature and the Kaap Plateau is subject to considerable variation, and from Kuruman northwards the crest line steadily falls towards the Kuruman and Mashowing Rivers.

West and south of Griqua Town along the Asbestos Mountains the width of the Lower Griqua Town Series across its third branch is more uniform and averages nine miles in width ; this value decreases somewhat on approaching Daniels Kuil. South of Kuruman the asbestos formation measures some eight miles across and steadily declines northwards.

It has been pointed out that the irregular distribution of the surface outcrops of the fibre belt is largely due to folding, and this is well seen along the northern section from Griqua Town to Kuruman. Thus west of Daniels Kuil the middle and westerly main branches of the Lower Griqua Town Series become merged into one continuous and much broader belt, owing to the almost complete removal of the overlying volcanic rocks of the middle division, which once filled the synclinal trough, but are still in evidence west of Griqua Town and north of Daniels Kuil. In the latter direction the westerly limb, corresponding to the middle branch further south, forms a separate belt of asbestos formation, known as the Khatu Kosis Hills.

During recent years a large number of economic developments have arisen in this part of the fibre area, e.g. the Northern Asbestos Co., Messrs. Gillanders & Campbell's Syndicate, Crown Lands Syndicate, Harris Syndicate, and others.

The total length of the Cape asbestos belt measures at least 240 miles and has a variable width from 30 miles downwards. From Prieska through Griqua Town towards Daniels Kuil along its more regular distribution values of width from three to nine miles are maintained. The figures leave little doubt that the present is the most extensive asbestos formation hitherto known ; as a source of crocidolite, it holds the record.

GEOLOGICAL FEATURES OF THE ASBESTOS BELT.

The asbestos formation is the Lower Griqua Town Series, belonging to the Transvaal System, of which the general succession is as follows :—

	Cape Colony.	*Transvaal.*
Jaspers, Slates, Phyllites, and White Quartzites	Upper Griqua Town Series	Pretoria Series.
Volcanic Lavas, Breccias, and Tuffs..	Ongeluk Volcanic, or Middle Griqua Town Series	
Ferruginous Jaspers, Banded Magnetic Rocks, Sandstones, Shales, Cherts, etc., and a Glacial Boulder Bed near the top	Lower Griqua Town Series	
Limestones, Dolomite, Cherts, and Shales	Campbell Rand Series	Dolomite Series.
Quartzites, Flagstones, and Pebble Beds	Black Reef Series.....	Black Reef Series.

It is worth while to point out, in the correlation appearing in the preceding table, that, whereas (apart from igneous rocks) the banded ironstones in the Cape very largely predominate over other kinds of rock, in the Transvaal the Pretoria Series consists typically of soft shales alternating with quartzite at certain horizons, while banded ironstones, practically for the most part indistinguishable from those of the Griqua Town Series, appear to any great extent only over the basal portion of series in the north-eastern Transvaal, are quite subordinate along the type section west of Pretoria, but become steadily more pronounced again in the western Transvaal. In view of the fact that the genesis of amphibole asbestos from ferruginous sediments is supported by a certain amount of evidence, these gradual changes in facies from the Cape to the Transvaal types of the Series are of wider interest in connection with the distribution of crocidolite or amosite in the two Provinces (see Chapter VI).

The *Upper Griqua Town Series* has only a very limited distribution on the western side of the fibre area, and a great unconformity separates this group from the Lower Matsap Series. No crocidolite from this group is on record.

The *Middle Griqua Town* or *Ongeluk Volcanic Series* occupies considerable stretches of country west of the Asbestos Mountains and Kuruman Hills, and often exhibits a synclinal arrangement, so as to fill the shallow portions of broader synclines or troughs ; elsewhere much of it has been removed by denudation.

The *Lower Griqua Town Series* forms a great succession of more thinly bedded ferruginous rocks, and it is in them that the crocidolite occurs as interbedded cross fibre veins. A little north of Griqua Town, where the beds are less disturbed than elsewhere, the thickness amounts to 2500 feet.

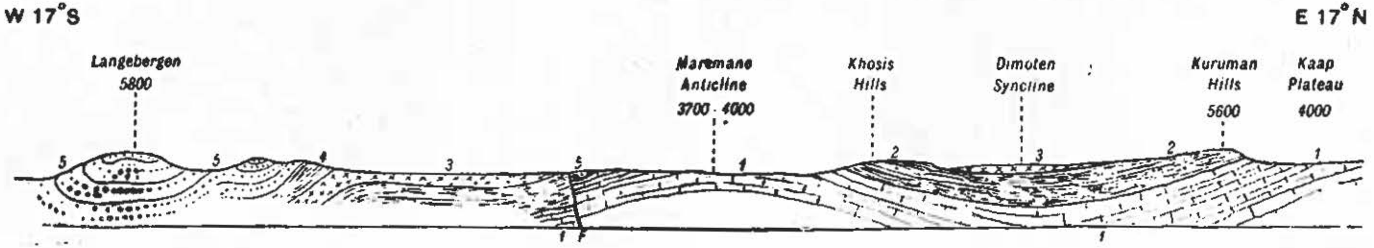
The *Campbell Rand Series* forms a somewhat monotonous succession of limestones, dolomitic limestones, and chert, covering extensive areas of the Kaap Plateau peneplain to the east of the Asbestos Mountains–Kuruman Hills, and defined by a fainter but still fairly distinct feature known as the Campbell Rand. The approximate thickness in Prieska has been estimated at 5000 feet. The above rock-groups make up a conformable sequence, in which the Lower Griqua Town Series as the home of the crocidolite deposits is the most important sub-division for the present purpose.

The strike of the asbestos formation shows great differences between the most southerly part of the fibre belt and the more extensive easterly branch. From Lovedale, south-east of Prieska, the strike is to the north-west along the Doornbergen to the Orange River, and is maintained with this alignment for some 40 miles from Prieska downstream through Westerberg to Stilverlaats, the rocks having been folded in conformity with the Doornberg system of folds. On the other hand, north of the Orange River, along the middle and easterly of the three main branches above referred to, a general northerly to north-easterly strike continues with much regularity over great distances, which cover the entire ranges of the Asbestos Mountains and the Kuruman Hills at least as far as the Mashowing River in Bechuanaland.

In amount and direction the dip is subject to extreme variations, depending on the degree of folding, which ranges from gentle rolls of broad synclines and anticlines up to sharp compressed folds, though over greater areas a low and more regular inclination may sometimes be maintained. Along the Asbestos Kuruman Hills the dip is distinctly lower and more steadily inclined to the west or west-north-west at angles in places up to thirty-five degrees, though much more often varying between five and ten degrees, at times even sensibly horizontal. In the Daniels Kuil area and Khatu Khosis Hills or generally over the western side of the northern section of the fibre area, values of less than five degrees are common, the direction of dip being towards the east in conformity with the folding. In the southern section, notably over the Doornbergen, Westerberg, Koegas, etc., where the folding is at its maximum, there are rapid and great variations in dip, which not uncommonly approaches the vertical.

The type of structure characteristic of areas of less intense folding is shown by figure 1, which is taken across the northern section of the asbestos belt. The great Kaap Plateau is terminated in the west by the Kuruman Hills, made up of the Lower Griqua Town Series, which is thrown into a broad shallow syncline, filled by remnants of the middle or Ongeluk group (Dimoten Syncline); further towards the west follows a broader anticline of the underlying Campbell Rand limestone (Maremane anticline), limited topographically on the east by the Khatu Khosis Hills as the westerly limb of the Dimoten Syncline. This kind of structure accounts for the stretches of asbestos workings lying south of Kuruman and separated from one another by an intervening belt of irregular low hills or flat ground due to volcanic rocks and including no fibre deposits. A little to the south and west of Daniels Kuil, where the middle group is almost completely removed by denudation, a broader

SECTION FROM THE KAAP PLATEAU TO THE LANGEBERGEN, DISTANCE 66 MILES.



1. Campbell Rand Series. 2. Lower Griqua Town beds (with crocidolite). 3. Middle Griqua Town beds = Ongeluk Volcanic Series. 4. Upper Griqua Town beds. 5. Matsap Series. Vertical to horizontal scales as 3 : 1.

Fig. 1.

[*After A. W. Rogers.*

expanse of Lower Griqua Town Series forms a series of smoother hills or ridges with low or undulating dip, so that the same outcrop may occur on successive hills. Still further south the synclinal arrangement is more definitely established (Ongeluk-Witwater basin), and the greater continuity of the Ongeluk Series once more determines a double band of asbestos formation, described above as the middle and easterly branch, the latter rising into the conspicuous Asbestos Hills west of Griqua Town (see Sheet No. 45, Postmasburg).

The same structural principle holds good for many parts of the fibre area, but is expressed in varying degrees of complexity, depending on the intensity of the folding. Thus, in the Doornbergen, near Glen Allen, north-west of Prieska, the underlying Campbell Rand limestones are folded into the Lower Griqua Town Series, and north of this point, on the Griqualand West side of the Orange River, a succession of synclines and anticlines can be made out (Leelyk's Dam, Paarde Vley, and Abram's Dam synclines). Other interesting localities of folding are: Enkelde Wilgeboom, an anticlinal inlier of limestone surrounded by Lower Griqua Town beds, some five miles below Prieska on the Orange River; the Juanana Syncline, about thirty miles due north of Prieska; and the Vlakfontein Syncline, forty miles west of Daniels Kuil; details of these and additional areas of folding can be obtained from the Annual Reports of the Geological Commission of Cape Colony (No. 36, pp. 180–188).

The relationship between the limestones of the Campbell Rand Series and the overlying Lower Griqua Town beds is well seen along the foot slopes of the eastern faces of Asbestos Mountains or the Kuruman Hills, and the junction between the two groups can sometimes be fixed to within a few feet, e.g. on Warrendale, nine miles south-south-west of Daniels Kuil, or on Wonderwerk, about midway between the latter village and Kuruman. The calcareous formation passes evenly underneath the banded ironstones, which do not begin suddenly as a steep escarpment, but continue over the upper slopes, since they do not consist of thickly bedded rocks likely to form more massive krantzes, but of a succession of more evenly thinly bedded strata.

As in the case of the base of the Pretoria Series of the Transvaal, the change in facies is not always at once permanently established, but may be associated with a narrow development of "Passage" beds. Thus, in the anticlinal inlier of limestone within the Enkelde Wilgeboom–Kliphuis area on the north bank of the Orange River below Prieska, there is a regular succession of strata exhibiting the Lower Griqua Town facies interbedded with blue crystalline limestone.

In places the lowest Lower Griqua Town beds are locally very much disturbed by minor folds and sharp contortions; this result was first described by Stow (No. 40, p. 655), and is also referred to in the Tenth Annual Report of the Cape Geological Commission.* It has been recorded from Ramaje's Kop on Mount Carmel, north

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* A. W. Rogers, No. 36, p. 166, No. 38, pp. 35–37.

of Daniels Kuil, where some small outliers of the Lower Griqua Town Series give rise to low but conspicuous hillocks a little east of the main feature of the Asbestos Mountains, also from Blockhouse Hill at Daniels Kuil, and is probably a more widely spread phenomenon, since it can be seen in several of the recent asbestos developments in the Kuruman and Asbestos Hills, e.g. on Warrendale, south of Daniels Kuil. Stow's explanation that these disturbances are due to pressure acting from the west is difficult to reconcile with the regular arrangement of the underlying Campbell Rand limestones. In the Eleventh Annual Report referred to, the section on the east side of Blockhouse Hill at Daniels Kuil is described as showing the dolomitic limestones dipping gently towards the west, and overlain by a thin band of highly disturbed jaspery rocks, in turn succeeded upwards by 10 feet of limestone, similarly disturbed. This second band of calcareous material gives place to a greater thickness of thinly bedded Lower Griqua Town Series, in which the structural irregularities decrease from the top of the limestone band upwards, until the highest beds are only slightly disturbed. The later explanation that these contortions are due to the sinking down of the higher beds into hollows dissolved out of the limestone is borne by the general impression left on examining similar appearances in some of the asbestos workings situated on the eastern edge of the main range of hills overlooking the Kaap Plateau.

In their essential features the *country rocks* of the *crocidolite deposits* present considerable uniformity over wide areas. The great bulk of them may be described as hard fine-grained to compact siliceous ferruginous slates or quartzitic ferruginous and jasper rocks, frequently referred to shortly as *banded ironstones ;* they are for the most part thinly and evenly bedded, so as to give rise to more rounded outlines in hilly areas. Over steeper slopes there may be a slight tendency to form steps, due to harder, more thickly bedded strata, but, as a rule, linear features are never maintained for any greater distance, and thin krantz-like ledges, up to a few feet thick and continuing for short intervals only, are the common scenic expression in a succession of these rocks under conditions of average surface relief.

Many colour shades are met with, but pale yellow, brownish black, bluish, and red predominate. Only one or other of these is generally seen in a given outcrop, and a mixture of bands with strong colour contrast, such as the association of black and red in one hand specimen, is exceptional. No sharp line can be drawn as regards the distribution of the various kinds of banded ironstones, but, broadly speaking, one finds more of the dark bluish black rocks along the Asbestos Mountains and Kuruman Hills than along the western edge of the fibre area, where pale yellowish brown kinds—to which the designation of jasper rocks is more strictly applicable—are very common, e.g. when comparing the asbestos workings of Warrendale, overlooking the Kaap Plateau, with those of Crawley, while softer bluish phases seem specially common in portions of the series bordering the Orange River, e.g. Westerberg.

Excepting locally near the top of the Campbell Rand limestones, the bedding planes are, on the whole, very regular, and, though individual layers may sometimes reach several inches in thickness, the great majority range from about 2 inches down to the thinnest films, so that an average section displays a fair amount of regularity in the distribution of divisional planes, a point of some advantage in mining development. On the other hand, in areas of more intense and repeated folding, there is much complexity owing to contortions, minor synclines, and anticlines, which go with rapid changes in thickness of individual layers, e.g. in some of the workings of the Cape Asbestos Co.

The variable colours of the rock depend largely upon the condition of the ferruginous constituents. Sometimes these take the form of small scattered octahedra of magnetite, as in the cherty layers on Tolo, thirty-seven miles due north of Prieska, but far more frequently this oxide is concentrated along certain layers arranged with the bedding planes. Where magnetite predominates, dark coloured rocks prevail, but where the iron ores are more thoroughly oxidized into limonite or where hematite is involved, brown, yellow, and red colours are found. At certain localities carbonate of iron has been observed.

The content of magnetic iron ore determines the frequent magnetic characters of the rocks, most noticeable in the dark coloured varieties, but also seen in some of the more yellow jasper rocks. In certain cases hand specimens may indicate a more or less distinct polarity in this respect.

Nearly always the rocks are highly siliceous, very fine grained, and hard, the iron ore in the dark magnetic bands occurring in a very finely granular condition intimately associated with a microcrystalline quartz mosaic of cherty nature.

An examination of the more typical forms of banded ironstone in thin section usually shows a well-marked arrangement in bands of lighter, almost clear, transparent, and darker or almost opaque, material, with great variety in detailed distribution. A fresh, finely microcrystalline base of quartz crystals with irregular or sometimes interlocking outlines is widespread, and affords the only mineralogical differentiation in the colourless or slightly yellowish bands, some of which are coarser than others. They are rarely quite free from iron ore, and are more often stained pale yellowish by scattered particles, clusters, streaks, or delicate bands of brown opaque hydrated oxide of iron. Such lighter coloured strips correspond to the pale yellowish brown layers in the banded jaspers, and alternate with others more deeply stained by compacter masses of the same decomposed oxide; though the impression of a seam of continuous brown material is sometimes produced, even the most opaque layers still show indications of a little residual very fine-grained cherty base. In the darker rocks the more deeply coloured bands consist of irregular grains of magnetite in a groundmass of minute quartz crystals.

An interesting variation has been recorded from Jacobsfontein in Hay, and consists of a magnetic rock banded along black, brown, and white layers; it shows both magnetite and opaque brown hydrated iron ore in a colourless or yellowish groundmass of very finely crystalline cherty material. Commonly the magnetite forms thin layers of ill-defined aggregates of grains. Along some of the bedding planes and less frequently in the clearer quartz mosaic the same iron ore occurs in larger rhombe-shaped crystals, made up in extreme cases entirely of magnetite, but varying from this habit down to a kind of skeleton crystal, defined by narrow black borders of magnetite filled with clear quartzose areas like those making up the base of the slide, or showing some brown iron ore as well. In these cases both forms of iron ore seem to be derived from siderite, but there are no criteria available how far such a derivation is to be applied to other rocks. In the case of the banded ironstone found over greater areas of the Lower Pretoria Series in the north-eastern Transvaal, which indicate a strong general resemblance to the Lower Griqua Town Series, such phenomena have not so far been observed, and it is more likely that in the majority of cases the hydrated iron ore was derived from original magnetite, both in the Cape crocidolite and the Transvaal amosite fibre areas.

Further details of the microscopic appearances of the normal and asbestos-bearing banded ironstones are given in the publications of the Geological Commission of the Cape Colony.* Those rocks which contain crocidolite or allied fibrous minerals, either as distinct cross fibre veins or in other forms, are referred to below in connection with the asbestos deposits.

Though the great bulk of the Lower Griqua Town Series is made up of banded jaspers and magnetic ironstones, several other phases have been noted, but are of much more restricted occurrence. These include *sandstones*, *limestones*, *shales*, *quartzite*, and *chert*, which may occur singly in a succession of the normal rock type or else several of them may be associated with one another.

Sandstones and shales occur on Rooilaagte, twenty-two miles due north of Prieska, where the rocks are much less siliceous and ferruginous than elsewhere, and contain calcareous matter. On one of the hills in this neighbourhood a succession of about 400 feet has been measured, made up of an alternating series of brown calcareous sandstone, hard blue clayey sandstones, grey sandstones, and shales with or without crystalline limestone; one of the shaly bands measures as much as 100 feet in thickness. Softer fine-grained sandstones also occur in the Krantzfontein neighbourhood close to Prieska, interbedded with banded magnetic jaspers. Dark blue or greenish sandstones lie higher up in the series along the north bank of the Orange River between Prieska and Koegas (Folmink, Kloof-fontein, Naragas, etc.).

Limestones appear to occur more often near the top of the series, where they are found in thin bands near Rooilaagte and often resemble

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* A. W. Rogers, Nos. 36 and 38.

the Campbell Rand limestones as blue or grey crystalline rocks with the rough brown surfaces familiar in calcareous rocks long exposed to weathering influences. Other occurrences have been noted on Tolo, north of Rooilaagte, and in Prieska Poort. In some places they are associated with shales and occur not far below the glacial bed near the base of the Ongeluk Volcanic Series, as on Kameelfontein or Koegas Puts, where the thickness ranges up to 150 feet.

Quartzitic rocks, including white, purplish, or greenish quartzites and quartz grit, ranging up to 300 feet in thickness, have been noted in the section of Griqua Town beds near Lucas Dam,* and also occur on Prieska Poort, where a more variable group of rocks is repre-, sented by quartzites, slates, phyllits, banded ironstone, limestone etc. The phyllites contain small lenticular layers of grit, limestone chert, ferruginous quartzite, and arkose ; round the common beacon of Punt, Dumore, and Schans, some twenty-five miles south-southwest of Griqua Town, a bed of coarse quartzitic sandstone has been observed with pebbles of cherty ferruginous material in a more variable succession of the Lower Griqua Town Series.†

Of special abundance near the top of the series are bands of chert, like those of Tolo, associated with thin limestones and hematite rocks.

Although these subsidiary phases are of no importance as economic asbestos horizons, they are of peculiar interest when comparing the distribution of different rocks in the Lower Griqua Town Series of the Cape with the Pretoria Series in the Transvaal, where shales and quartzites so largely predominate. The marked lateral changes in sedimentation appear to have an important bearing on the interrelation between the widely divergent facies, and thus indirectly on the problem of asbestos genesis, referred to in Chapter VI. These changes in their genetic aspects are probably also related to the question whether the softer, more argillaceous phases to be observed at several localities (e.g. Kameelputs) represent the original character of the hard banded ironstones, resulting from subsequent introduction of other material, since there can be little doubt that the rocks have undergone a good deal of alteration since their deposition.

VARIETIES OF CROCIDOLITE OCCURRENCES.

All the asbestos occurrences within the Cape fibre belt belong to the soda amphibole variety, and occur only in the yellow jaspery rocks or banded magnetic dark coloured ironstones of the Lower Griqua Town Series, though on Prieska Commonage crocidolite has been observed in a ferruginous limestone.

The different asbestiform minerals may be classed into the following four varieties :—

(1) *Crocidolite Proper.*—This is the commonest kind and is made up of densely packed lavender blue fibres, usually very regularly

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* A. W. Rogers, No. 36, p. 173.

† A. W. Rogers, No. 38, p. 43.

oriented along interbedded cross fibre seams. It has the general properties described in Chapter I.

(2) *Griqualandite*, a golden yellow softer mineral, with somewhat similar fibrous structure and also occurring as interbedded seams of the cross fibre type. It has a much more restricted distribution and occurs, e.g., on Buis Vley and Westerberg, on the left bank of the Orange River, but is of no use for the manufacture of asbestos goods.

(3) *Tigereye* or *Cat's-eye* is the highly silicified pale brownish very hard variety, characterized by a large amount of infiltrated quartz. It is used to some extent in the manufacture of small trinkets in the jewellery trade, where it is called (wrongly) crocidolite. Comparatively little of this variety is met with, Naauwpoort, in the District of Hay, being the principal locality. It also occurs in interbedded seams, specially in the brownish jaspery rocks, and, in spite of the large proportion of quartz, a distinct fibrous appearance is still traceable, though actual fibres cannot be separated. A thin section shows long narrow oriented ribbons of fresh quartz, often preserving optical continuity throughout their length and alternating with extremely delicate hair-like fibres, presumably of crocidolite, in general orientation with the direction of the original fibrous structure (Prieska Commonage).

(4) *Potential Crocidolite.*—This term may be conveniently applied to certain very remarkable vivid blue or green heavy rocks, which show no resemblance to crocidolite in hand specimens and are without the oriented fibrous structure. These occur fairly frequently, e.g., on Westerberg and elsewhere in the south end of the Doornberg Range, in the Hay District, or on Wonderwerk, near Daniels Kuil; they show a higher specific gravity, as much as 3·27. Usually rocks of this class form distinct bands, occurring here and there in a succession of the more normal type of banded ironstone, as on Wonderwerk, but may give rise to many thin bands over a short section, as on Westerberg. The very close-grained, almost compact, dark blue heavy boulders with smooth shining nearly black weathered surfaces, frequently met with as pebbles in the dry spruits of the Orange River basin or among the gravelly surfaces elsewhere, belong to this same variety of potential crocidolite, and was probably the form in which the asbestiform material was first brought away by Lichtenstein for investigation. Both in the bedded and boulder forms the crushed blue rock is seen on microscopic examination to consist of small fragments with the optical properties of crocidolite, and a thin section of the boulder type is nearly all composed of densely matted aggregates of crocidolite fibres, with less marked orientation and interrupted by small irregular lighter coloured, apparently cherty areas.

There is no reasonable doubt that the bands of potential crocidolite are sediments which have to a large extent undergone subsequent recrystallization into crocidolite, since along the same horizon they are represented by ferruginous sandstones and calcareous rocks.

The conclusion arrived at in the Tenth Annual Report of the Geological Commission, viz., that "Further investigation will prove the derivation of the crocidolite from ferruginous sediments," is borne out by a study of the recent asbestos discoveries in the Lydenburg District, where a greater variety of connecting links are found. The fact that one is there dealing with amosite instead of crocidolite does not appear to the writer to imply any essential difference, since the country rocks in both localities are so nearly identical and both asbestos varieties are monoclinic amphiboles (see Chapter VI).

Analyses of the preceding four varieties appear in Chapter I, that of the heavy blue rock being No. I of the table of composition for crocidolite.

In the case of crocidolite proper, variations from the normal uniformly blue variety are not uncommon. Though, on the whole, rather rare in the southern portion of the fibre belt, they are fairly frequent in the Daniels Kuil and Kuruman areas. Such variations take the form of changes in colour, the lavender blue material passing into pale yellowish or rusty brown phases. This change is not sudden, but gradual, and may be complete in a distance of an inch or more measured along the seam. Sometimes it affects the entire thickness of one band of fibre, and the writer is indebted to Mr. Olds for a very beautiful example from Leelykstaat, on the right bank of the Orange River north of Koegas, in which a cross fibre seam, about ¾ inch wide, of pale lavender blue crocidolite very gradually passes through blended colours of yellowish violet into delicate yellowish fibre. Elsewhere the change is more rapid and pronounced, and yields dirty reddish brown or deep rusty brown tones; these are rather common further north (Wonderwerk, Crawley, Mansfield, Brettby, Hurley, Warrendale, etc.). Such discoloured fibres become harsh to the touch, but, in spite of their unpromising appearance, a limited sale for this cheaper grade has been found. At certain localities, e.g. Crawley or Brettby, these secondary changes are restricted to both ends of the fibres, where they touch the encasing wall of yellow limonitic country rock. After examining a larger number of such variegated deposits, the strong impression is left that they are due to hydration and oxidation, depending upon proximity to the present surface. The great majority of asbestos workings are small quarries, from which short tunnels or stope chambers may extend underground along the dip, but usually only for a few yards, so as to fall still within the zone of weathering. In the deeper workings of the Cape Asbestos Co. this discoloured fibre is not in evidence, except very occasionally.

It is not yet clear what connection is implied by the association of potential crocidolite with cross fibre proper, and whether any analogy can be drawn between this and the predominance of silicified forms in the brown jaspery phases of the Lower Griqua Town Series.

In many workings seams of fibrous crocidolite occur at the surface, and are maintained as such on being followed along the dip; in others the hard yellow material on the outcrops passes after a few feet into soft crocidolite proper. At still other localities the vivid blue layers of potential crocidolite are associated with cross fibre seams of the lavender blue commercial crocidolite. If these changes solely depended on influences conditional upon the zone of weathering, surface outcrops would be expected to show a greater predominance of the hard yellow phase than is the case. On the other hand, the variously discoloured soft seams are most probably due to chemical changes arising in the belt of weathering. In case of the very similar banded ironstones of the Pretoria Series in the Eastern Transvaal, where some of the developments have reached ground-water level and extend to a greater depth, a parallel change is noticeable from the hard yellowish brown or rusty brown rocks at the surface carrying brownish asbestos to soft dark coloured rocks at the lowest levels containing the same groups of seams, but made up of fresh pale grey or whitish amphibole asbestos.

The association of potential crocidolite with crocidolite proper does not appear to have any relationship to the present surface, but expresses stages in the genesis of asbestiform minerals from ferruginous sediments arising from conditions operating at a time long anterior to the present physiography.

In addition to the forms already referred to, asbestiform mineral is occasionally observed in scattered blue needles, of which some can be identified as crocidolite, while others are monoclinic amphiboles of the same, or almost the same, colour, but of somewhat different microscopic characters. The most interesting of the latter occurs on Enkelde Wilgeboom.

Some seven miles below stream from Prieska on the north side of the Orange River, over Wilgebooms Dam and Enkelde Wilgeboom, typical blue crocidolite is abundant, but there are also rocks full of an almost black or very deep blue hornblende in long slender needles, but without the fibrous habit of true crocidolite proper and not distributed as interbedded cross fibre seams. These are the varieties referred to in the Thirteenth Annual Report of the Geological Commission of Cape Colony,* and consist of very dark, strongly magnetic banded rocks, made up of broader layers of fresh dark coloured more or less ferruginous chert, alternating with narrow bands of compact magnetite. In one place the broader layers are densely crowded with slender black elongated prismatic needles, usually about $\frac{1}{5}$ inch long, arranged without orientation; in another there is a tendency to orientation along a common direction inclined about thirty degress to the bedding planes; the thin magnetite layers are practically free from this mineral (183*p*, 190*p*, and 192*p* of the Geological Commission's collections). Thin sections show an almost clear cherty groundmass of very fine quartz mosaic associated with bands of black

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* A. W. Rogers, "Report on the Geology of parts of Prieska, Hay, Britstown, Carnarvon, and Victoria West," Geological Commission for 1908, p. 96.

magnetite or less regular areas and aggregates of the same mineral. Very delicate oriented fibres of crocidolite proper lie in some of the more regular magnetite layers. The conspicuous crystals of the hand specimens are seen as many deep blue sharply defined needles, accompanied by small highly idiomorphic fresh lozenge-shaped sections of the characteristic outlines and cleavage of amphibole. A very close resemblance to crocidolite proper is seen in general habit and intense pleochroism, but the extinction is much less, only amounting to a few degrees, thus contrasting strongly with the value of eighteen to twenty degrees usually associated with crocidolite. One example (No. 188*p*) was crushed, sifted, and the material separated in methylene iodide adjusted to float quartz. The heavy portion appeared to consist only of one fibrous mineral, faintly translucent, magnetic, and anisotropic. This fibrous mineral gave results as follows (analysis by G. Gardthausen, Assistant Curator) :—

SiO_2	37·4	Manganese and titanium tested for and not found.
Al_2O_3	trace	
FeO	50·1	
Fe_2O_3	trace	
MgO	3·6	
Na_2O	7·9	
Ignition	·6	
	99·6	

The preceding remarks show that the mineral in question is a soda amphibole, closely allied to but not identical in all optical characters with crocidolite proper. The occurrence in this district of another but very pale coloured amphibole in star-shaped bunches, the presence of matted tufts of a yellow or pale bluish mineral elsewhere in the fibre belt with an appearance not unlike amosite, and the further occurrence of the last-named amphibole with more variable colours and feeble pleochroism, all containing soda, seem to show that the group of soda amphiboles comprises a number of species, exhibiting some range in colour depth, perfection of fibrous growth, extinction, and pleochroism, so as to differ more or less from the best-known variety of crocidolite proper. Further chemical and microscopic data are wanted before individual members of the crocidolite group can be satisfactorily differentiated.

Distribution of Crocidolite Occurrences.

Crocidolite and its allies are found more or less throughout the entire Cape fibre belt, from the neighbourhood of Prieska in the south to the north at least as far as Tsenin on the Mashowing River in the Kuruman District, through a total distance of some over 250 miles. In the Hay District there is hardly a farm covered by the Lower Griqua Town Series where it does not occur, and many further occurrences lie northwards from Griqua Town through Daniels Kuil to Kuruman and beyond. Instead of being found, like some other mineral deposits, at certain localities only and in well-defined reefs occupying a definite horizon in the succession, the mineral is seen in many and scattered outcrops spread out over a very large number of farms, too great for enumeration.

In the northerly section of the belt crocidolite has been found both in the easterly branch defined by the Kuruman Hills as well as in the westerly limb of the Diometen syncline in the Khatu Khosis Hills.

Only a certain proportion of these occurrences have been followed up by economic developments, but this has steadily increased, specially in the Daniels Kuil–Kuruman section, where asbestos workings only started about ten years ago, whereas some of the older mines nearer the Orange River have been in existence since about 1893.

THE DISTRIBUTION OF THE ASBESTOS WORKINGS, NORTHERN AND SOUTHERN SECTIONS.

Though the fibre belt represents a continuous expanse of the same Lower Griqua Town Series with no essential differences in mode of occurrence of the fibre, associated rocks and general field relationships, it is convenient for practical purposes to recognize a southern and a northern section.

The *southern section* extends from the extreme south across the Orange River to about Griqua Town, and includes all the workings of the Cape Asbestos Co., as well as Elandsfontein, Blackridge, and others. Most of these depend on the De Aar–Prieska–Upington line for railway connection, though the Kimberley line is sometimes used on account of obtaining better chances of transport on return journeys. Included in this section are the Westerberg developments of the Cape Asbestos Co., which are most advanced as regards mining operations and the most important producers.

The *northern section* embraces a great number of more recent workings scattered between Griqua Town in the south, and Tsenin, some thirty miles north of Kuruman. The majority are more concentrated round Daniels Kuil and along the higher portions of the area near the edge of the Kuruman Hills or in the more westerly belt of the Khatu Khosis Hills. These are in a less advanced stage as regards mining development.

(1) *The Southern Section of Crocidolite Workings.*

In the southerly section, which includes the oldest and most productive workings, crocidolite has been found at a large number of localities, among which may be mentioned Westerberg, Buisvley, Nauga, Rietfontein, Kliphuis, Enkelde Wilgeboom, Leelykstaat, Stilverlaats, Kranzfontein, The Kloof, Koegas, Hounslow, Pypwater, Keikams Poort, Klein Naauwte, Naauwpoort, Kameelpoort, Elandsfontein, Blackridge, etc. These are spread over a stretch of hilly country extending from south of Prieska (Keikams Poort) to the neighbourhood of Griqua Town, the bulk of the occurrences being situated on the north side of the Orange River, i.e. in Griqualand West.

Producing Concerns.—During 1917 recovery of crocidolite was carried on by the *Cape Asbestos Co.* on eight farms; by the *Carn Brea Syndicate* on Keikams Poort, some twenty miles south of Prieska in the Doornbergen; by the *Good Hope Syndicate* on Kliphuis and adjoining ground, about six miles north of Prieska, on the right bank of the Orange River; a certain amount of fibre was also produced on *Blackridge*, some thirty miles north-north-east of Koegas, and on *Elandsfontein*.

By far the largest share in the combined output from these concerns falls to the Cape Asbestos Co., who are essentially manufacturers of asbestos goods in Europe and supplement the recovery of raw material from their own mines by purchasing fibre from other producers.

Mode of Occurrence and Mining Developments.—Crocidolite deposits assume the form of interbedded cross-fibre seams, and the regularity with which these conform to the directions of bedding is a very striking feature throughout the fibre area. No instance is on record of such cross-fibre veins being disposed across the lines of stratification.

The deposits are opened up in a more thorough manner on some of the mines worked by the Cape Asbestos Co., who are carrying on production on the following farms:—Koegas, Westerberg, Buisvley, Klein Naauwte, Naauwpoort, Kameelpoort, Leelykstaat, and Stilverlaats. The most thoroughly opened up and also the oldest mine is Westerberg, which, together with Koegas, contributed about 45 per cent. of the company's total output during 1917, and has been exploited since about 1893. On Koegas itself only a small amount of fibre is now obtained, so that the figure quoted above is not far short of the production from Westerberg alone (see table below).

Westerberg lies some thirty-five miles in a direct line north-west from Prieska and extends along the left bank of the Orange River. The mine is situated some three miles from Koegas, the local centre of the company. It occupies the lower slopes of both flanks of a broad, somewhat shallow, boat-shaped valley, tributary to that of the main stream, and surrounded on the east, west, and south by ridges of banded ironstones belonging to the Lower Griqua Town Series and forming the foothills of the Doornbergen. The general trend of this valley is roughly from south to north, merging in the latter direction into the alluvial flats of the Orange River.

The mine was opened up first by surface trenchings (see Plate II), which extend more or less round the entire valley, but the seams are not continuous, being interrupted by stretches of barren country rock. The distance across this depression is from about a quarter to half a mile, the distance from the head to the Orange River measuring in the neighbourhood of two miles. The dip on the eastern flanks being directed roughly towards the west and on the western flanks to the east, the structure approaches a wide synclinal arrangement, but not quite symmetrical with regard to the valley floor, since over the eastern side the dip ranges from forty to eighty-five degrees, while on the western side lower values, down to twenty degrees, are the rule ; locally the detailed structure is more complicated owing to minor folding, as in No. 2 adit on the main " reef." Fig. 2 represents the general disposition of principal groups of crocidolite seams.

The deposits were originally exposed by trenches, from which the seams were followed downwards on the dip ; later on development was extended by means of adits, so that Westerberg is now the most regularly mined asbestos occurrence in the Cape fibre belt. Some twelve adits are now to be found, varying in length up to a maximum of about 1200 feet ; they run with the strike of the country formation and are really drives along the " reefs."

DIAGRAMMATIC SECTION ACROSS THE WESTERBERG VALLEY.

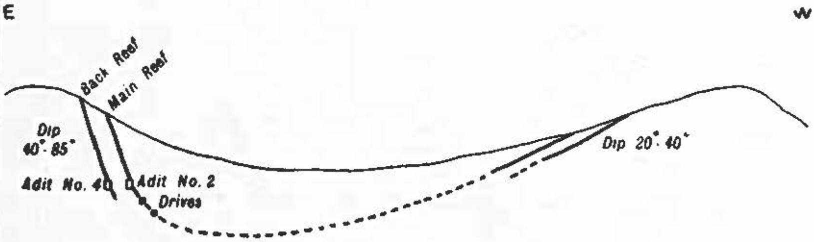


Fig. 2.

Two distinct sets of interbedded cross-fibre crocidolite seams can be distinguished over the mine, and are well defined on the eastern flanks, where they are opened up by two adits, known as No. 4 and No. 2, and connected by cross-cuts. The name, "*Back Reef*" (furnishing about one-sixth of the total Westerberg output), is applied to the lower set of seams, situated more towards the east and exposed along No. 4 adit. About 60 feet of country (measured along the thickness) separates this set from the upper or "*Main Reef*", (furnishing about five-sixths of the total Westerberg output), which lies more to the west and is seen along No. 2 adit—over this part of the mine (see Fig. 2 and Plate II). These " reefs " are conformable, and their former surface trenches ran up to the slopes of the valley, but have by now developed into more extensive stopes, reaching from the surface down to the adits referred to over distances ranging up to 120 feet on the dip. From these adits further development proceeds by means of several shafts inclined with the dip and leading to tunnels or drives at two lower levels. In this way the asbestos-carrying ground is laid out in regular blocks for stoping purposes. Making allowance for such deeper levels, the seam-fibre continuity in the north-eastern portion of the mine has been demonstrated over about 220 feet on the dip.

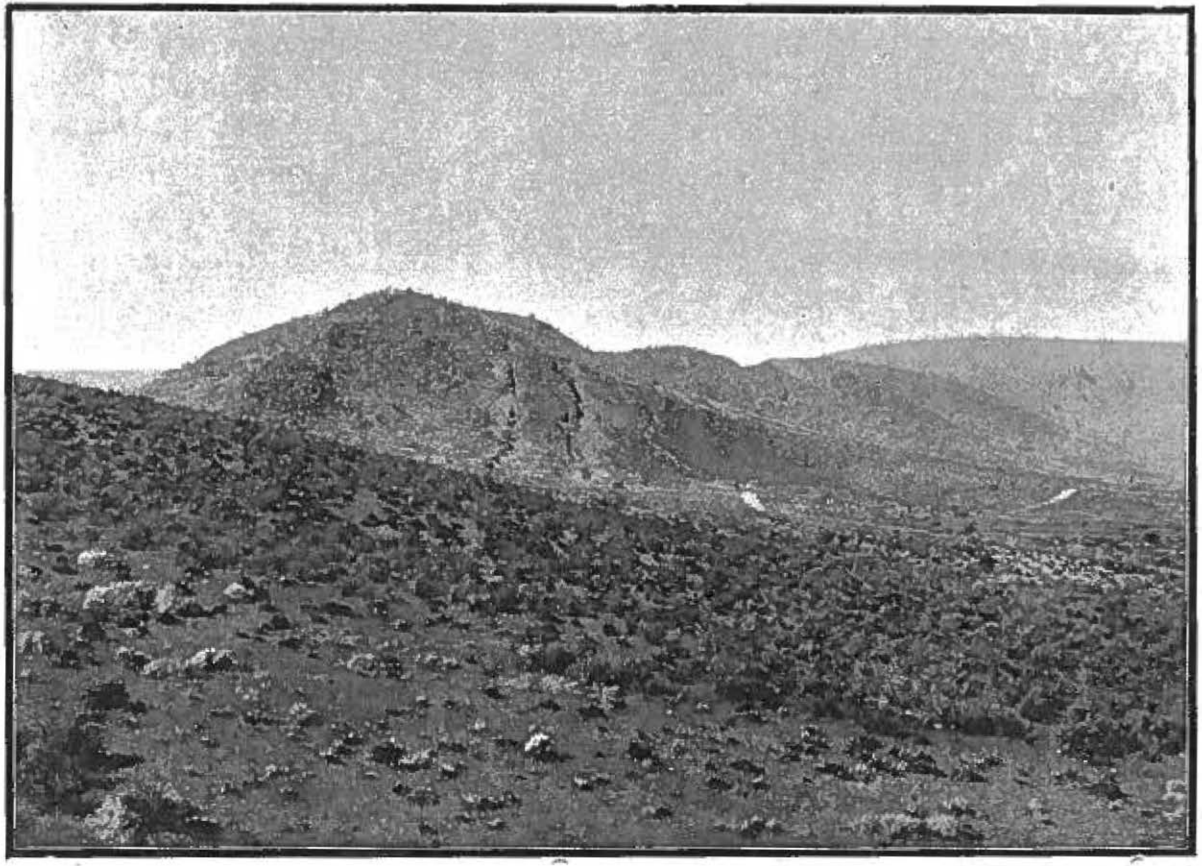


Plate II.—General View along the eastern flanks of the Westerberg Valley, showing the main groups of crocidolite workings—the Main "Reef" (more towards the right) and the Back "Reef" (more towards the left).

Each " reef " consists of a number of interbedded and therefore conformable seams of blue cross-fibre crocidolite ; their number usually ranges from three to seven, spread out over 9 to 15 inches of country rock. This consists of thinly bedded dark bluish or greyish blue shaly ferruginous slates, much softer than in many occurrences at other mines of the company. Locally a series of vivid electric blue very fine-grained bands of " potential " crocidolite (without fibrous structure) can be observed ; where they alternate with greyish yellow bands, a strongly marked striped and variegated effect results. Individual seams often persist without a break for many yards, and such continuity frequently applies to two or three seams running alongside one another and close together. Now and then a seam ends in a gradually tapering manner, but the general persistence of the deposits is never entirely lost throughout the length of a drive or adit on any one section of the mine. Where the strata show minor folds or other contortions, the seams are twisted with the country rocks, when they show a tendency to thicken in the arches and thin down in the troughs. At a break caused by dyke intrusions the whole succession is cut off, showing the vein formation to belong to a period prior to that of igneous intrusion.

From the north-eastern portion of the Westerberg Mine the two principal fibre horizons are traceable at intervals all round the flanks of the valley, but not in direct continuity. Thus a little south of the mouths of No. 2 and No. 4 adits no trace of fibre was located at the surface for a stretch of about 500 feet ; neither have underground workings revealed any fibre, so that a barren zone exists here. Still further south one reaches adits No. 1 and No. 3, along which the Back and Main Reefs have been further developed. In No. 1 adit a basic dyke from 15 to 30 feet wide causes a sharp break in the seam continuity and answers on the surface to a smooth grey feature in the ridge ; for the last 2 or 3 feet before striking the dyke the seams distinctly darken in colour and become harder and more brittle, without losing the fibrous appearance, similar stony variations being traceable on the other side of the dyke. The latter may, perhaps, represent the phase of minor intrusions of that igneous activity of which the Ongeluk Volcanic group of the Middle Griqua Town Series represents the extrusive phase. The changes which the fibre undergoes near the dyke in Westerberg strongly recall similar effects of metamorphism in amosite veins in the Lydenburg District, referred to in Chapter IV. Near No. 1 adit also the persistence of the seam horizon reaches its maximum hitherto observed, i.e. about 400 feet on a forty-degree dip.

On the western side of the valley water level has been reached at a vertical depth of 220 feet below the surface in No. 5 adit, which appears to be the only locality in the Cape fibre belt where ground water level has been struck. Under these conditions the country rock assume a softer, more clayey character, but there is no indication of any deterioration in fibre quality beyond slight discoloration, an experience in close agreement with that observed at the ground water level in the Egnep Mine near Lydenburg (see Chapter IV).

While in many workings a very regular arrangement is maintained as regards dip and strike, distinct folds now and then occur. The Main Reef in No. 2 adit thus shows a sharp and clearly marked fold on such a scale that a triplication of the seam group occurs in a distance of about 50 feet, measured along a horizontal cross-cut, a structural irregularity representing an important and valuable asset in fibre production. To what extent the Back Reef is involved in this folding is not yet established.

Though a close general similarity exists between the Westerberg Mine and the other workings of the Cape Asbestos Co. as regards mode of seam occurrences, there are minor differences in the nature and average length of fibre, as pointed out below; more obvious contrasts are presented by the country rocks, e.g. Stilverlaats, Leelykstaat, or Buisvley.

On *Stilverlaats*, situated some twelve miles north of Koegas, the present development is of recent date only and is following up earlier workings, which were mainly concerned with the present surface. Here the banded ironstones dip from forty-five to sixty-five degrees, and although crocidolite is again restricted to interbedded cross-fibre seams, there are sharp twists in the strata, something like a horseshoe in shape, affecting both seams and country rock. The latter—in contradistinction to Westerberg—consists almost entirely of hard yellowish jaspery rocks, very little of the bluish softer phases being seen. The workings lie close to the common boundary of Stilverlaats and Leelykstaat near a short nek, whence the main level extends for some 200 feet into the slope at right angles to the strike. A little way in, a drive branches off laterally along the strike, but leads back to the main level, owing to the folding. From the latter a number of shafts go down on the dip for about 60 feet, so as to allow the fibre rock to be exploited in regular blocks, 60 feet long, in the direction of strike. The seam continuity is thus proved for a distance of at least 120 feet on the dip. Though the quantity of fibre so far available here is much smaller than at Westerberg, there is a much higher proportion in the neighbourhood of an inch in length.

On *Leelykstaat*, adjoining Stilverlaats, the formation dips from forty to ninety degrees, and also exhibits sharp local folds. Along the main level, extending for some 200 feet into the hill, the Lower Griqua Town Series is represented by a much smaller proportion of yellow jaspery rock than on Stilverlaats; potential crocidolite in the characteristic blue bands is also found on Leelykstaat. Probably the marked subordination of the yellow jaspery rocks in favour of the bluish ferruginous shales is in some way associated with more stringy and darker coloured fibre, both on Leelykstaat and Westerberg, as contrasted with Stilverlaats (Buisvley and Keikams Poort). Yellow tigereye—the so-called crocidolite of the jeweller—has also been recorded from Leelykstaat, and the occasional occurrence on this farm of colour combinations showing a gradation within the same seam from pale bluish crocidolite proper to golden yellow fibre of the griqualandite type was referred to above. Leelykstaat only began to be systematically developed during the last twelve months or so; hence the output is still small, but a higher percentage of long fibre to some extent compensates for this.

Among the remaining farms of the Cape Asbestos Co. may be mentioned Buisvley and Klein Naauwte, situated some fifteen miles north-west of Prieska, the former on the left and the latter on the right bank of the Orange River. Over the *Buisvley workings* the country formation consists of very regularly banded and hard but brittle jaspery ironstones with a pronounced dirty yellowish colour, in strong contrast to the Westerberg, while closely resembling the Stilverlaats and Keikams Poort variety of country rock. The development of Buisvley consists mostly of long surface trenches, following the strike and passing now and then into tunnels or stopes along the low dip; on the whole, the country is very little disturbed. A single fibre horizon is composed of from two to five seams, of which only one is generally payable; it has been shown to persist up to a depth of about 70 feet on the dip, the payable seam frequently maintaining a fibre length round 1 inch.

Near Buisvley some crocidolite workings on Nauga illustrate the exceptional occurrence of fibre seams high up, practically on the crest line of the Doornbergen. Far more commonly the fibre occurrences in the southern section lie over the lower slopes of the hills. Possibly this topographical restriction depends on the particularly hard nature of those rocks which gave rise to the highest portions of "ridge-poles" of the major ranges, but the rule is not without exception.

South of Koegas and within some six miles north of Prieska are the workings of the *Good Hope Syndicate* on Kliphuis, etc., close to the right bank of the Orange River, while some twenty miles south of Prieska, in the Doornbergen, the *Carn Brea Syndicate* have opened up a number of deposits on Keikams Poort.

Keikams Poort is a rather wide but very conspicuous gap in the Doornbergen; after passing through it from the east, one enters a wider longitudinal valley running almost due north and south. It narrows into a kind of kloof near its northern end, where the main asbestos workings are situated. The principal development has been over a comparatively small area, locally referred to as the "horseshoe," on account of the contorted strike; in addition, fibre has been located in a number of prospecting works over surrounding portions of the farm. The "horseshoe" workings occupy the lower slopes round the northern head end of the valley in a succession of hard yellowish jaspery ironstones, closely resembling the country rocks of the Buisvley and Stilverlaats Mines and dipping from forty to eighty degrees to the north-west. Running up these slopes are two conspicuous sets of surface workings some 450 feet in length, and separated by a thickness of about 80 feet of ironstone. These two groups of workings correspond to the principal seam horizons, across which the succession is as follows, from west to east :—

Topmost Reef : Locally payable.
Ironstone—a few feet.
Top Reef : Payable.
Ironstone—about 80 feet.
Bottom Reef : Payable.
Ironstone—a few feet.
Lowermost Reef : Not payable.

SKETCH PLAN OF A PORTION OF KEIKAM'S POORT SHOWING THE FOLDED ASBESTOS SEAMS ROUND THE "HORSESHOE."

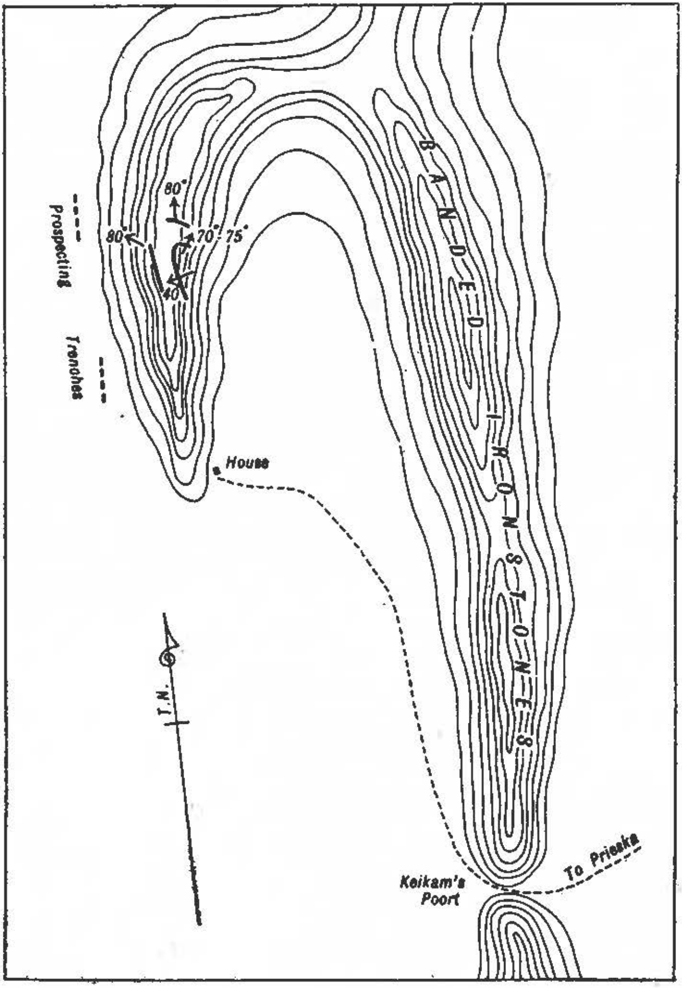


Fig. 3.

Following the surface from the valley floor upwards in a general northerly direction, the strike is at first normal and the beds scarcely disturbed. but higher up the dip rapidly increases to eighty degrees.

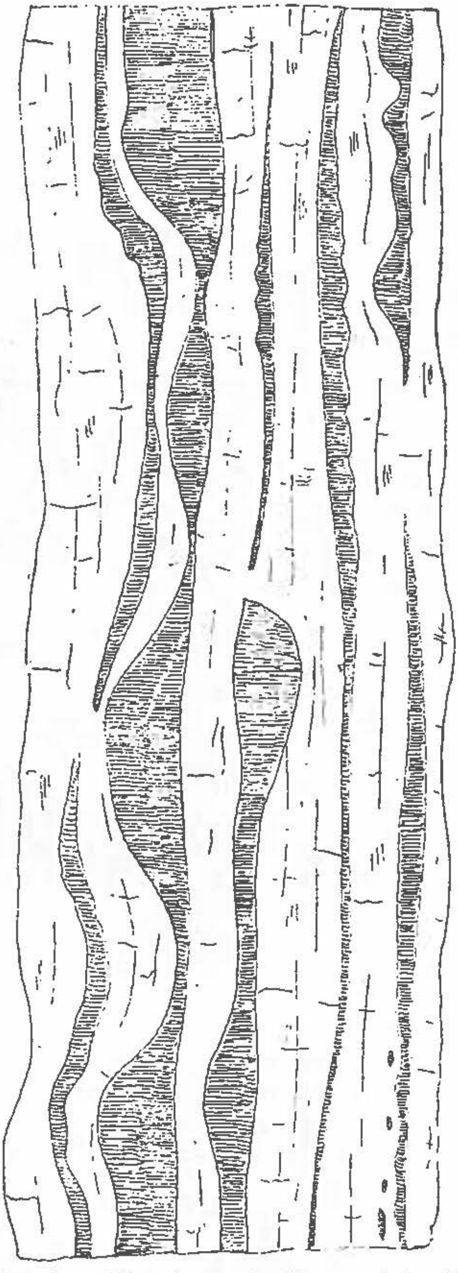
while the strike bends very steeply round the east and north-east, so as to cause curved dip slopes in places (see Fig. 3). The development includes some twelve adits, of which the longest extends for 250 feet, the seam persistence at present reaching the maximum of 220 feet on a forty-degree dip. Each of the two principal reefs (Top Reef and Bottom Reef) consists of several seams, usually from three to five, occasionally as many as ten, of which, as a rule, only one or two are payable; they occur again in the form of interbedded cross-fibre seams of blue crocidolite. Owing to the hard nature of the country rocks, development has proved somewhat expensive, though practically no timbering is required.

The method of working the mines adopted by the Cape Asbestos Co. and others, e.g. the Carn Brea Syndicate, consists in laying out the fibre ground in blocks of uniform size and handing them over to the natives for stoping. The dimensions of such sections vary in different mines. On Stilverlaats the blocks measure 60 feet in length along the strike and 60 feet in depth along the dip; on Westerberg they measure 100 feet along the strike and 60 feet on the dip. They are handed over to two boys, who contract to stope out the whole slab of asbestos rock, being paid by the foot of stopage, in addition to receiving so much per bag of cobbed fibre, according to the grade; all necessary tools and mining material, except candles and dynamite, are supplied. Work begins at the bottom of a section and proceeds by horizontal strips, 6 feet high, and continued for the whole length of the block. A slab of " reef " formation, 100 feet long, 6 feet high, and not less than 18 inches thick, takes on the average about three months to remove, the entire section being completed in from two to three years, during which waste rock accumulates from below upwards. A little under eight bags (of 112 ℔. each) per month is an average rate of cobbed fibre production, and it is estimated that thirty tons of rock must be shifted for one tone of fibre recovered. Very little timbering is necessary.

Characters of the Seams and Fibre.—The very striking regularity of the interbedded cross-fibre mode of occurrence has already been emphasized. More often than not the crocidolite deposits are found in groups of seams, generally concentrated in a smaller width of country rock. Individual seams are always sharply defined against their containing walls, which along the stopes and drives appear as sharp straight lines, but not infrequently one or other, sometimes both, margins form irregular wavy lines, presenting an infinity of variety in their undulations. These appearances may be described as " cone " and " corrugated " structures. Bifurcation of one seam is rare and then encloses very acute angles.

The phenomena of "cone" and "corrugated" structures are well displayed at Westerberg and other mines of the Southern Section, but are repeated with essentially the same characters in the Northern Section (e.g. Wonderwerk, Warrendale, Cubbie, etc.), while they have also been noted in the Lydenburg–Pietersburg fibre area, both in crocidolite and amosite seams (see Fig. 4).

Corrugated Structure in Crocidolite. Warrendale, near Daniel's Kuil.

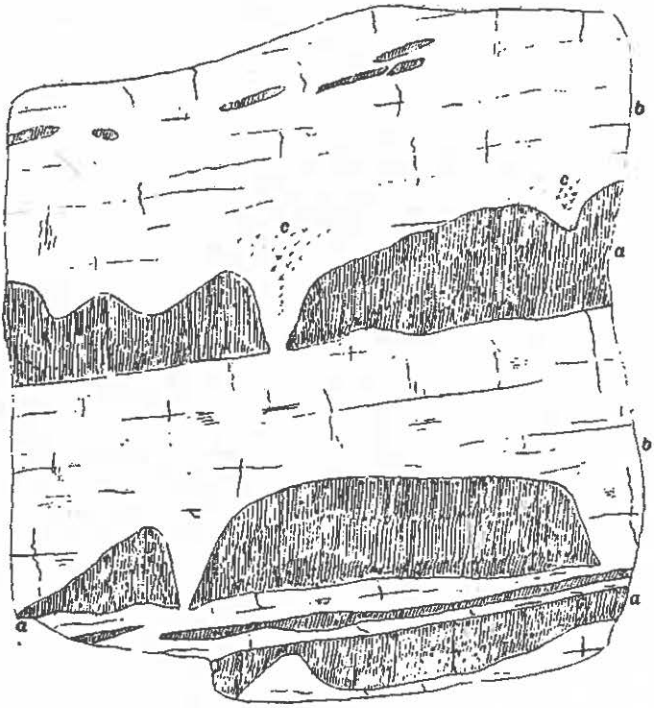


Irregular seams of blue, yellow, and chocolate coloured crocidolite in pale brownish jaspery ironstones.

Fig. 4 (Natural Scale).

Often the dip slopes of country rocks in direct contact with a sheet of fibre exhibiting such structures show a series of corrugations, sometimes distributed more regularly in a group of parallel ridges and troughs, the former corresponding to long and the latter to shorter fibre. In length and amplitude such waves vary between fairly wide limits; at the same time the ridges may slope symmetrically towards the troughs, or else the slopes are steeper on one side. On the dumps of the Westerberg Mine and elsewhere (e.g. Cubbie in the Kuruman area) casts of such irregularly banded seams can be picked up, which in their furrowed, pitted, and generally complex undulating surfaces illustrate the variable disposition of the walls bounding a seam. The term "cone structure" is applied to those very rapid and sudden increases in fibre length which are reflected on dip slopes by isolated conical outgrowths, sometimes scattered sparingly, sometimes occurring in many small peak-like protuberances up to about 2 inches high, so that a larger slab of seam with its adhering country rock resembles a miniature relief model of an island landscape or of a number of conical peaks associated with straight valleys or ridges in a region of high surface relief.

CONE AND CORRUGATED STRUCTURE IN AMOSITE, PIETERSBURG DISTRICT.
(No. 4202 S.A. MUSEUM.)

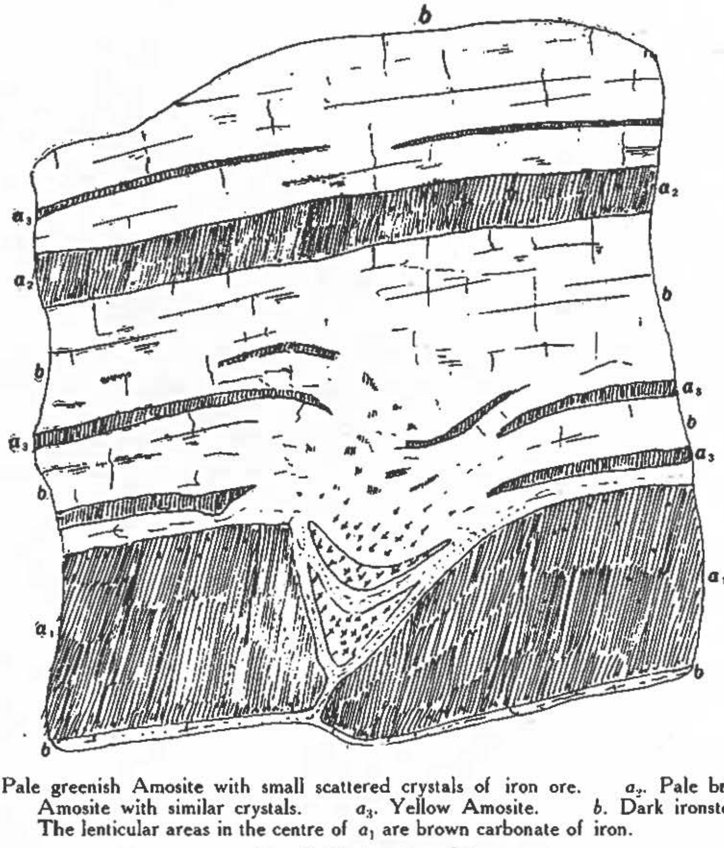


a. Cross fibre pale greenish yellow Amosite with scattered crystals of iron ore.
b. Dark banded ironstone. *c.* Carbonate of iron.

Fig. 5 (Natural scale).

In a section along a drive or stope these irregularities appear as conical prolongations of country rock into a seam (see Fig. 5) with an outline approximating an equilateral triangle, the apex of the triangle being directed now downwards, now upwards into the succession, while the axis of the "cone" sensibly coincides with the common fibre orientation. Not uncommonly some carbonate material, probably of secondary origin, occurs within the triangular area (see Figs. 5 and 6). Wherever a seam of even width begins to develop these structures, a rapid variation in fibre length is readily apparent. The views of crocidolite and amosite genesis developed in Chapter VI preclude the deposition of fibre by lateral secretion in open spaces, but depend upon growth *in situ*, and the general impression left by the phenomena of "cone" and "corrugated" structures is that they are conditioned by variations in fibre length, depending either upon unequal rate of growth or on growth maintained for a longer period of time at certain points. During growth a certain degree of pressure was no doubt exerted on the country rock, as evidenced by the disturbed extension of bedding planes in a festoon-like manner across

CONE STRUCTURE IN AMOSITE. PIETERSBUG DISTRICT.
(NO. 4197 S.A. MUSEUM.)



a_1. Pale greenish Amosite with small scattered crystals of iron ore. a_2. Pale brown Amosite with similar crystals. a_3. Yellow Amosite. b. Dark ironstone. The lenticular areas in the centre of a_1 are brown carbonate of iron.

Fig. 6 (*Natural scale*).

some of the conical portions of country rock (see Fig. 6). The predominance of undulations on only one side of a seam appears to suggest that growth began along one side of a stratum of suitable composition and proceeded upwards or downwards at varying rates or as the same rates for varying time periods.

In a recent contribution by Professor Taber,* the phenomena of asbestos veins have been closely imitated experimentally by partially immersing a porous battery cell in a saturated solution of copper sulphate, when cross-fibre veinlets of crystals were produced with rupturing of the cell walls.†

Individual crocidolite seams consist on an infinitely large number of very tightly packed and thoroughly oriented extremely delicate blue flexible fibres, disposed sometimes truly at right angles to the planes of stratification, but more often inclined to these at angles departing from verticality by anything up to ten or fifteen degrees; exceptionally such departure amounts to forty degrees or over, as on Leelykstaat and Stilverlaats. Now and then an apparently wider seam is seen on close inspection to be interrupted by a delicate irregular stony parting; scattered particles of foreign minerals, which sometimes destroy the commercial value of crocidolite in other fibre areas, are very rare in the Cape belt. The same fibrous structure is maintained throughout a seam, except where, owing to the effect of igneous intrusion—as explained above—the fibre becomes brittle. The colour is invariably blue in fresh seams and varies from pale lavender tint to a dark steely blue, a change often associated with a certain gradation in the perfection of fibrous structure. Paler lavender colouration often goes with high fleeciness, depending upon a very highly developed fibrous structure, so as to lead to a consistency not unlike silk. Dark coloured seams, specially when associated with bluish softer and more shaly ferruginous rocks, often exhibit a more stringy consistency; this kind is the most highly prized variety of crocidolite for the factories of the Cape Asbestos Co. The former often goes with hard yellow jaspery rocks. In the Westerberg Mine blue fibre is maintained as such from the surface to the lowest depths so far reached, and no clear evidence has yet been found of "potential" (mass fibre) crocidolite passing gradually into the oriented fibrous variety; certain phases, probably to be regarded as intermediate between "potential" and true crocidolite, are referred to below. Lumps of fibre long exposed to weathering influences acquire a darker appearance, at times not unlike coal, but fresh fractures once more exhibit the more common lavender bluish tints.

Variations from the common blue kind are much rarer in the southern than in the northern section. Colour combinations, ranging from pale delicate blue through violet to yellow tones, have been

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* S. Taber, "The genesis of Asbestos and Asbestiform Minerals." Bull. Amer. Inst. Min., Eng., 1916, pp. 1973–1998.

† Compare A. L. Hall, "On the mode occurrence and distribution of asbestos in the Transvaal." Trans. Geol. Soc., S.A., 1918, p. 21.

observed in one and the same seam from Leelykstaat, and discoloured fibre is also found at water level on the western portion of the Westerberg Mine. On Keikams Poort, specially round the vortex points of the horseshoe fold, several varieties of oxidized fibre are fairly common in vivid gold or bronze yellow and dirty silvery grey tones.

The *length of fibre* or thickness of seam varies between wider limits, though the bulk of the deposits fall within narrower limits. The greatest length hitherto observed over the mines belonging to the Cape Asbestos Co. is 5 inches on Stilverlaats; the longest fibre on Westerberg was 4 inches. Such fibre is very rare and only forms small pockets, the latter instance producing about half a ton only. In going through the various workings, one now and then observes a seam 2 inches or a little more in width, but values ranging from ½ inch to 1 inch are by far the commonest. In arriving at the average fibre length for one mine or all mines together belonging to the above company, the detailed output of each grade in each mine has been used, covering the year 1917. Since the company are working eight separate mines and contribute the largest share of the whole output for the Southern Section, the average obtained from their figures probably approximates very closely to that of the whole workings in the section. The writer is indebted to Mr. Rundle Olds for the detailed information required for these rather laborious calculations, which give ·62 inch as the average over the mines together, individual mines giving average lengths ranging from the minimum of ·508 inch on Naauwpoort through ·750 inch on Leelykstaat to 1·027 inch on Stilverlaats as the maximum.[*] According to Mr. Neil MacLeod, for the Carn Brea Syndicate, who have now[†] been developing Keikams Poort for twenty months, the proportion of longer fibre (1 inch and more) for the last six months has averaged about 50 per cent. of the output, that of grade E (over 2⅛ inches) so far only amounting to about two tons.

The influence of depth has so far scarcely affected fibre quality, but at several places (e.g. Westerberg, Keikams Poort, Buisvley) a tendency has been noticed for the seam thickness to decrease at lower levels, expressed by the same seam showing shorter fibre length, or being represented along its horizon by more numerous and thinner seams. No marked deterioration, on the other hand, is noticeable in other qualities, but there is an appreciable increase in specific gravity.

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[*] In arriving at these figures I have ignored grade E (length 2 in.) which only formed ·138 per cent of the total output of the company during 1917.

[†] April, 1918.

Preparation for the Market.—After leaving the mine the lumps of fibre rock are worked up for the market by methods essentially the same throughout the Southern Section, though rather more advanced in case of the Cape Asbestos Co. These operations may be distinguished as cobbing, sieving, and bagging.

Cobbing is performed in close proximity to the mouths of the adits, etc., and by native hand labour without machinery (see Plate III). The rock matter adhering to seams is removed by pounding the asbestos rock with square-shaped hammers on stone anvils, after which the separated fibre is grouped according to the established grades. It is found that, after some practice, the standards of length can be maintained with considerable nicety by the eye alone, so that, after careful scrutiny, the various grades are ready for bagging. In some workings the whole production is subjected to hand cobbing alone, without the subsequent process of sieving. In other cases, e.g. Koegas and Westerberg, cobbing is applied down to fibre ¾ inch in length, all asbestos of shorter length going to a common pile for later sieving.

The sieving process serves to separate several grades of short fibre, and is usually carried out, both in the southern and northern sections, by an inclined cylindrical sieve of wire-netting or perforated sheet-iron, open at both ends and revolving by hand labour (see Plate IV). Sometimes the whole sieve is made of mesh of one size; in other cases it consists of two halves of different coarseness, or is otherwise slightly modified to suit particular grading schemes.

At Koegas, the local headquarters of the Cape Asbestos Co., all fibre below ¾ inch from certain mines, e.g. Westerberg, is sieved by rather more elaborate machinery, including first the use of the simple sieve referred to, followed by further treatment in the classifier (see Plates V and VI); this combined process yields the grades known as X (0 inch to ¼ inch), S (¼ inch to ½ inch), and A (½ inch to ¾ inch). All fibre less than ¾ inch with its detrital rock chips is introduced into the upper end of the single cylinder hand-sieve, provided with uniform meshes of such dimensions that the undersize (what falls through) constitutes a mixture of grades S and X with rubbish. The oversize passes on and forms grade A (½ inch to ¾ inch). The undersize is next removed to the classifier and first passes (see Plate V) between two short cylindrical metal rollers, pressed tightly against one another, but capable of some yielding action. Their rates of revolution are slightly differentiated, so as to subject the fibre to a kind of tearing action; from them the material is discharged into the innermost cylinder of the classifier. This ingenious device consists of four slightly inclined coaxial cylinders of perforated sheet-iron, the perforation diminishing in size by slight intervals from the innermost to the outer ones. At the roller end the cylinders are conterminous, but overlap towards the lower end (see Plate VI). What passes out of the shortest or outermost cylinder is rejected, while the oversize from the next two forms grade X (0 inch to ¾ inch);

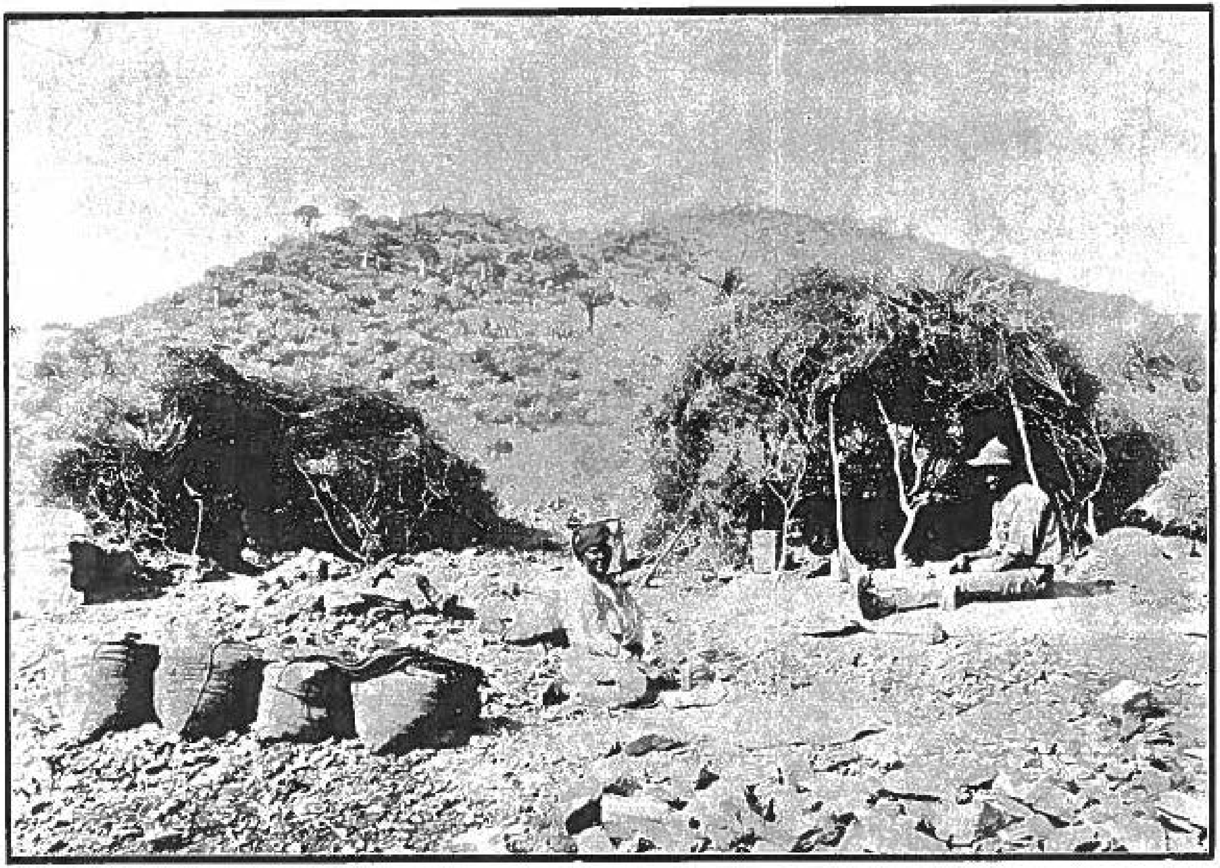


Plate III.—Cobbing Operations, Westerberg Mine. Cape Asbestos Co.

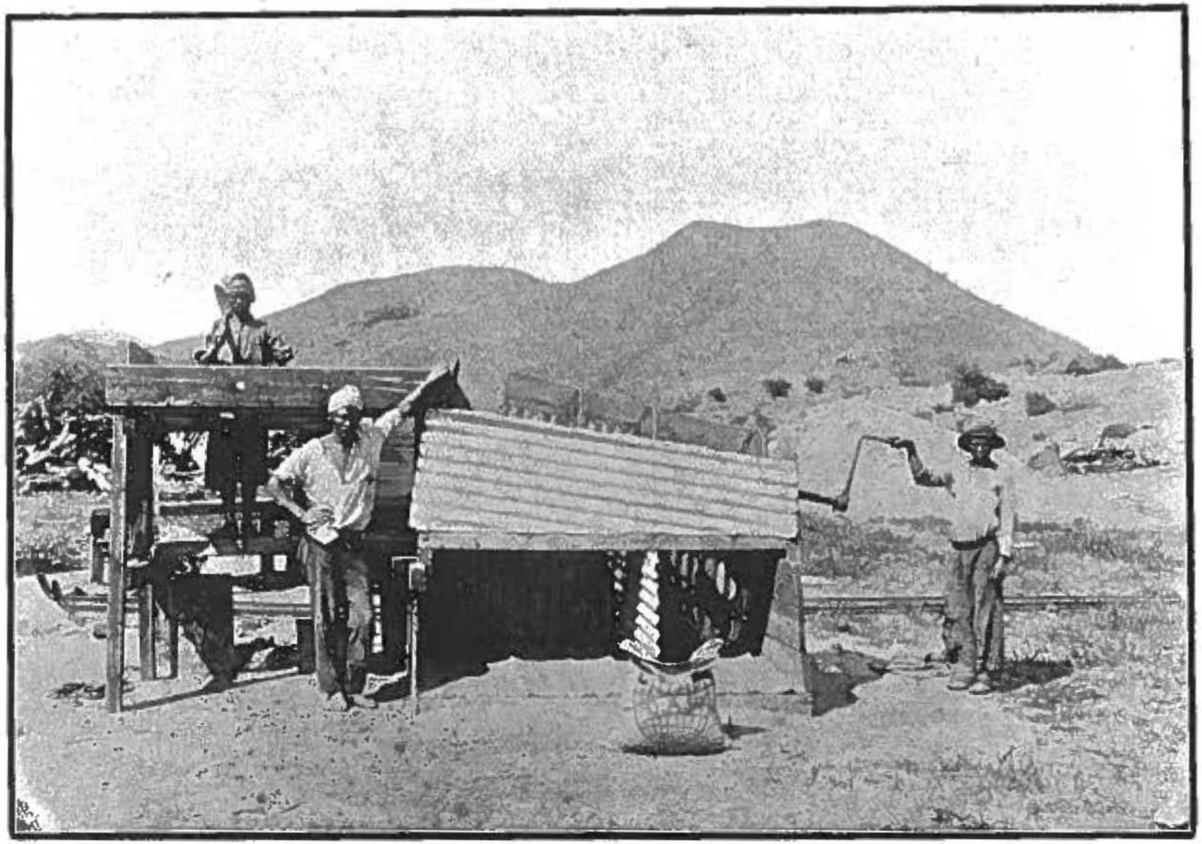


Plate IV.—Preparation of shorter crocidolite grades for the market ; the operation of hand sieving at Koegas, Cape Asbestos Co.

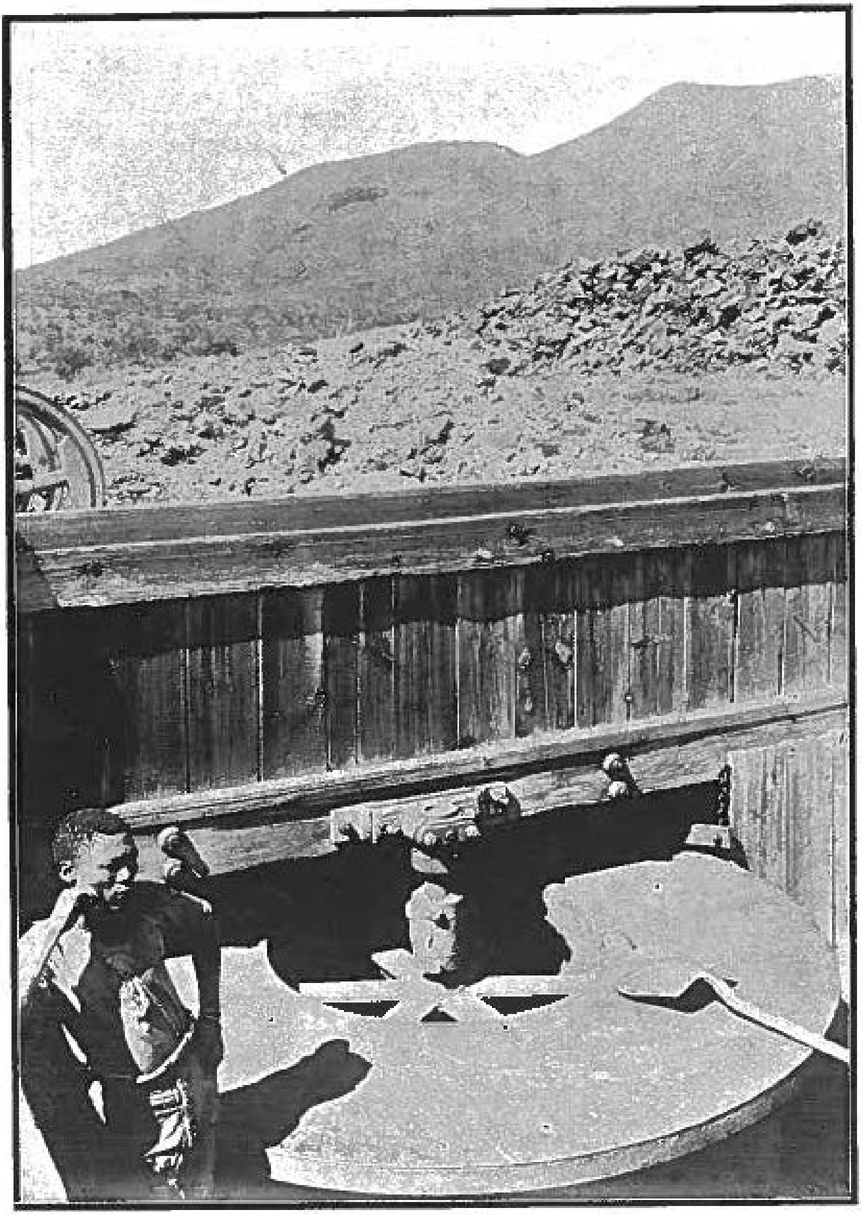


Plate F.—Preparation of shorter grades of crocidolite for the market; the upper end of the classifier, where mixed fibre enters the rollers. Koegas, Cape Asbestos Co.

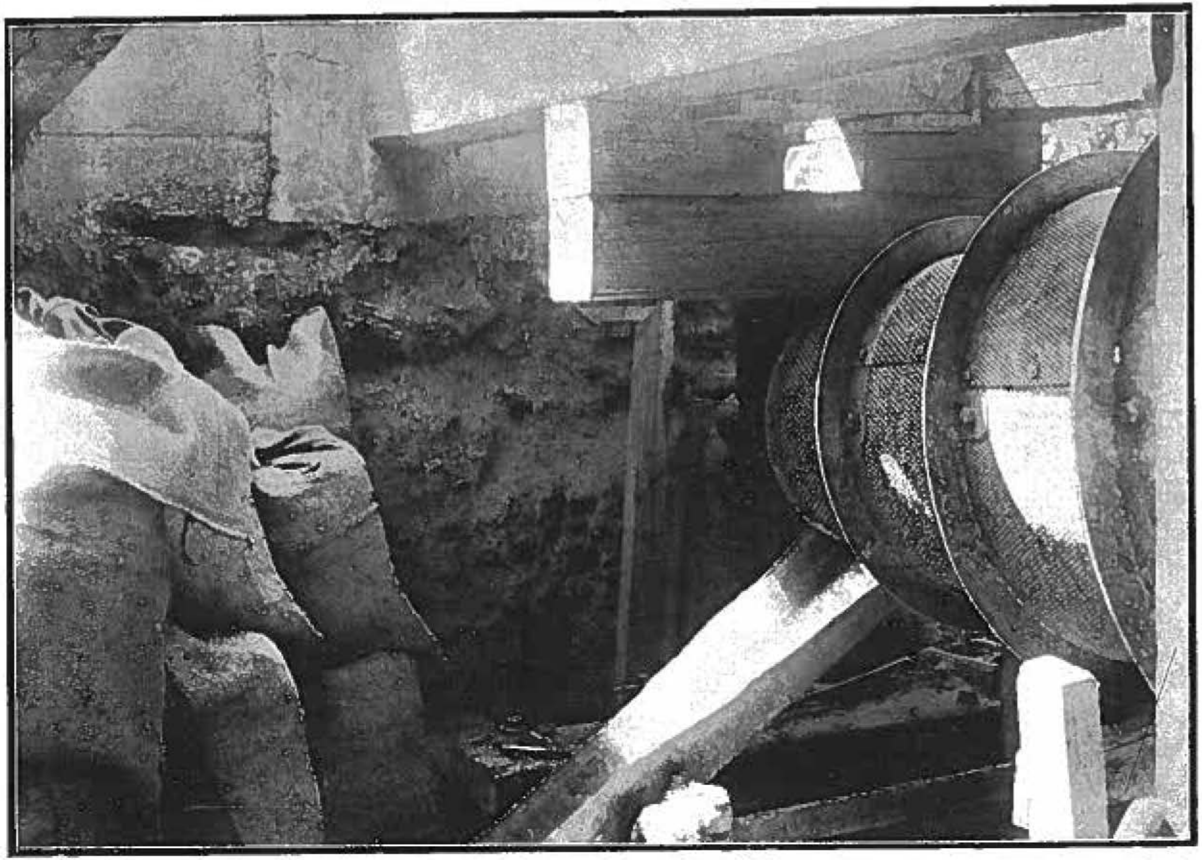


Plate VI.—Preparation of shorter grades of crocidolite for the market. The classifying cylinders (for explanation see text). Koegas, Cape Asbestos Co.

finally from the innermost cylinder (provided with the largest perforations) the oversize issues at its lower end as grade S ($\frac{1}{4}$ inch to $\frac{1}{2}$ inch)—(see Plate VI).

Grading is invariably based on fibre length and a variety of schemes are in use. The Cape Asbestos Co. recognize the following :—

GRADING SCHEME OF THE CAPE ASBESTOS COMPANY.

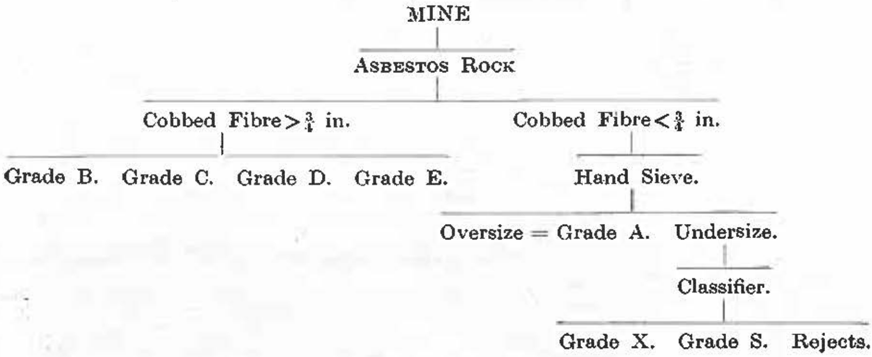
Designation.	Description.	Remarks.
X	0 in. to $\frac{1}{4}$ in.	Graded by machinery.
S	$\frac{1}{4}$ in. „ $\frac{1}{2}$ in.	
A	$\frac{1}{2}$ in. „ $\frac{3}{4}$ in.	
B	$\frac{3}{4}$ in. „ $1\frac{1}{4}$ in.	Grading by hand only.
C	$1\frac{1}{4}$ in. „ $1\frac{3}{4}$ in.	
D	$1\frac{3}{4}$ in. „ 2 in.	
E	greater than 2 in.	

In case of the Carn Brea Syndicate the scheme assumes the following form :—

CARN BREA SYNDICATE'S GRADES.

Designation.	Description.
S	Up to $\frac{1}{2}$ in.
A	$\frac{5}{8}$ in. „ $\frac{3}{4}$ in.
B	$\frac{7}{8}$ in. „ $1\frac{1}{8}$ in.
C	$1\frac{1}{4}$ in. „ $1\frac{3}{4}$ in.
D	$1\frac{7}{8}$ in. „ $2\frac{1}{8}$ in.
E	over $2\frac{1}{8}$ in.

The complete schedule of operations thus assumes this form :—



Quantity of Fibre available—Output, Spinnability Ratio, Prices, and Disposal.—To give any accurate estimate of the total quantity of crocidolite available in the Southern Section is out of the question, in view of the fact that of the very large area of fibre formation only a mere fraction has been opened up. There is no doubt that in at any rate some of the mines the output could be materially increased without any difficulty. It may be confidently asserted that very large quantities of fibre are available, even if only the comparatively few present workings were to be carried down to the maximum depth to which the seam persistence has been demonstrated. The relatively small output—compared with some foreign fibre areas, notably the Canadian chrysotile deposits—is largely due to the difficulties of overcoming the severe competition of white asbestos, with its much larger and more regulated supply, difficulties which have obliged the Cape Asbestos Co. to establish their own factories. In course of time an improvement in this respect may be anticipated with confidence (see Chapter VII), when the present abnormal difficulties of freight and general unstable market conditions have improved.

The total output for the Cape fibre belt is given in Chapter VIII. All the mines of the Cape Asbestos Co. lie in the Southern Section and account for the bulk of the production from that section, of which about seven-ninths represents the production of the main company for the second half of 1917.

The output * of each grade throws some interesting light on the proportions of fibre length, and is as follows in case of the Cape Asbestos Co. :—

OUTPUT DURING 1917 OF THE CAPE ASBESTOS COMPANY.

Grade.	Description.	Long Tons.	Percentage.	Remarks.
X..........	0 in. to ¼ in......	69·55	5·729	Non-spinnable = 35·478%.
S..........	¼ in. ,, ½ in......	363·60	29·949	
A..........	½ in. ,, ¾ in......	538·00	44·314	Spinnable = 64·322.
B..........	¾ in. ,, 1¼ in......	192·60	15·864	
C..........	1¼ in. ,, 1¾ in......	37·25	3·068	
D..........	1¾ in. ,, 2 in.......	11·40	·938	
E..........	over 2 in.......	1·65	·138	
		1,214·05	100·000	

In the above output individual mines share according to this table :—

OUTPUT DURING 1917 FOR SEPARATE MINES OF THE CAPE ASBESTOS COMPANY.

Mine.	Long Tons.	Percentage.
Westerberg and Koegas......	553·45	45·587
Buisvley....................	97·65	8·043
Klein Naauwte...............	137·30	11·310
Naauwpoort..................	162·25	13·364
Kameelpoort.................	218·70	18·014
Leelykstaat.................	9·90	·815
Stilverlaats.................	34·80	2·867
	1,214·05	100·000

Some idea of the scale of operations under which the mines are being developed may be gathered from the fact that on Westerberg, the largest mine in the Southern Section and with a monthly output varying between 30 and 35 long tons, some seventy natives are employed, and about the same number on Keikams Poort (April, 1918). A comparatively small mine, like Buisvley, employs about fourteen.

The limit of spinnability has been variously estimated as from ⅜ inch to ¾ inch, and fibre between these limits is not considered directly adapted for yarn without some proportion of fibre over ¾ inch being added.

Taking the limit as ½ inch, over 64 per cent. of the main company's output is spinnable (see above table). In this respect the Cape fibre area is greatly superior to the Canadian chrysotile fields.

The prices realized depend upon the fibre length, and in case of the Cape Asbestos Co. range from £10 to £60 per long ton free on board at Capetown. The average selling price for the Carn Brea

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* Allowance has been made in these tables for the Leelykstaat and Stilverlaats records embracing only the second half of 1917.

Syndicate amounted to £23 per long ton for the first twelve months, free on rail Prieska, since when the figure has risen to £26, the increase denoting a higher percentage of larger fibre ; the extreme values were £15 and £50.

The various grades are put up in uniform bags of 112 ℔. each, this size being easy to handle and bearing a simple proportion to the long ton. They are sent by road to Kimberley, Draghoender, or Prieska Stations. The Cape Asbestos Co. deliver mostly to Draghoender, about eighteen miles from the Westerberg Mine, but their Buisvley and Klein Naauwte Mines deal directly with Prieska by road, to which station also goes the production from the Good Hope and Carn Brea Syndicates.

During 1917 the average monthly production of the Cape Asbestos Co. was about 105 long tons, and about the same amount was bought from other producers per month. Since this company are the principal manufacturers of blue asbestos goods, the supply goes to feed their factories, one each at Turin, Laval in Northern France, and Barking, near London ; their fourth factory at Bergedorf, near Hamburg, was supplied up to the outbreak of the war. A beginning has also been made with the use of Cape "Blue" for the manufacture of asbestos building material in the Union (see Chapter VII).

Distinctive Characters of the Southern Section.—Though the mode of occurrence and no doubt also the origin of crocidolite are identical over the whole of the Cape fibre belt, its southern has certain distinctive features as compared with the northern section. The average fibre length is probably slightly lower in the former, where there is also a larger proportion of the deep blue stringy variety ; its tendency to predominate in the bluish more shaly kind of ironstone—of rather more common occurrence in the Southern Section—has been pointed out. This variety is specially desired by the European factories for spinning purposes.

In the present part of the fibre area a greater proportion of more systematic underground mining development is going on, partly because some of the mines have been exploited for a longer period, but partly also on account of the more limited application of the contract system of labour ; the special effects of this are more noticeable in the Northern Section, where prospecting for fibre and the methods of opening up deposits are often left to the natives, whereas in the southerly parts the selection of mine ground and its methods of development are more often directly controlled by the management.

(2) *The Northern Section of Crocidolite Workings.*

In this section a number of smaller companies and syndicates have been prospecting and developing crocidolite for about ten years. Among these may be mentioned the Northern Asbestos Co., Messrs. Gillanders & Campbell's Syndicate, the Crown Lands Syndicate, and Harris' Syndicate ; of these the first named is next in importance to the Cape Asbestos Co. These concerns, as well as the remaining ones, usually hold a number of farms, some of which are being exploited at a larger number of localities. Thus the Northern Asbestos Co. is interested in Warrendale, Owendale, Wonderwerk, Fairview, Happy Valley, Cubbie, and Kramersfontein; Gillanders and Campbell's Syndicate includes Brettby, Hurley, Klipvley, and Gamohaan. Crawley is one of the holdings of the Crown Lands Syndicate, while Harris' Syndicate controls twelve holdings, of which seven are worked and five prospected, partly situated on Crown lands, partly on native reserves. Other crocidolite occurrences or workings lie on Khosis, Lambley, Fairholt, Carrington, Woodstock, Langley, Newcastle, Skietfontein, Langsrust, Billinghurst, Mansfield, Gamopedi, etc., though this list * is not exhaustive.

In some cases the workings are situated on private ground; where they fall on Government ground, the interest may take the form known as a base mineral lease, carrying a higher rental, but permitting an unrestricted exploitation of asbestos, or it may be a prospecting area, to be acquired on more favourable terms, but limiting the disposal of fibre to such quantities as are required for through tests.

From Owendale, nine miles south-west of Daniels Kuil, these workings extend northwards to Tsenin, on the Mashowing River, through a distance of some eighty miles and over a belt of country up to eighteen miles wide. A greater number are concentrated in the Daniels Kuil vicinity, but here and elsewhere generally nearer the western limit of the Kaap Plateau, scattered over the higher parts of the Kuruman Hills, though several workings lie on the easterly of the two main belts of Lower Griqua Town Series that are separated by the Middle Griqua Town or Ongeluk Volcanic Series along the Diomoten Syncline. The better exposures over the more elevated tracts of country, better accessibility from Kuruman and Daniels Kuil as the main centres of habitation, and questions of transport may account for the tendency of the workings to keep to the main feature of the hills, but the possibility of a genetic reason is not excluded, and the repetition of further workings along the Khatu Khosis Hills may depend on the synclinal reappearance of the lower horizons of the Lower Griqua Town Series, while the apparent repetition of occurrences across the strike from west to east might, in fact, be accounted for by minor folding or faulting; this question is touched upon in Chapter VI. The northern limit is at present at Tsenin, thirty miles north of Kuruman, but there is little doubt that the fibre belt continues, though probably exposed at intervals only, into the Bechuanaland Protectorate, a practical limit being set to exploitation by scarcity of water, inaccessibility, and other economic working conditions.

The great similarity in geological conditions between the various workings recommends a general over a topographical order of treatment.

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* Most of these names are shown on the Geological Maps, Sheet 49, Kuruman, Sheet 45, Postmasburg, of the Cape Geological Commission.

Mining Operations.

These, in their local characteristics, are to a large extent determined by the outstanding fact, observable practically throughout the Northern Section, viz., that the asbestos does not occur in more massive seams of greater individual persistence and regularity, concentrated in a few localities, but is found at countless points spread out over a very extensive country. This principle does not admit of more systematic underground mining, such as, e.g., a well-defined regularly bedded gold reef often calls for in other districts. In this respect the workings of the Northern Section afford some contrast, when compared with the more typical mining possible in the Southern Section, e.g. Westerberg, and is in very strong contrast to the regular manner in which the very thick amosite seams of the Egnep and Amosa Mines, north of Lydenburg, can be laid out along levels, drives, and stopes (see Chapter IV).

Just as the greater irregularity in distribution of payable fibre is rather more marked in the northern as compared with the southern section, so the special features of the contract system of labour, favoured in the Cape fibre belt, come into greater prominence in the northern belt. Native labour is paid according to the grades per 100 ℔. of asbestos in a condition ready for the market, the management supplying the tools and mining material. A native generally does his own prospecting for the most suitable spots, or may have such indicated for him, but follows his own method of mining. He arranges to live close to the scene of operations, and his family help to swell the budget by picking over accumulated débris for the most promising seams and cobbing them by hand. Thus, probably more often as not, the family and not the individual is the unit of labour. The whole labour situation is not unlike a more widely applied tributor's system.

Due to this method of labour employment, combined with the countless occurrences of fibres on many farms, which provide abundant opportunities to shift development to another point as soon as the work becomes less remunerative, there are very few more extensive underground workings and scarcely any true mines at all, the great majority of developments forming small scattered quarries, in places leading into short stopes, along which more promising seams are being followed up on the dip, but rarely exceeding a few yards. On Warrendale alone some twenty of such workings occur, and at least several exist on every developed property. A promising seam having been located, it is then opened up in a shallow quarry, and often the presence of a harder band in the frequently low-dipping banded ironstones serves as a roof when the seams are followed up into the stopes, as on Brettby or on some of the Warrendale workings. More extensive underground development is seen on Wonderwerk, but this is exceptional.

One advantage of the contract system of labour is that payment is made only for actual output ; when this declines, the outgoings are proportionally reduced, so that there is very little dead mining.

Then, again, the system is well understood and liked by the local native population, and since blasting operations in the Cape are permissible in case of natives, a smaller permanent staff of white men is required, which is mainly occupied in checking the grading, issuing stores, or general supervision, thus reducing the standing charges. The disadvantages arise from the methods of prospecting, the lack of control in principles of mining, the results of which are seen in the appearances presented by some of the quarries and underground extensions, which at times recall the tributor's methods. The strict system of paying only for fibre delivered may lead to less legitimate means of obtaining additional supplies from adjoining properties exposing seams. While there is no doubt that the system of open quarrying and short-stope extensions does yield a relatively rapid return in the earlier stages of development, it is not certain whether it amounts to the best system in the long run, where thicker seams suggest the feasibility of more systematic methods. The piece-work system, furthermore, does not admit of the output being regulated in the best possible manner as regards rate of production, in proportion as this depends on the continuity of individual effort.

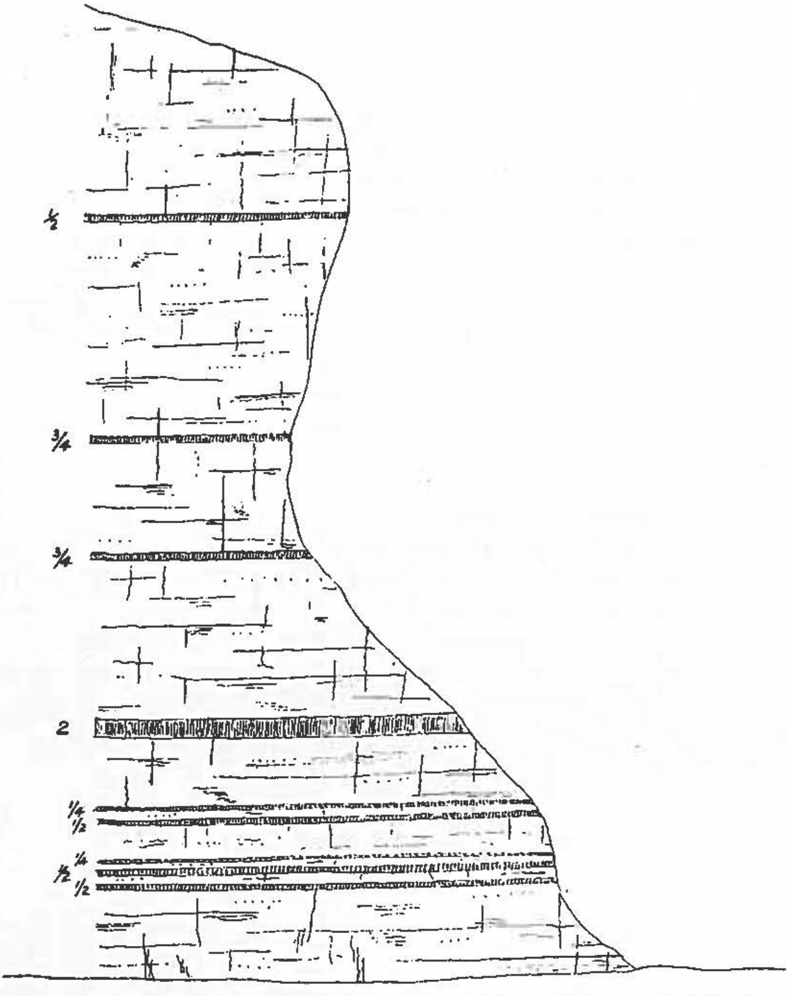
Mode of Occurrence.

The crocidolite occurs in interbedded cross-fibre seams, sometimes in the hard pale brownish jaspery rocks or in darker, more magnetic ironstones, also occasionally in very dark bluish slightly softer phases of country rock. The latter maintains, as a rule, a steady low dip at any one working, often almost horizontal, though higher angles up to thirty or thirty-five degrees are found, e.g. on Mansfield. Near the top of the underlying Campbell Rand limestones the beds are locally very much contorted on a small scale and generally more or less highly disturbed, which affects both the seams and their country rock, and can be seen in a fair number of instances, as in No. 4 workings on Warrendale, south of Daniels Kuil, thus pointing to the disturbing cause having arisen subsequent to the date of crocidolite formation. On Cubbie, next door to Mansfield, the dip varies from the neighbourhood of thirty degrees down to nearly zero, while on Crawley, on the westerly branch, some thirty-eight miles south-south-west of Kuruman, low values are more steadily maintained.

No case was observed of a seam running across the direction of bedding, and even examples of bifurcation of individual seams are rare and associated with very low angles in the forks. In exceptional cases a single seam is found in the workings, and far more commonly a number of these are associated in the same face, spaced out at intervals displaying a wide range of variation. On Warrendale, at No. 4 workings, the "seam density," i.e. the number of seams per foot of succession, may be gathered from Fig. 7, which shows nine seams, ranging from 2 inches down to ¼ inch in thickness; these consist all of the pale or at times a little darker lavender blue thoroughly fibrous kind.

In No. 3 workings on Brettby, which consist of a large open cast working some 150 yards long leading into a stope extending for some 25 yards into the hillside on the dip (varying from zero to twenty-five degrees), one point exposes the succession represented in Fig. 8. Here over a thickness of some 8 feet from the roof of the stope to the floor some twelve to fifteen seams are exposed, the great majority of which are less than 1 inch thick. On Cubbie a face some 18 feet high shows a large number of seams, many of which are under 1 inch across, though occasionally values up to or slightly exceeding 2 inches can be seen. The more extensive underground development on Wonderwerk consists of longer but somewhat irregular stopes supported by pillars, and taking the average

No. 4 Workings, Warrendale, showing seam density.



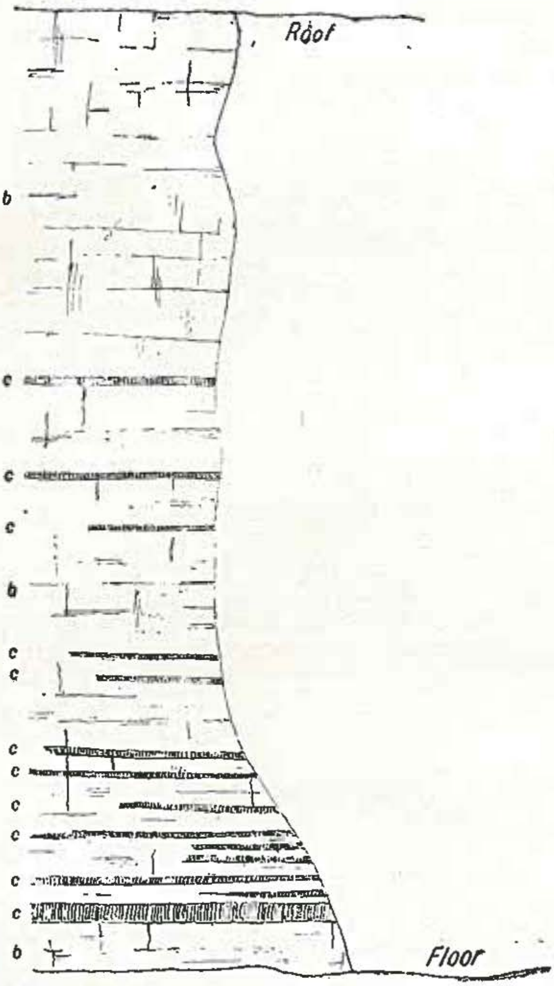
Approx. scale 1 : 20. Nine interbedded seams of crocidolite, with thickness in inches in hard jaspery banded rocks.

Fig. 7.

stoping width as 7½ feet, the combined fibre width measures from 5 to 6 inches, but made up largely of seams under ¾ inch across. On Klipvley, near Daniels Kuil, from twelve to fourteen seams occur in a 7-foot face and sometimes admit of more regular mining.

The figures given above may be taken as typical of a large number of workings, but much minor variation in "seam density" occurs; in the majority of cases the seams are spaced singly or close together in twos or threes, while locally the number may considerably rise so as to give five or six thin seams in a foot of succession. This is very noticeable on Warrendale, close to the underlying limestones; the association is perhaps accidental, but the possibility of a genetic connection is admissible.

No. 3 Workings, Brettby, near Daniel's Kuil.



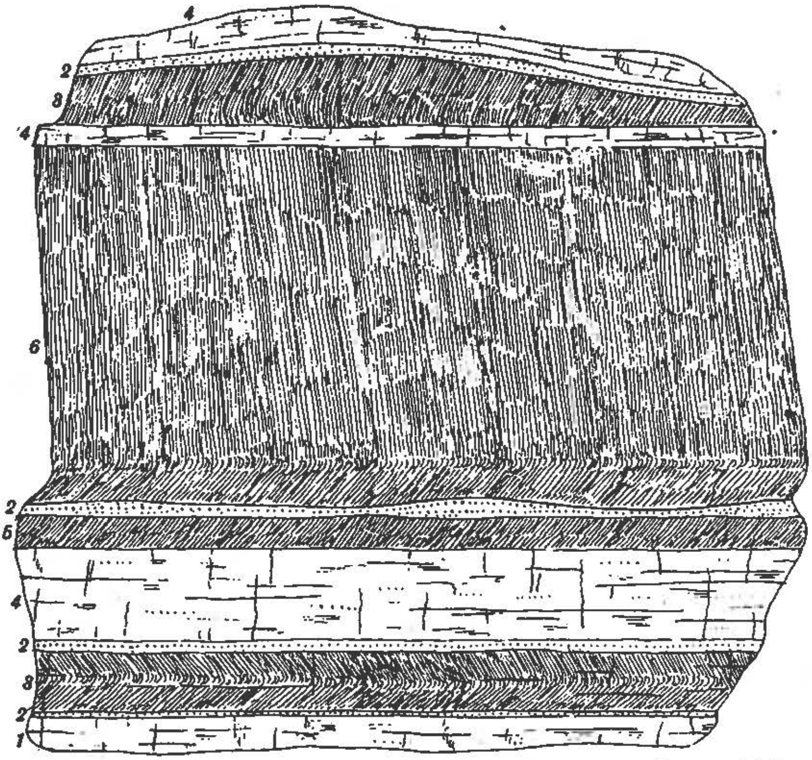
Approx. scale 1 : 20. From 12 to 15 interbedded cross fibre veins of blue crocidolite. c. Maximum width of 2", many under 1". *b*. Banded magnetic ironstones from roof to floor is 8 feet.

Fig. 8.

Character of the Seams and Fibre.

The perfection of fibrous growth is a very striking feature in all the fresh lavender blue seams; these consist of tightly packed fibres with very regular parallel orientation and arranged more or less at right angles to the bedding planes, against which a seam terminates very sharply. This directional property is not in truly vertical arrangement with the encasing walls, but departs slightly from this value to the extent of five to ten degrees, more or less; in other cases the deviation is hardly perceptible, in still others it rises to forty degrees, but the latter is unusual. The fibres commonly extend right across with uniform inclination to the planes of bedding, but in wider and more persistent seams there is a tendency for a distinct and sudden bend in the fibres close to one or other or both containing walls (see Fig. 9).

LUMP OF CROCIDOLITE ROCK, SCHIETFONTEIN, NEAR DANIEL'S KUIL: ILLUSTRATING VARIATION IN FIBRE ORIENTATION.



1. Pale reddish jasper. 2. Black ironstone. 3. Golden yellow crocidolite.
4. Brownish jasper. 5. Pale blue crocidolite passing into yellow fibre.
6. Main seam of blue crocidolite, two inches wide.

Fig. 9 (*Natural scale*).

A comparison of a large number of occurrences of bent fibre in the Cape belt and the close similarity between this phenomenon here and in the chrysotile of the Carolina District indicates the effect to be due to pressure from superincumbent rock masses, perhaps accompanied by lateral movements depending upon the present surface. This structural peculiarity is not of the same kind as regards origin, as the highly variable seam width along one stratum of fibre, referred to below. The inclination of the crocidolite strands oscillates round ninety degrees, sometimes in opposite senses in neighbouring seams included in one hand-specimen, or even in the same seam. In a very fine example from Skietfontein, north-west of Daniels Kuil, the bending has occurred very symmetrically in one seam, so that the locus of the vortex points is a plane keeping very nearly midway between the containing walls. The result is very much like that produced by exerting strong symmetrical pressure on a pack of cards along their length and held tightly, so as to prevent sliding (see Fig. 9).

The example shown in Fig. 9 illustrates very well the occasional association of differently coloured seams. The wide uniformly lavender blue band over the central portion (6) shows the exceptional width of over 2 inches, but is separated by a thin layer of dark bluish compact ferruginous cherty material from a thin bluish seam (5), which dies out in one direction to a mere film (not seen in the figure), while undergoing a progressive colour change towards dirty violet and finally to bright rusty yellow. Two further seams, one symmetrically bent (alluded to above) and another with a fibre orientation opposite to that of the main seam, are also noticeable, and consist in each case of uniformly rusty brown material throughout (3).

Normally the colour remains a delicate lavender blue—sometimes very dark, as on Klipvley—over the vast majority of seams, independently of their thickness and apparently also of the character of the associated country rock. A seam, beginning blue at the surface, continues as such underground, but yellow seams may change into the blue kind. Since all the workings are still close to the surface, are dry, and are still a long way off water level, the question of a possible genetic connection between colour and depth cannot be decided. Local discoloration, often more noticeable at the ends of the fibre, is fairly common, e.g. well seen at Crawley and Wonderwerk; likewise the gradual transition from blue to yellow in the same seams, as pointed out.

Individual seams rarely persist for more than a few feet or yards, when they very gradually taper off to mere films, so that the shape of an asbestos layer is probably that of a very flat and extensive "cake" ending laterally along a very irregular margin. In the faces of the workings the section of such a "cake" appears as highly elongated lenticle, in which the length is very often many times greater than the thickness, but on Wonderwerk larger slabs of drift are found—not yet traced *in situ*—due to ovoid sheets of very dark blue, almost black, asbestos.

A single seam may maintain a more uniform width for considerable distances and die out very gradually, but in almost every quarry one can observe some kind of more rapid variation in thickness up to extreme irregularities conditioned by rapid changes in fibre length. Sometimes one wall of a seam continues evenly throughout, but the common termination of the fibres along the other wall forms a series of waves of great range in length and amplitude. Both terminal planes may behave in this way, when the evenly developed seams break up into a series of bulging ovals or an alternating succession of rudely cone-shaped portions of fibre and corresponding depressions of country rock. In detail there is a never-ending variety in this respect, which strongly recalls similar phenomena in the amosite and crocidolite seams of the Transvaal, as well as of the Southern Cape Belt, e.g. Westerberg, where they are specially pronounced. These are the " cone " and " corrugated " structures referred to above and in Chapter IV. They were noticed in No. 4 workings on Warrendale, where several seams are in close association and show up on the face as highly irregular semi- or fully detached series of segments of circles, jagged patches, or ovoid portions, ranging from 4 by 1½ inches downwards, etc. ; they also occur on Cubbie and elsewhere (compare Figs. 4, 5, and 6).

Potential crocidolite is occasionally met with, as on Crawley, Klipvley, or Wonderwerk, and behaves structurally like a regularly interbedded softer stratum, but such layers stand out strongly in the succession of associated hard magnetic rocks on account of their vivid blue colour. No definite fibrous growth is exhibited by such layers, but on Wonderwerk is a short cutting exposing bands of this unusual rock up to 2 feet thick in a series of harder jaspery beds. Here certain portions assume a roughly fibrous structure, intermediate between potential and true crocidolite. In one instance they lie in contact with coarsely fibrous crocidolite matter, but the strands are oriented along instead of across the bedding planes, a very unusual mode of occurrence. A second instance of an apparent transition from compact to fibrous growth has been recorded in the Tenth Annual Report of the Geological Commission of Cape Colony from near Claradale, south-west of Griqua Town.

In character the crocidolite from the Northern Section is practically indistinguishable from that found further south, except that a lighter coloured, less stringy, and more fleecy nature is often observable ; it permits a lump of fibre being pulled out and disintegrated between the fingers to an extent only limited by manipulative skill, but it is doubtful if this great perfection of fibrous growth is sufficiently characteristic of any portion of the Cape fibre belt to enable one to tell the source of a particular specimen from a collection of fibre lumps representative of the whole asbestos field.

The *length of fibre* is very variable and ranges from about 4½ inches downwards ; this value is very exceptional, and even lengths exceeding 2 inches are by no means common. Values most commonly observed in many workings oscillate round ¾ inch as the approximate average, which is probably slightly higher here than in the Southern

Section. In case of the Northern Asbestos Co., which was responsible for the largest output in the Northern Section, blue fibre from ⅜ inch to ¾ inch is represented during the second six months of 1917 by 70·2 per cent., and that from ¾ inch upwards by 10·9 per cent. It is estimated that of the production of the Harris' Syndicate 18 per cent. is fibre 1 inch and over in length ; 72 per cent. is under 1 inch long. More complete data are not available for publication, but, taking the development all round and placing the limit of spinnability at ⅜ inch, probably about 80 per cent. is spinnable fibre, which compares very favourably with the Canadian chrysotile field.

Quantity Available.

From the examination of a single working one may gather, in most cases, that only a limited quantity of fibre is available in this section, but the combined output from the various concerns, each maintaining development at a number of points on several farms, amounts to a good total, and the geological foundations of the asbestos occurrence strongly indicate that production could be very materially increased, as soon as freight and market conditions permit, and the situation as regards labour supply is also good.

Preparation for the Market, Grading, and Disposal.

The asbestos rock is hand-cobbed by native labour, and the shorter fibre, usually mixed with chips of rock, etc., is sieved by simple mechanical devices, i.e. horizontal swinging sieves and inclined rotary trommels provided with screening material graded, as to meshes, according to the criteria of fibre length on which the grading is based. The latter vary as to standard lengths in different concerns. On Wonderwerk, for example, the higher half of such a trommel consists of a wire screen with smaller meshes, so that the grade known as SX, or short siftings, accumulates under this part ; the oversize descends to the lower part, consisting of coarser mesh, which allows grade S, up to and including ⅜ inch, to be collected under it. The finest fluffy very short fibre, e.g. on Brettby, is known as "Droppings." Discoloured fibre is kept separate, but finds a certain demand in spite of its impaired colour. No machinery for cobbing, crushing, or drying is in use.

Between different producers the schemes of grading vary, due to the particular requirements of various manufacturers and the fact that the market is not yet sufficiently developed. In course of time greater uniformity in this respect will probably result.

The following is the scheme of grading adopted by the Northern Asbestos Co. :—

Designation.	Description.	Colour.	Prices.
SX	Siftings	—	—
S	Up to and including ⅜ in.	Blue	These vary up to £45 per ton delivered at Kimberley according to grade.
A	From ⅜ in. to ¾ in.	,,	
B	,, ¾ in. ,, 1¼ in.	,,	
C	,, 1¼ in. ,, 2 in.	,,	
D	From 2 in. upwards	,,	
Da	Up to and including ¾ in.	Discoloured	
Db	From ¾ in. upwards	,,	

On Crawley (Crown Lands Syndicate) the grading is as follows :—

Designation.	Description.
Extra A 1	1½ in. and over.
Long 1	From 1 in. to 1½ in.
Medium 2	,, ½ in. ,, 1 in.
Short 3	,, ¼ in. ,, ½ in.

In case of Messrs. Gillanders & Campbell's Syndicate the fibre is generally graded as follows :—

Designation.	Description.
E S	Over 1½ in.
No. 1	1 in. to 1½ in.
No. 2	⅝ in. to ⅞ in.
No. 3	Up to ½ in.
No. X	Discoloured, all lengths.

Output and Scale of Operations.

Figures showing the production from each asbestos concern cannot be given here, but it is permissible to state that the output from the largest company within the northern field amounted to 246 tons for the six months ended December, 1917. In Chapter VIII the values for the whole Cape belt are given, including the Cape Asbestos Co. The latter account for the lion's share.

Some idea of the scale of operations may be gathered from the fact that on Brettby during February, 1918, one white man and fifty-five boys were employed, an additional twenty being busy on Hurley. On Crawley two whites and seventy boys and on Warrendale three white men and seventy boys were employed at that period.

The bagged grades have to be transported by road to Taungs, Vryburg, or Kimberley Stations, over distances ranging from 100 to 130 miles. On the Warrendale–Kimberley route the transport works out at 1s. 3d. per cwt.

CHAPTER III.

DEPOSITS OF ASBESTOS IN THE TRANSVAAL.

I. CHRYSOTILE.

Varieties and General Distribution.—Within the limits of the Transvaal Province asbestos deposits of commercial character are so far represented by chrysotile, amosite, crocidolite, and tremolite, which is the chronological order in which the fibre was exploited. From the point of view of available quantity and economic importance generally, the order would be *amosite, crocidolite, chrysotile,* and *tremolite.*

The exploitation of the varieties mentioned is confined to certain districts only: *amosite* in the North-Eastern Transvaal, between *Lydenburg* and *Pietersburg*, where this variety occurs in conformable cross-fibre veins in a banded siliceous ironstone of sedimentary origin at the base of the Pretoria Series; *crocidolite* in the *Pietersburg District*, and found in the same manner as amosite along the same horizon of banded rocks; *chrysotile* has been opened up in the *Carolina District*, also as bedded cross-fibre veins, but in an altered dolomite in contact with an intrusive basic sill near the top of the Dolomite Series. *Tremolite* has been exploited on the farm Corea No. 1304, north of Mara Siding in the Zoutpansberg District.

These constitute up to the present the only sources of supply from the Transvaal, but asbestos has also been found in a number of other localities, without hitherto acquiring economic importance.

In the *Barberton District* the Jamestown Series of the Swaziland System consists of a variety of basic schists associated with massive igneous rocks rich in magnesia, such as dunite, serpentine, talc, etc., and in them cross-fibre veins of chrysotile were found at several localities during the writer's survey of that area. The best example lies on the northern slope of Ship Hill, about one mile south of Kaapmuiden Station, where a broad belt of fibrous serpentine, arranged vertically, runs up the slope nearly at right angles to the length of Ship Hill. The width of the fibrous belt measures about 8 feet, but consists rather of chrysotilic zones in less altered serpentine than of continuous chrysotile. The fibres are somewhat coarse, not readily separable, and harsh, while the tensile strength and flexibility leave much to be desired. This deposit is only accessible in surface material, and not enough development has been accomplished to show whether any improvement lower down is indicated. Some of the asbestos is of the slip-fibre type.

In the same geological formation cross-fibre chrysotile veins have been found near Clutha Siding and north-west of Jamestown, a little before the main belt of the Jamestown Series passes under the escarpment of the Drakensberg north of the Barberton-Kaapsche Hoop main road. In the latter case many widely parallel but thin cross-fibre veins were observed in the serpentine belt, some of the rocks thus assuming a more regularly ribbed or banded appearance.

During 1905 the writer found north of *Krugersdorp* thin veins of fibrous serpentine in the massive basic rocks associated with the Older Granite west of Mulders Drift, and these are referred to in the Annual Report of the Geological Survey of the Transvaal for 1906.* During 1917 similar deposits from this area were reported,† though further information is not available.

On the farm *Rhenosterfontein No.* 50, twelve miles south-south-east of Zeerust, the occurrence of an asbestos has been established in the basal portion of the Pretoria Series. It takes the form of interbedded cross-fibre veins in a brownish shale with layers of chert and cherty quartzite, and altered by contact metamorphism. A number of prospecting pits, trenches, and cuttings have been made, and in a cutting near the centre of the area several layers of asbestos were found up to 1½ inches wide, consisting of very pale green fibre of good quality. This fibre belt appears to be limited to an oblong area about 12 to 30 yards wide, and further prospecting has not up to the present led to more discoveries.‡

On the farm *Staanplaats No.* 365, in the Pietersburg District, in close proximity to Chuniespoort, another occurrence of chrysotile has recently § been discovered. This lies in the Dolomite Series and is distributed with reference to an intrusive sheet, the sedimentary rocks overlying the fibre horizon being obviously metamorphised. Several parallel seams are found with fibre lengths up to an inch or over under conditions which strongly recall the Carolina variety of occurrence. The discovery of a further locality where the asbestos formation depends on the metamorphism due to an intrusion of carbonate rocks should lead to additional discoveries of this kind, whether in the Dolomite Series itself or in the thin intercalations of calcareous or dolomitic rocks occasionally met with in the Pretoria Series.

I. CHRYSOTILE (CAROLINA DISTRICT).

General Remarks.—The commercial exploitation of serpentine asbestos is restricted in the Transvaal to a short fibre belt situated east of Carolina along a definite horizon just below the base of the Pretoria Series. This represents the earliest mining operation for any kind of fibre in the Province. Though the output has been

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* H. Kynaston: "On the southern portion of the area occupied by the Pretoria-Johannesburg Granite." Annual Report for 1906, p. 14.

† S.A. Mining Jl., 1917, p. 268.

‡ The writer is indebted to Dr. Wagner for this information.

§ Information kindly communicated by Mr. T. H. B. Wayne.

intermittent and never represented a big factor in the market, the geology of these occurrences is of exceptional interest in forming a remarkably close parallel to the deposits of the Grand Cañon, Arizona. described by L. F. Noble and J. S. Diller.

The Carolina asbestos workings are concerned with cross-fibre chrysotile, and are on the adjoining farms,* Rietfontein No. 70, Goedverwacht No. 32, Silverkop No. 31, and Diepgezet No. 33. situated some twenty to twenty-five miles by road from Carolina as the nearest railway station, in bare hilly well-watered country at an elevation of some 4500 feet above sea-level and very favourably conditioned for mining operations. Over all the farms mentioned chrysotile occurs under the same conditions and along an identical horizon.

Operations began about 1905 on Rietfontein by the Anglo-Swiss Co., though not much development work was accomplished. About this time the same deposits were opened up along their easterly extension on Diepgezet and continued to about 1909 in connection with the Transvaal Asbestos Syndicate and the Carolina Asbestos Co. Several years after this first period of activity, the same workings were proceeded with by another syndicate, who carried on from about December, 1913, to the outbreak of the war with fairly successful results.

In 1914 mining was again begun on Rietfontein by the Andes Prospecting Syndicate, who acquired the interests of the older company and later on transferred to Goedverwacht, where a steady output was kept up for some eighteen months.

Diepgezet No. 33.—This farm occupies a large deep valley facing more or less east and cut up by numerous lesser spruits and dry gulleys descending down to a tributary of the Buffelspruit on Boschhoek No. 117.

Along the higher bare slopes of the valley and following the sinuosities of the surface runs the fibre horizon from 15 to 25 feet below the base of the Pretoria Series, forming a series of thin cross-fibre chrysotile veins, the average trend of which follows the dip of the country to the north-west at angles varying from eight to fifteen degrees conformable to the structure of the Transvaal System. Two important indicators help to define this horizon all over Diepgezet and the neighbouring chrysotile farms: the Rooihoogte Quartzite above and an intrusive sill with diabasic affinities below.

In contrast with the Pretoria Series elsewhere, an additional quartzite band, up to 20 feet thick, can be traced east of Carolina and south of the Delagoa Bay railway, to which the name Rooihoogte Quartzite has been applied.† It sometimes forms the topmost layers of the uppermost krantz of dolomite of the Dolomite Series, but on Diepgezet it is underlain by black slate before the main series is reached. Since along its upper limit the quartzite very often

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* The general geology of this area is shown on Plate VII of the Annual Report of the Geological Survey of the Union of South Africa for 1913.

† Annual Report Geological Survey of the Union of South Africa for 1913, p. 49.

develops a whitish cherty conglomerate with characteristic pebbles, and also generally makes a faint but defined feature, it forms a useful indicator for the fibre belt and a convenient line along which to place the bottom of the Pretoria Series, thus taking on the stratigraphical function of Bevets Conglomerate in the Eastern Transvaal. From the Rooihoogte Quartzite the downward succession is as follows :—

SUCCESSION ACROSS THE CHRYSOTILE HORIZON OF DIEPGEZET.

		Feet.
Pretoria Series	1. Rooihoogte Quartzite, with Cherty Conglomerate at the top	3– 4
Dolomite Series	2. Hard Dark Slates....................................	6–10
	3. Black Slate in thinner layers alternating with Chert Bands..	8–12
	4. Black Manganese Earth............................	1– 3
	5. Serpentinized Dolomite carrying Interbedded Cross Fibre Veins of Chrysotile............................	2– 5
	6. Basic Intrusive Sill..................................	30·?
	7. Dolomite and Chert..................................	—

A line of large white blocks, readily traceable in the scenery across the valley, indicate the Rooihoogte Quartzite above the asbestos workings, while the underlying slate, chert, manganese earth, and the altered dolomite give rise to no distinctive feature, and can only be studied satisfactorily in artificial exposures near the mouths of the adits.

The second important horizon indicator serves to mark the lower limit of the fibre horizon and is conditioned by a persistent basic sill. It rarely gives rise to continuous outcrops, but more often tends to form larger isolated, somewhat rounded, and dark blocks, traceable across the Diepgezet Valley and maintained throughout the whole extent of the Carolina fibre area, always in the same position with reference to the chrysotile veins ; it is also very clearly defined on the more recent workings on Goedverwacht. In the various adits its upper limit is sharply marked off against the overlying altered dolomite, but its base is nowhere definitely seen, and no prospecting appears to have been carried out with a view to locating a corresponding set of fibre veins below it. About three-quarters of a mile from the Diepgezet Mine house the sill gives rise to a short better-defined krantz, indicating a minimum thickness of about 30 feet. Fresh samples a little below the upper contact show an evenly fine-grained basic rock, assignable to the diabase family, and a compact dark selvedge is seen towards the overlying sediments, up to 2 feet wide, and at times difficult to differentiate in hand-specimens from the very close-grained dark dirty brownish dolomite rock which rests against the intrusion with a sharp contact. The identity of this igneous rock as a sill rests on the distribution conforming to the dip of the sedimentary rocks, on the selvedge effect, and on the alteration of the dolomite. At the little krantz referred to the rock in direct contact with the sill has been altered through several inches into a crystalline variety containing slender light coloured tremolite needles.

At several places across the valley prospecting has been carried out along the upper limit of the sill, but not everywhere have indications of chrysotile been proved; possibly this may be due to operations not having been pushed far enough into the slopes. Elsewhere the igneous rock has failed to appear along its theoretical position, a result probably depending on variations in the lateral extent of the invading magma.

The asbestos developments comprise several adits and tunnels in the southern slopes of the valley, driven for a distance of over 400 feet; no quarries or other open-cast workings exist, comparable to those characteristic of the Canadian " mines." As a rule, the workings are solid and display a regular succession without important breaks, the base of the overlying dolomite forming the clean roof in some of the adits. Locally the name " mud dyke " is applied to a certain cross feature which interrupts the regularity of the succession; these breaks have been regarded as true dykes, but no corresponding indication appears at the surface. They consist of soft dark clayey matter and behave like water partings, with more through decomposition of the accompanying rocks. It is not excluded that they are very compact basic dykes, such as have been intersected in the neighbouring workings of Goedverwacht.

The fibre is restricted to a zone of altered dolomite, reaching for a width of about 5 feet from the upper contact of the sill upwards, but no indication of chrysotile exists at the contact plane itself, since the first signs of veins begin a few inches above, and these increase in number and thickness within the maximum limit just indicated. At and close to the contact a very fine-grained dark brown dolomitic rock predominates and changes upwards into lighter coloured pale greenish, greenish grey, and pale greyish varieties of finely crystalline rocks, until in between the cross-fibre veins greenish colouration predominates. Such colour changes are not definite, but are related to one another in shadowy, streaky, or smeary outlines. Certain varieties assume a variegated appearance due to variously coloured bands, sometimes marked by vivid yellowish green streaks or ill-defined patches. In several cases a vein of chrysotile is limited on one side by pale greenish, on the other by dark coloured brown dolomite. Generally the rocks are thickly bedded, compact, or finely crystalline and brittle, with a faint delicate banding in the direction of bedding. Collectively the chrysotile-bearing portion of the dolomite, with its variable colours, differs markedly from the dark grey, more coarsely crystalline variety, typical of the normal Dolomite Series, and the restriction of the former to the fibre zone is as striking on Diepgezet as in other parts of this fibre area.

The chrysotile veins are invariably disposed more or less markedly parallel to the bedding planes of the country rock, and are concentrated in greater number closer to the upper sill contact than further away, but not noticeable at the contact plane itself. Exceptionally only a single vein occurs; far more commonly they are associated in groups of parallel seams placed at varying intervals to one another.

These run alongside, overlap, coalesce, bifurcate at low angles, or sometimes anastomose, and furthermore exhibit a great range of structural modifications in detail, though maintaining a definite average trend with the direction of bedding. Some veins may keep a uniform width for inches or even feet, but always end sooner or later in a gently tapering manner, or die out more gradually by degenerating into asbestiform fibre or bulging out before coming to a more sudden end, when another one, starting a little above or below, sets in and maintains the general continuity. Though exhibiting minor twists, undulations, or "rolls," the fibre horizon is never displaced by any definite beaks.

The limited and intermittent output from Diepgezet makes an accurate estimate of the average fibre length very difficult. Exceptional instances of several inches have been observed, but the most frequent values fall between ½ inch and 1¼ inch. When the first period of mining activity came to an end, the following information was available as indicating the proportion of different grade fibres :—

Average stoping width......	40 inches.
Average asbestos width........	·92 inch.

Over 1300 feet of slope face various fibre grades were distributed in accordance with the statement :—

Seams of ¼-inch fibre and less.....	19	per cent.
Seams between ¼ inch and 1 inch..	33	,,
Seams of 1 inch and over.........	48	,,

During the twelve months ended September, 1918,* altogether 281 tons of asbestos were recovered, and for every ton obtained 42 tons of rock had to be mined ; 62 per cent. of the fibre obtained was over 1 inch in length, but for the last six months this proportion had fallen to 40 per cent. The fluff obtained by sieving the fibre out of the fines constituted 14 per cent. of the year's output, but had risen to 38 per cent. for the last three months of the year. No machinery for recovering the asbestos was made use of.

In the later period of exploitation the lumps of fibre were transferred to sheds and native labour employed in "cobbing," i.e. removing the adhering rock matter by hammering, coarse hand-worked sieves being the only mechanical appliances in use. Mining proceeded on the basis of 30-inch stopes, and, after cobbing and sieving, the fibre was graded into bags ready for the market. The following classification was adopted :—

A Quality—First.......	Fibre over 1¼ inch.
B Quality—Second.....	Fibre between 1¼ inch and ¾ in.
C Quality—Third......	Fibre between ¾ inch and ½ inch.

It was found that, after sufficient practice, native labour was capable of carrying out this grading by eye with sufficient accuracy. Contrary to the Canadian practice—where, however, sorting machinery

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* Cirkel, Monograph on Asbestos, 2nd ed., p. 242.

is available—all fibre under ½ inch is rejected, and consequently a large dump of waste has slowly been built up containing fibre possibly recoverable economically with proper machinery.

The Diepgezet veins are of the cross-fibre type and are made up of thoroughly oriented tightly packed fibres, usually a delicate pale green or olive green in unbroken lumps, arranged for the most part at right angles to the containing walls, though not infrequently slightly departing from this transverse arrangement, so as to become bent on one or the other side. At times the whole vein consists of parallel fibres in a "lying-down" position, an appearance probably due to rock pressure, accentuated by minor movement near the surface. Thin strands can be readily separated and twisted into thoroughly flexible threads of considerable tensile strength. On effective fiberizing and working up between the fingers, a thicker pale green bundle assumes the clean white appearance of cotton-wool, with a brilliant silky lustre and the unctuous "feel" typical of high quality chrysotile. Those fibre lumps which contain intergrown rock matter become stony or brittle, and are in consequence valueless; such cases are only occasionally met with.

The characteristic high percentages of magnesia and water of constitution are also found in the present occurrence, as shown in the analysis in Chapter I, the only one so far available.

Some doubt has been felt regarding the possibility or otherwise of the fibres decreasing in number and width after the development should have proceeded further into the hill. This involves the genetic problem and is referred to in Chapter VI.

Goedverwacht No. 32.—The beds involved in the preceding fibre horizon are directly continuous southwards into the adjoining farm Goedverwacht, where the Andes Prospecting Syndicate have opened up a further stretch of chrysotile veins; these workings are about two miles distant from Diepgezet.

The Goedverwacht Mine lies in the northernmost portion of the farm, which is traversed by a long deep gulley reaching from west to east into the principal valley of the Buffelspruit; obliquely across the northern slope of this gully runs the asbestos line, and the succession of its associated beds only differs in minor points from that described above. The order from above downwards is as follows:—

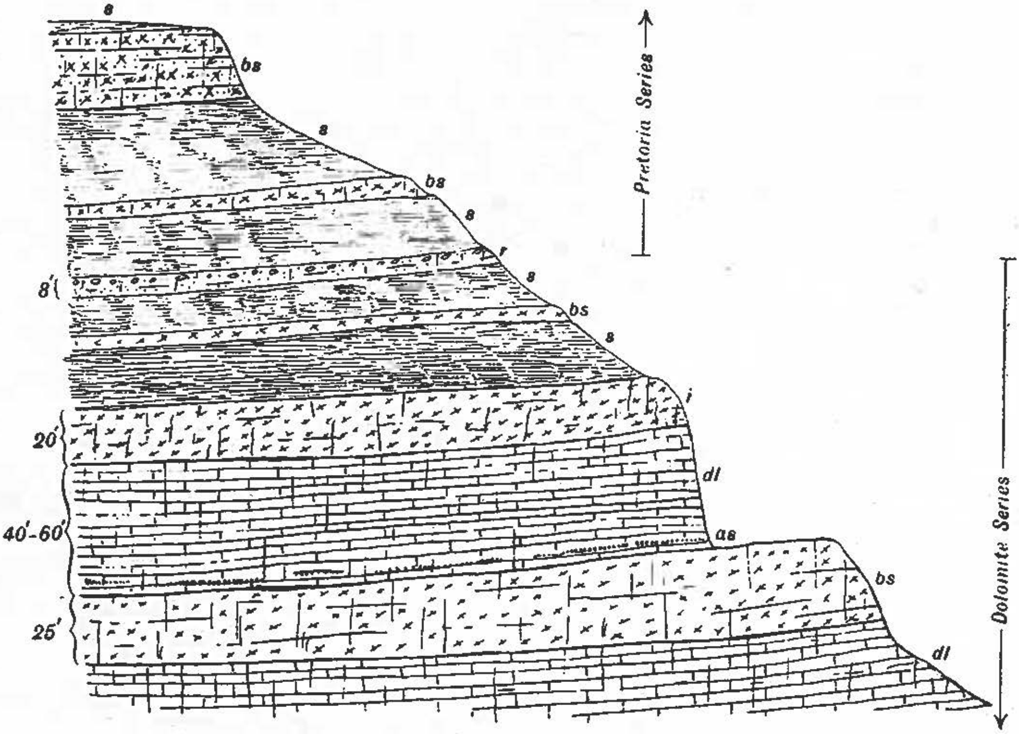
SUCCESSION ACROSS THE CHRYSOTILE HORIZON ON GOEDVERWACHT.

		Feet.
Pretoria Series	1. Rooihoogte Quartzite with about 6 inches of a Cherty Conglomerate at the top	8
Dolomite Series	2. Shales and Slates	—
	3. Thin Basic Sill	—
	4. Shales and Slates	—
	5. Basic Sill	20
	6. Dolomite, interleaved with Chert and Black Slate; altered and carrying Cross Fibre Veins of Chrysotile near the base	40–60
	7. Basic Sill, its base is not exposed, but its width is not less than	25
	8. Main Dolomite Series	—

The preceding section is represented in Fig. 10, which also illustrates the influence of the harder bands on the surface.

The same reliable indicators as on Diepgezet are again found; of these the Rooihoogte Quartzite is even more marked, e.g. on the footpath leading up the gully to the manager's house. Underlying this quartzite are two thin basic sills which do not appear to be represented on Diepgezet, and they are followed by a distinctly greater thickness of chert and dolomite before the lower indicator or main basic sill is reached; this is identical on both farms as regards petrographical characters, order of magnitude, and relationship to the overlying chrysotile veins. The latter are likewise arranged with the dip of the country, i.e. inclined from five to ten degrees into the hill towards the north-north-west, occur over a maximum width of 8 feet from the top of the main intrusion upwards, and associated with the same pale green or greyish green altered dolomite, exactly similar to the one seen in the Diepgezet workings. No definite evidence of the width of the main sill is available, but it cannot be less than 25 feet.

SUCCESSION AT THE BASE OF THE PRETORIA SERIES ON GOEDVERWACHTIG, SHOWING THE CHRYSOTILE ASBESTOS HORIZON.



s = Slates and shales. *bs* = Basic sills. *r* = Rooihoogte quartzite, with 6 inches of conglomerate at the top. *dl* = Dolomite and chert. *as* = Asbestos seams (cross fibre) in serpentinized dolomite.

Fig. 10.

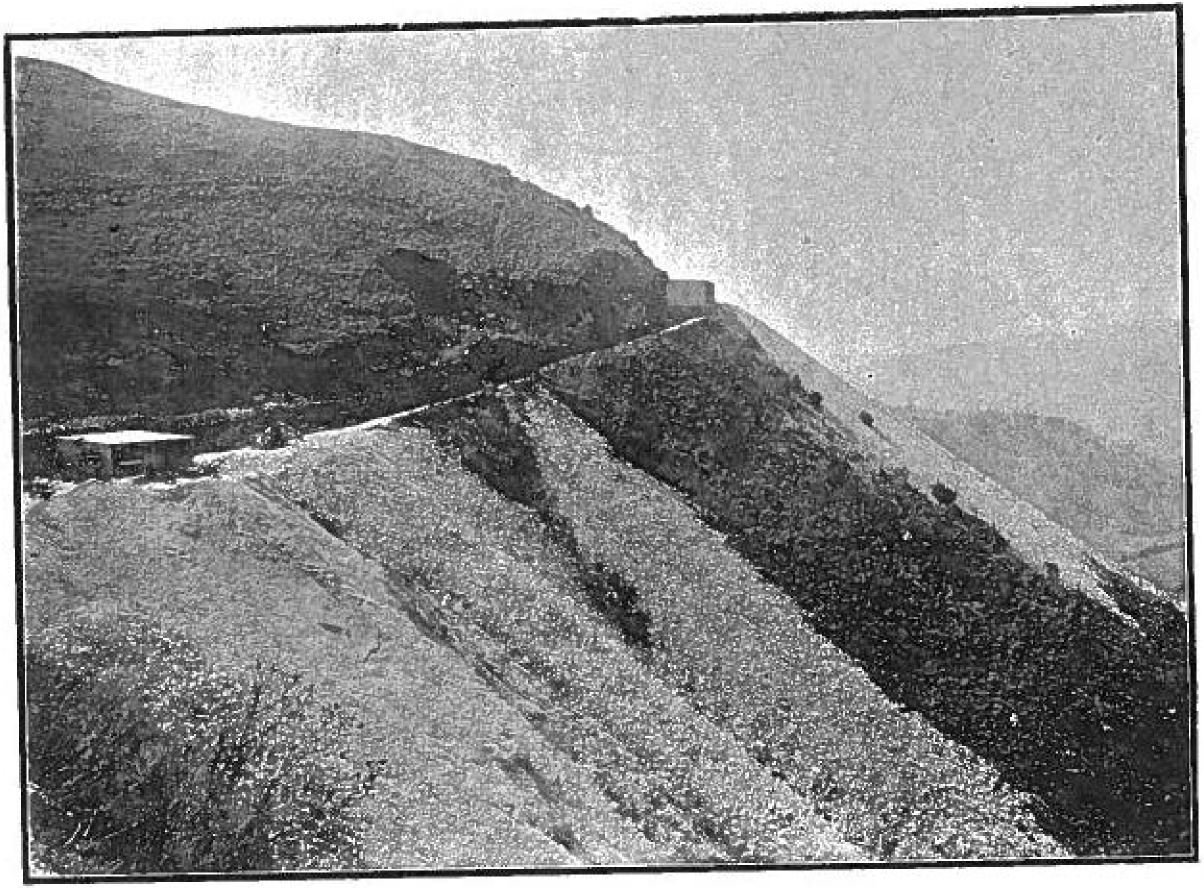


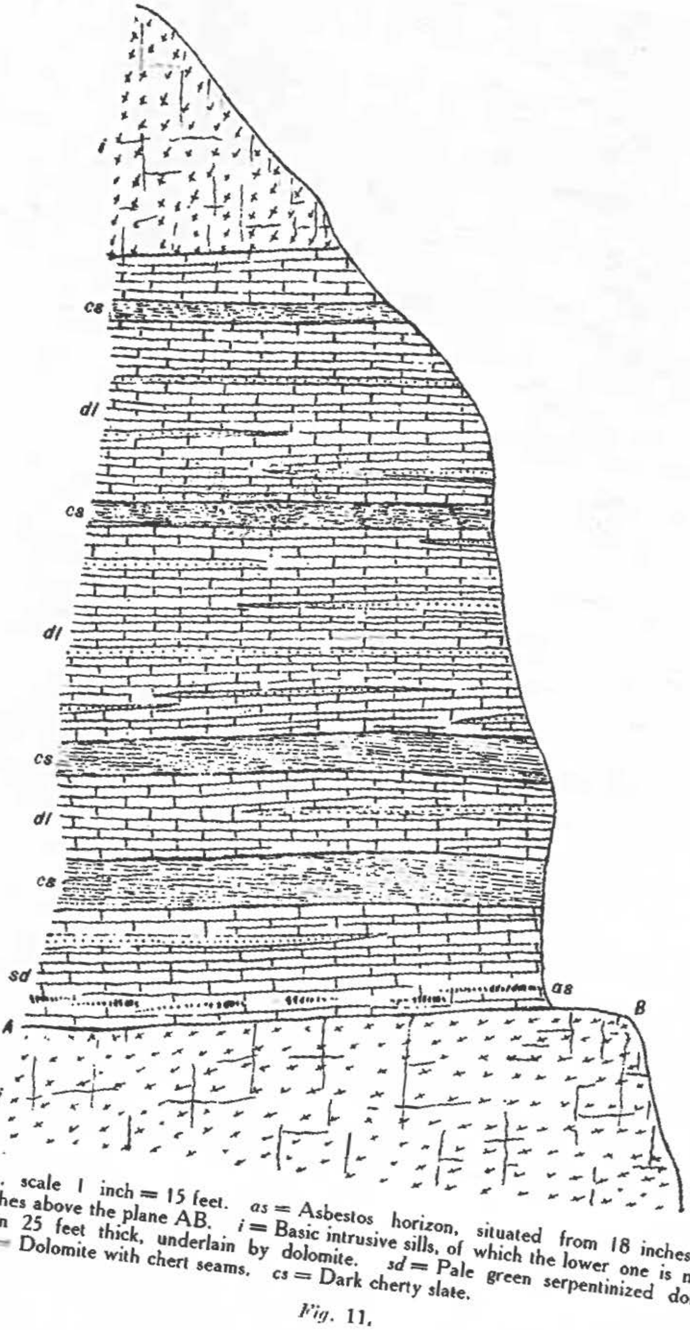
Plate VII.—General View of the Goedverwacht Chrysotile Mine, east of Carolina.

Plate VII gives a general view of the Goedverwacht Mine looking down the valley, and shows the outcrop workings following the upper contact of the sill with the overlying altered dolomite. From the surface the fibre veins have been followed underground in five adits, grouped into an East Section, consisting of adits No. 1 and No. 2, connected by an intermediate adit, and a West Section comprising the remaining adits. The furthest workings are 250 feet into the hill on the dip. Near the junction between the East and West Sections some abandoned workings show much soft black manganese earth, but this phase of the country rock is less marked here than on Diepgezet. The surface cuttings joining up the openings to the adits afford an almost continuous exposure (compare Plate VII) of the upper limiting plane of the sill, though fresh well-defined chrysotile veins are better seen some way into the adits. For a total length of about one-quarter of a mile fibre has been proved. Production started about the middle of 1915 and some 200 tons of fibre were recovered by August, 1917, the usual monthly output amounting to 10 tons approximately. The mine gave employment to some seventy natives and one white man in September, 1917.

Development proceeded in such a manner as to keep the solid upper contact plane of the sill as the floor of the adits, and in No. 3 adit the sharp junction with the overlying altered dolomite is well exposed. The latter is a pale greyish white, very fine-grained, thickly bedded crystalline dolomite marble, with many minute scattered needles or small nests of a monoclinic mineral, probably answering to tremolite in thin section. Above this light grey rock, but without any distinct break—structural or lithological—comes a more brittle dolomite in different shades of grey green, dirty olive green, and bright green, and sometimes streaked or otherwise variegated by more indefinite smears or bands of greenish to yellowish colouration. These phases may extend up to about 8 feet from the top of the sill upwards, but are more often restricted to a zone lying from 1 to 3 feet above the sill and include the chrysotile horizon at a normal distance of 18 to 24 inches above the adit floors (compare Fig. 11).

Often it is found that more abundant and persistent veins of asbestos go with more strongly marked green colours of thickly bedded country rock, whereas very much less or even no fibre lies in the whitish, more thinly bedded phase of the dolomite, a point of possible genetic importance. The chrysotile horizon may consist of one, but is more often composed of a number of parallel cross-fibre veins trending with the dip of the country. Solitary veins may show greater persistence, sometimes continuous for 3 yards, but gregarious overlapping veins are the usual rule. Their shapes are those of extremely elongated lenticles ; in places these end in a gently tapering manner, but may swell out into bulges before terminating more rapidly, while in still other cases they slowly degenerate into extremely thin films of asbestiform matter with more shadowy outlines. In the highly variable manner of distribution in detail, the veins show the strongest similarity to the same fibre horizon elsewhere in the Carolina belt.

SECTION ACROSS THE CHRYSOTILE ASBESTOS HORIZON ON GOEDVERWACHTIG, EAST OF CAROLINA.



Approx. scale 1 inch = 15 feet. *as* = Asbestos horizon, situated from 18 inches to 24 inches above the plane AB. *i* = Basic intrusive sills, of which the lower one is not less than 25 feet thick, underlain by dolomite. *sd* = Pale green serpentinized dolomite. *dl* = Dolomite with chert seams. *cs* = Dark cherty slate.

Fig. 11.

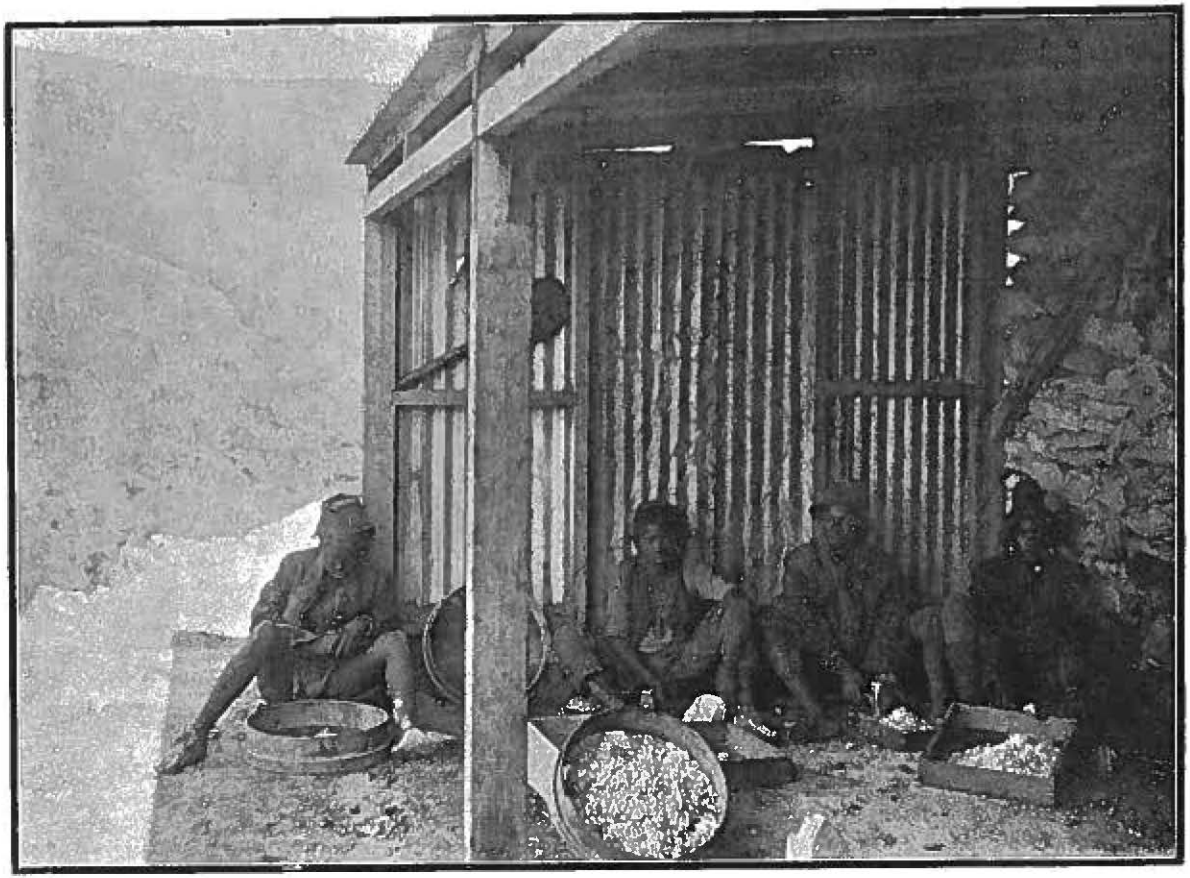


Plate VIII.—Cobbing shed, Goedverwacht Chrysotile Mine, east of Carolina.

The longest fibre observed on Goedverwacht was a little over 6 inches, but this is quite an exceptional case. Far more frequently the values vary between ½ inch and 1 inch and may decrease down to the minutest dimensions.

As regards character of the fibre, colour, and other properties, there is no distinction observable between this and the Diepgezet deposits (see above).

The methods of preparing the fibre for the market and grading involve only very simple means, since no sifting, drying, concentrating, or other appliances are in use, with the exception of hand-worked coarse sieves. Hand picking, cobbing, screening, and bagging constitute the operations for market purposes.

Sometimes blasting operations reveal veins sufficiently free from adhering rock matter for hand-picking and ready for the bagging shed, and the same may apply to the cleaner lumps of fibre retained by the screen when the shattered asbestos rock is subjected to sieving.

Cobbing implies the removal of country rock matter from the fibre veins and is performed by means of native labour; square-shaped hammers are used on iron plates as anvils (see Plate VIII).

The screening operations consist in introducing the fibre rock fragments into rectangular hand-worked suspended screens ("cradles"), provided with a coarse wire-netting (¾-inch to 1 inch); the larger lumps are hand-picked and removed to the cobbing shed, the finer material passing through the sieve and thence being removed to a set of double-rocking sieves with finer mesh. This apparatus separates the fibre into two grades (see Plate IX).

Fibre length and method of separation are the criteria for grading, the term "cobbings" being applied to all hand-picked and cobbed varieties, while "screenings" denotes fibre isolated by the screens. The former grades are made up of usually unbroken and cleaner fibre, still easily separated into delicate strands, whereas in the "screenings" the agitation process gives the fibre a more fluffy character and single thin strands can no longer be readily separated; for this reason the latter is not so valuable for spinning purposes and commands a lower price.

Five grades were observed on Goedverwacht as follows:—

Grade.	Fibre Length.	
1XL	Over 3 inches	Cobbings = straight fibre.
1X	1 to 3 inches	
2X	Under 1 inch	
1A	Retained by Middle Screens	Screenings = fluffy fibre.
2A	Retained by Finest Screens	

The best grade is exceptional, while the relative abundance of the others may be estimated by the fact that 3 : 7 was the approximate ratio of cobbings to screenings in an average month's output.

After thorough drying, the fibre is put up in bags for road transport to Carolina Station. Of these some thirty-six make up a

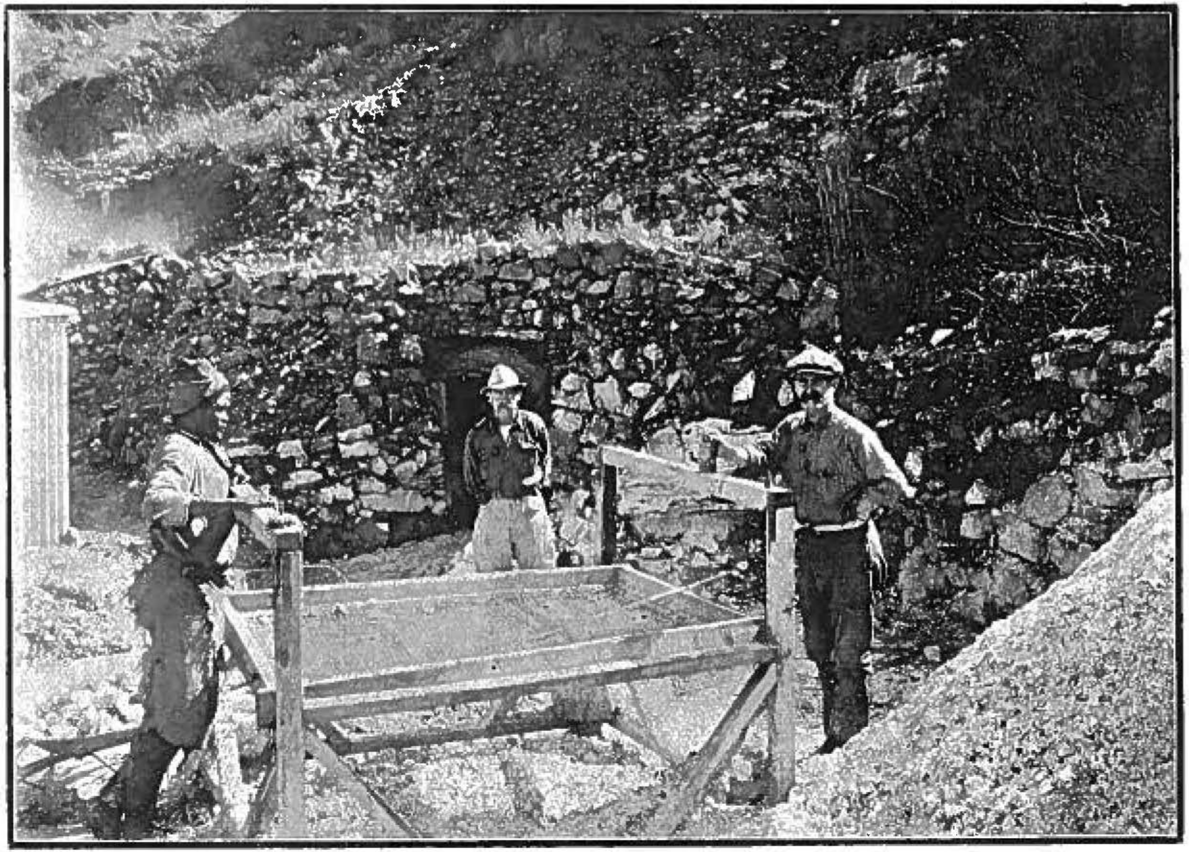


Plate IX.—Sieving operations, Goedverwacht Chrysotile Mine, east of Carolina.

ton. There being no drying machinery in use, the occasional prevalence of misty weather, owing to the position of the farm in the mist belt of the Drakensberg slopes, has sometimes caused delay.

Two vertical dykes from 3 to 12 inches thick and made up of compact basic rocks were noticed in No. 1 adit. They have an important influence as water partings, but gave no indication of a genetic bearing on fibre origin ; they may, perhaps, correspond to the so-called "mud dykes" on Diepgezet. In one instance the normal pale greenish colour of the chrysotile gave way to a bluish colouration, due most likely to local staining and not to be mistaken for an indication of amphibole asbestos.

CHAPTER IV.

DEPOSITS OF ASBESTOS IN THE TRANSVAAL—(*Continued*).

II. AMOSITE. III. CROCIDOLITE.

General Remarks.—The distribution and varieties of commercial asbestos deposits in the Transvaal have been indicated at the beginning of Chapter III, which contains an account of the chrysotile veins. The present chapter deals with the geology of *amosite* and *crocidolite*, which are of much greater industrial importance than fibrous serpentine, since very large quantities are available and the new variety of amphibole asbestos, termed amosite, possesses the unique average fibre length of 6 inches. The exploitation of this asbestos began only some three and a half years ago and shows good promise.

Both crocidolite and amosite occur under the same geological conditions along an identical horizon in the north-eastern and northern Transvaal in the country extending from the Steelpoort River, some thirty miles north of Lydenburg, to the Chuniespoort neighbourhood, about twenty-five miles south of Pietersburg. Nearer the southern end of this belt amosite predominates exclusively as far as present knowledge goes, but nearer Chuniespoort this variety is accompanied by crocidolite, exactly similar in appearance to the well-known Cape blue asbestos.

II. AMOSITE (LYDENBURG DISTRICT).

1. *History and Distribution.*—While the total output of asbestos in the Transvaal amounted to only 55 tons during 1915, this figure had risen to 3192 tons for 1917, due to the exploitation of the newly discovered amosite deposits in the Lydenburg District, which have given a great impetus to the South African asbestos industry.

This activity dates from only about three years ago, though the existence of asbestiform minerals north of Lydenburg was established at least as early as 1907. The actual discoverer is not known, and the first mention of this asbestos is found in the Annual Report of the Geological Survey of the Transvaal for 1907, where its presence is recorded on the right bank of the Olifants River in Eastern Sekukuniland on farms including some of the present mines. These references are based on the writer's survey of that area during 1907, when several old prospecting pits were found with thoroughly decomposed brownish fibre of remarkable length. On that occasion Mr. T. H. B. Wayne, general manager of the Egnep and Amosa Mines, accompanied the writer. The same kind of deposit was noted, associated with similar country rock of banded ironstone, in the northward progress during 1907 and 1908 as far as Chuniespoort, and many instances of cross-fibre crocidolite were observed in the adjoining district of the Haenertsburg Goldfields, east of Pietersburg. The earliest reference to this crocidolite is furnished by Molengraaf in 1905.*

Thus the present fibre area extends for a distance of not less than sixty miles along the strike and has a width up to some six miles. Its horizon lies below the Timeball Hill Quartzite within, but close to the base of, the Pretoria Series, and here are found all the economic occurrences of amosite so far opened up. In the underlying Dolomite Series at least two separate thin bands are found of siliceous ironstone, indistinguishable from the country rock carrying the principal asbestos veins, and in them additional bands of amosite have also been observed, e.g. near the Chuniespoort Police Post.

These amosite deposits are interbedded cross-fibre veins lying always in the same kind of banded siliceous ferruginous slates, essentially similar to the bulk of the Lower Griqua Town Series of Cape Colony. A large area is thus available to the prospector.

Between the location of the new asbestos variety and its systematic development an interval of some seven years elapsed, and many difficulties had to be overcome before a market could be established. The first material available was by no means fresh and its composition was regarded as not promising, while inaccessibility and the difficulty of inducing manufacturers to try a fresh source, the continuity of which was difficult to establish at once, are causes contributory to the delay. The predominating position held by chrysotile in the world's market, its large regulated output, combined with the abnormal length of the new variety from this district necessitating different machinery, gave rise to further difficulties in placing orders, but these obstacles have now been to a large extent overcome, so that the rising asbestos industry of the north-eastern Transvaal gives a fair promising of having come to stay.

2. *Situation.*—Veins of amosite have been found on Penge No. 780, Streatham No. 1083, Zamenloop No. 588, Kromellenboog No. 585, Weltevreden No. 579, and others. Mining operations have been going on since about 1914 on Penge No. 780 and Streatham No. 1083, where a good deal of development has been accomplished, exposing large quantities of fibre, the extension of which is being followed by further prospecting.

The above farms are situated † in Eastern Sekukuniland, i.e. in the portion of the Lydenburg District running along the right bank of the Olifants River north-west of its confluence with the Steelpoort River and at a distance of fifty to sixty miles north of Lydenburg;

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* Note on some Rock Specimens exhibited at the meeting of the Geol. Soc. of S.A. in Feb., 1905. Trans. G.S.S.A., Vol. VIII, 1905, p. 63.

† Sheet No. 13, Olifants River, of the Geol. Sur. shows the general geology of the country.

this is the nearest railway station. The fibre belt forms fairly densely wooded low veld and rather broken hilly country from 2000 to 2500 feet above sea-level and, on the whole, poorly watered, with the Olifants River as the only reliable perennial supply.

SECTION ACROSS THE ASBESTOS HORIZON ON PENGE. APPROXIMATE LENGTH OF SECTION, 1½ MILES.

as. Altered shales. *tq.* Timeball Hill quartzite. *b.* Bevets conglomerate, 10 feet. *d.* Dolomite, 30 feet. *bf.* Banded ferruginous quartzitic slates. *i.* Intrusive diabasic sills. *D.* Main dolomite series. The principal asbestos horizon lies approximately 200 feet above *D*.

Fig. 12.

From the preceding asbestos area the same country rock extends north-westwards, so that the geological conditions for further fibre deposits are maintained at least as far as Chuniespoort ; additional occurrences of amosite or crocidolite may therefore be expected, and

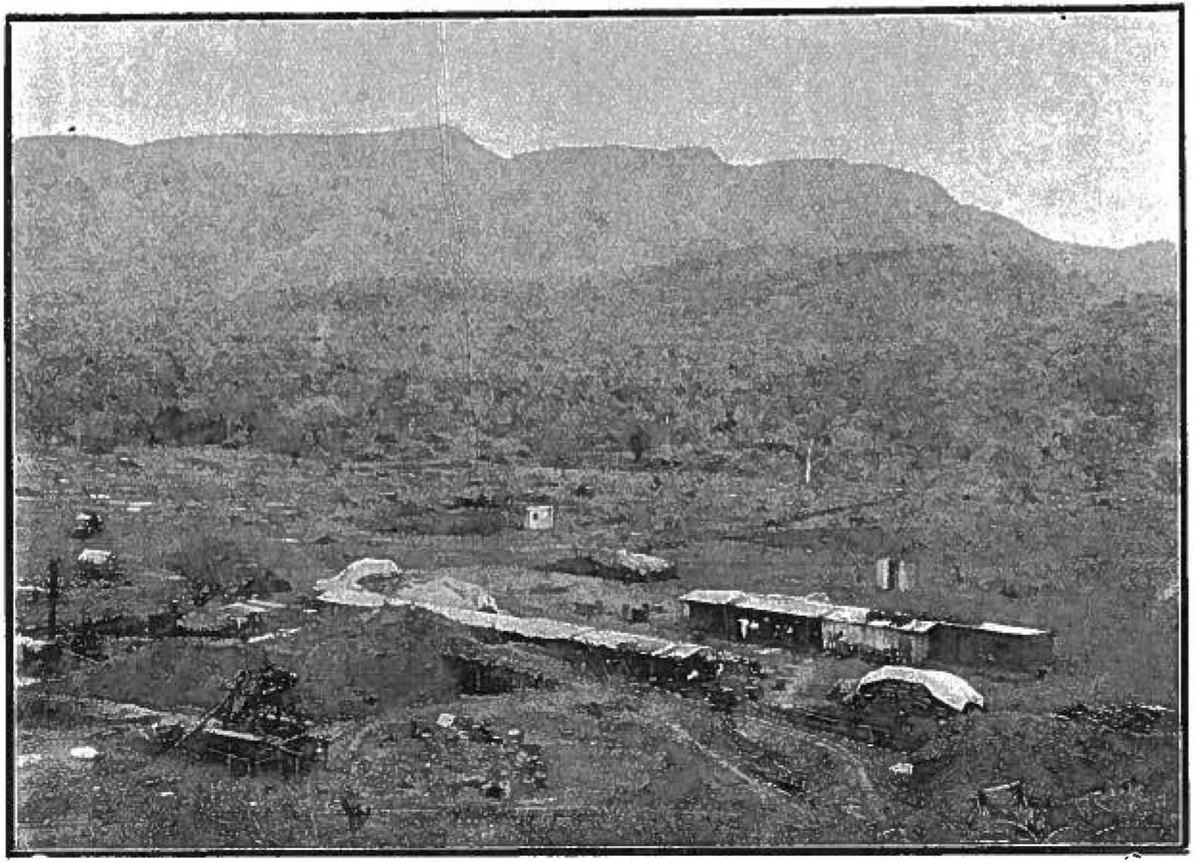

Plate X.—General View of the Egnep Amosite Mine, north of Lydenburg. In the background the escarpment of Timeball Hill quartzite; in the foreground the hoisting shaft, cobbing shed, drying floors, etc.

this remark also applies to the intercalated bands of ironstone in the main succession of dolomite on the left bank of the Olifants River, where asbestos has been reported from the farm Dalton No. 2646.

3. *The Succession across the Principal Asbestos Horizon and Mode of Occurrence of the Fibre Veins.*—The sequence of beds across the lower portion of the Pretoria Series is shown in Fig. 12, which is taken at right angles to the strike, the dip being from fifteen to twenty-five degrees to the south-south-west. The Timeball Hill Quartzite stands out as a well-defined high escarpment on the west, and is a prominent feature in the scenery surrounding the asbestos mines (see Plate X). It is overlain by highly altered staurolite and chiastolite slates and rests on a great thickness of altered slates and siliceous ironstones, which become predominant near the base of the series. These ironstones are specially marked below the narrow Bevets conglomerate, about 10 feet thick. Immediately underlying the latter is a thin band of pale greenish grey fine-grained dolomite some 25 feet wide, but the main series of the Dolomite does not become permanently established until below the ironstone beds. Two thin basic sills are found near the base of the Pretoria Series; from the top of the Dolomite to Bevets conglomerate about 300 feet of the succession are represented.

The asbestos occurs as cross-fibre veins bedded with the dip of the associated rocks, and invariably restricted to the siliceous ironstone phase, and does not occur in the sills or the dolomite. This ironstone may be described as a more thinly bedded or banded ferruginous siliceous rock, consisting nearer the surface of alternating harder and softer layers, the former due to compact dark bluish black material of silicified hematite or magnetite, the softer layers having a more earthy brown or rusty appearance. Due to various stages of oxidation of the iron ore, the colour and general appearance may vary a good deal. In the lower levels of the mines the same asbestos country rock is much softer and sometimes more like a ferruginous shale. There is a strong general resemblance to the banded ironstone of the Lower Griqua Town Series. In case of the narrow bands of similar ferruginous material found much lower down in the Dolomite Series, further cross-fibre veins of amosite have also been located.

It is convenient to draw the base of the Pretoria Series at the top of the main development of dolomite and regard the narrow subsidiary band below Bevets conglomerate as a local change in facies from argillaceous to calcareous rocks; the same variation has been recorded elsewhere at different horizons within the Pretoria Series, and does not imply a fundamental change in conditions of sedimentation.

Throughout the interval between Bevets conglomerate and the main Dolomite many amosite veins are met with exhibiting a great range in width, but those at present developed follow a fairly definite horizon, approximately 200 feet above the base of the Pretoria Series,

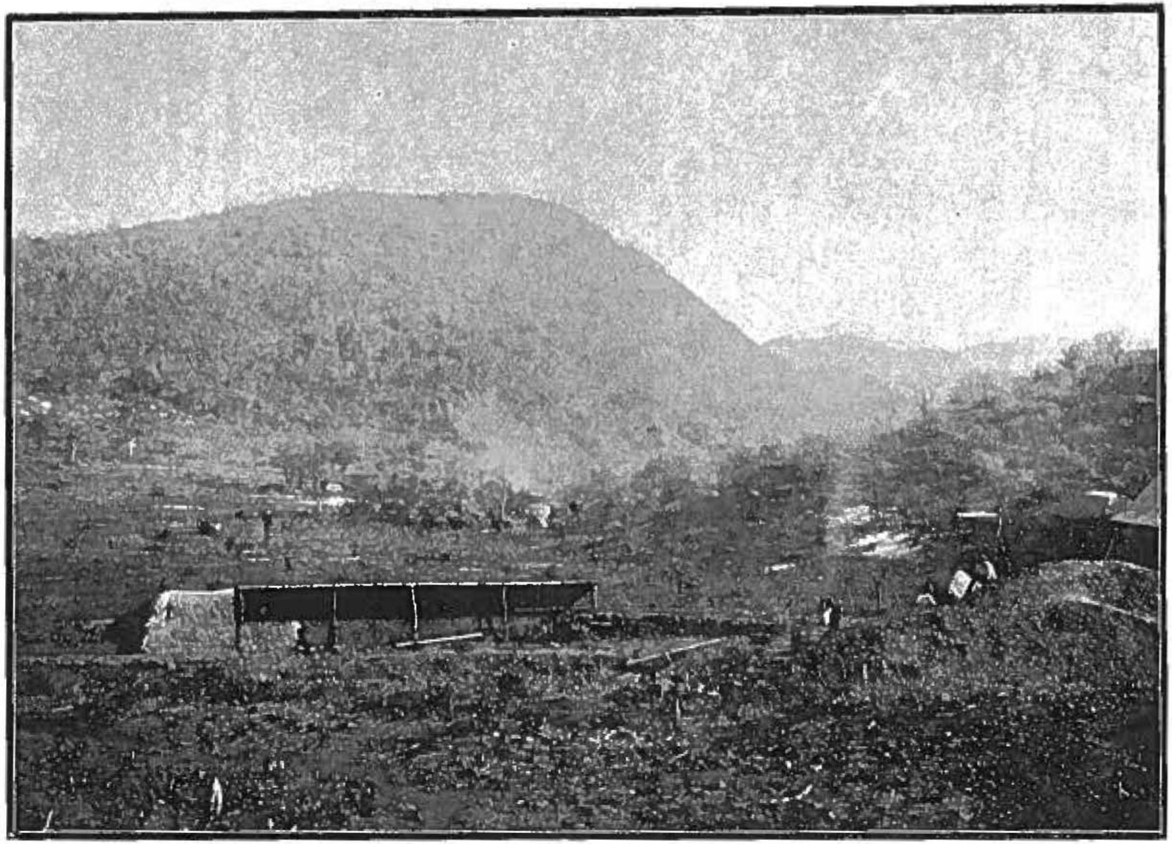

Plate XI.—Amosa Hill (banded ironstone) with the surface workings of Section C, Egnep Mine.
A cobbing shed in the foreground.

in the sense in which that line is interpreted above. The economic group of fibre veins are here referred to as the principal asbestos horizon.

All the veins of fibrous amphibole belong to the cross-fibre type and lie in banded ironstone only (see Plate XII). They trend with the dip of the country, and no instance has been recorded of their cutting across the formation ; in width they range from about 12 inches downwards. Many are too thin for exploitation, but the principal asbestos horizon can be followed with much persistence across Penge into Streatham.

4. *The Egnep and Amosa Mines.*—The principal horizon of fibre now being worked is well opened up by two mines, known as the *Egnep* and the *Amosa Mines*, distant about one to one and a half miles from one another.

Plate X gives a general view of the position of the *Egnep* * *Mine*, which lies in the floor and over the lower easterly flanks of an open valley, hemmed in on the west by the Timeball Hill Quartzite escarpment and extending roughly north and south across the western position of the farm Penge. The common boundary between the latter and the adjoining farm Streatham on the north runs over the summit of a low but conspicuous kopje, to which the name Amosa Hill is conveniently applied. It is easily recognized by its many surface workings (see Plate XI) ; those lying on its southern side belong to the Egnep, while the Amosa Mine includes the surface and other workings on the northern face (not seen in Plate XI) of this hill over Streatham.

The Egnep Mine consists of three sections : that known as Section C comprises the surface workings on the southern face of Amosa Hill ; Sections A and B lie a little to the south under the floor of the valley or over its lowest eastern slopes and include both surface and underground workings. They are the most important fibre area and the principal development, now carried out in the Egnep Mine, is centred on B Section. There are altogether seven levels ; the three highest of these form A and the four lower ones the B Section, so that No. 4 B is the lowest part of the mine. The method of development aims at maintaining between successive levels a stope face 100 feet long in the direction of dip, the latter averaging twenty-two degrees. The normal alignment of the levels is along the strike, and the middle group of seams lies very commonly shoulder high. It can be traced along the whole length of the levels, i.e. for a distance of from 300 to 500 feet in B Section. In the fourth level of the latter portion the development had just reached ground water at a depth of about 60 feet below the valley floor ; this point represents the lowest workings and implies a continuity of fibre veins of 300 feet measured along the dip over Section B, though this value is more than doubled if Section A is also included.

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* This word is formed by reading the name Penge backwards.

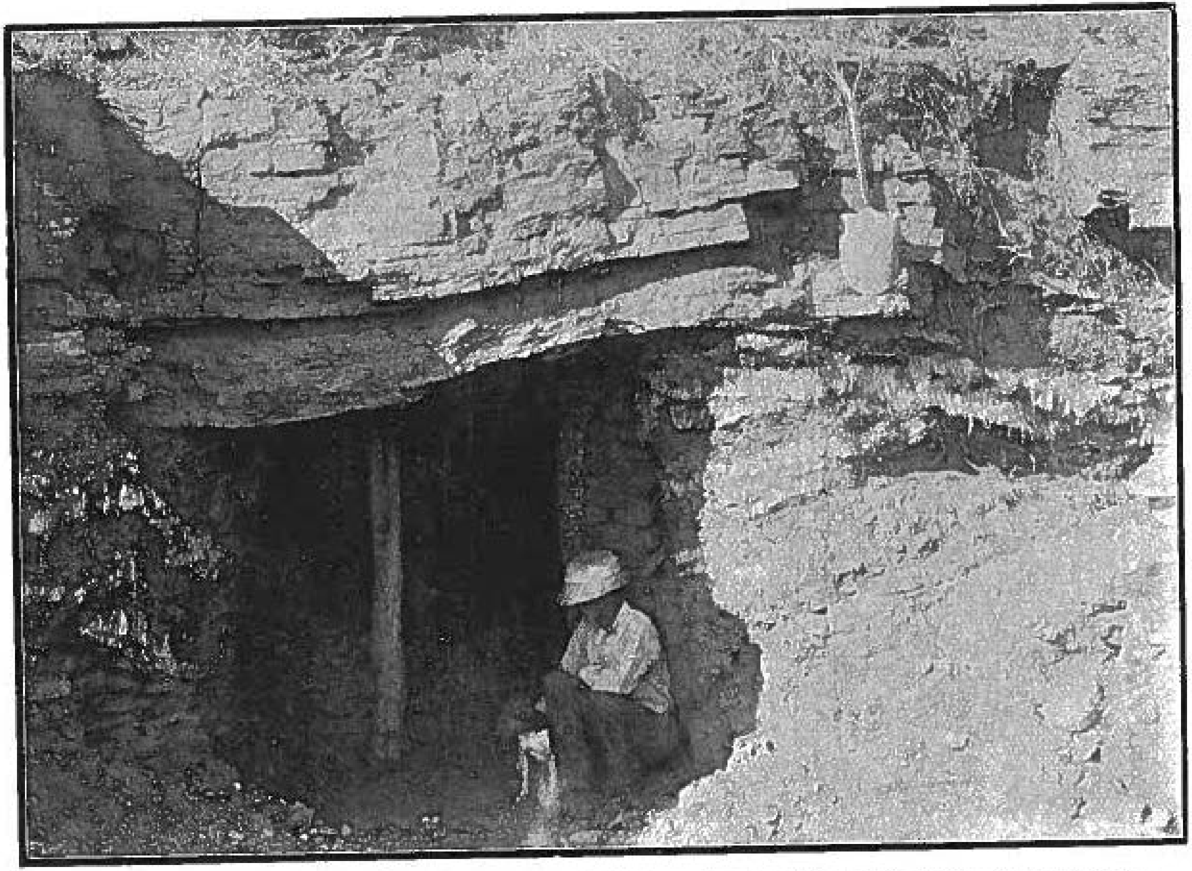


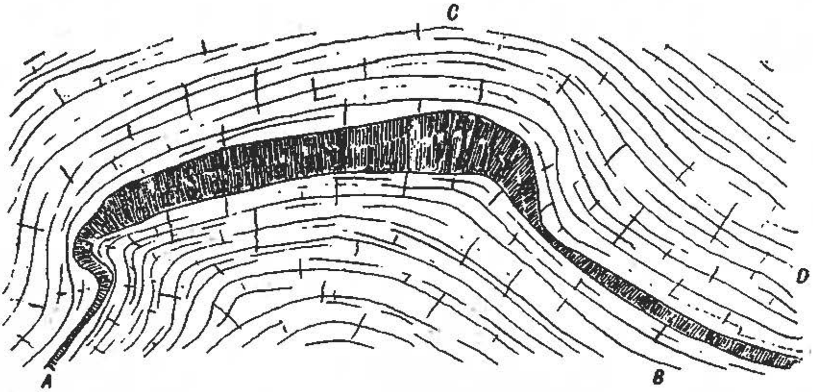
Plate XII.—Bedded cross fibre veins of Amosite in banded siliceous ironstone, Egnep Mine, Penge, near Lydenburg.

On the whole, the arrangement of the seams is very regular, and no fault or other disturbances interrupt the succession. An occasional minor roll is sometimes observed, of which Fig. 13 is an instance.

The Egnep Mine furnishes about four-fifths of the current output, and the third and fourth levels of B Section are the principal source of fibre.

In some of the upper levels and in many surface workings, irregular veins, stringers, or nests of dull white magnesite are found, but lower down nearer ground water level such occurrences are less frequent or even scarce. Such veins generally follow planes of bedding and rarely cut across them; they persist for a few feet at the most and show much variation in width and detailed distribution; on the whole, they strongly recall the occurrences of similar carbonate as the result of the decomposition of magnesian rocks in the belt of weathering. A sample of the freshest obtainable country rock from the lowest level showed a little magnesia on qualitative analysis, and since this constituent enters to the maximum of 6 per cent. into the composition of the asbestos, the material of the magnesite veins may conceivably be derived from that source, since even the apparently unaltered ironstone often contains extremely minute asbestiform layers. More probably, however, the oxide points to magnesia-bearing layers of the country rock. Its conversion into carbonate seems fairly clearly to depend on the present surface as a process of carbonation typical of the zone of weathering.

ANTICLINAL STRUCTURE IN THE LOWER ASBESTOS SEAM, FIRST LEVEL, B SECTION, PENGE.



From *A* to *B* represents 5 feet. The width of the seam measures 7½ inches below C and 3 inches on the left of *D*.

Fig. 13.

From the summit of Amosa Hill the workings of the *Amosa Mine* on Streatham extend down the northern slopes, known as D Section, and the further extension of the same group of seams is being established by systematic prospecting; both surface and underground development has been carried out, exposing the fibre more or less continuously over the northern face, as well as for a maximum distance of at least 300 feet into the hill on the dip. Normally this mine furnishes about one-fifth of the combined output, and in the eight levels over Amosa Hill there are the same features of vein distribution and characters as in the Egnep Mine. None of these workings have so far reached water level. Their position agrees with that of the southerly mine and is along the same principal asbestos horizon, of which they also form the middle group of seams, but do not quite come up to the best grade obtained in the Egnep Mine. As previously pointed out, the main source of fibre lies about 200 feet above the dolomite, and on the eastern slopes of Amosa Hill one of the basic sills alluded to above is well seen. It does not appear that its presence has any genetic significance.

Cutting obliquely from north-east to south-west across Amosa Hill are several fine-grained basic dykes up to about 40 feet wide. They are of an age subsequent to the formation of the amosite veins, since in some of the drives they are clearly seen to cut the fibre deposits and alter them. On approaching one of these dykes the asbestos undergoes a progressive change, most pronounced over a distance of 1 to 2 feet from the contact, the fibre becoming very hard and stony without altogether losing its asbestiform habit, until after the gap occupied by the intrusion, the same vein is picked up at the other contact with the same altered appearance in its proper position (compare the Westerberg Mine, Chapter II).

The behaviour of the dykes and sills appear to preclude a direct origin of the fibre veins, due to the effect of igneous intrusions of this character.

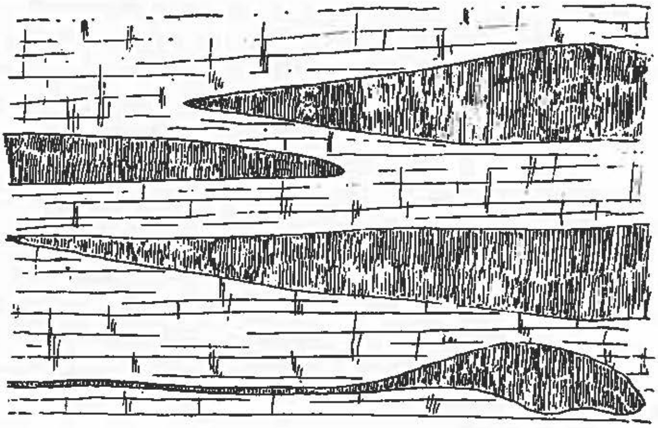
5. *The Amosite Veins and Fibre Length.*—A comparison of the various workings along the principal asbestos horizon shows that three fairly well-established groups of veins can be recognized following the dip of the country, each group occurring in several parallel rather than in single seams.

The upper group often comprises from three to five veins, underlain by some 7 feet of ironstone. This group is not exploited, since the veins are much thinner, though in a chrysotile mine they would be regarded as showing most desirable fibre length. The middle or main group embraces several seams, most of which, sometimes all, of commercial width. This has led to the main development at both mines and supplies nearly the whole of the output. At an average distance of 10 feet lower down the succession comes the lower group, as a rule due to one seam, of economic width in places. The only associated rock between the various veins is siliceous ironstone, apart from magnesite.

An outcrop measured in No. 1 level, B Section, Egnep Mine, showed a combined fibre length of over 30 inches distributed over nine seams, ranging from 7 inches to ¾ inch through a total succession amounting to roughly 21 feet. This is represented by Plate XV (at end of volume).

The amosite veins invariably assume the cross-fibre habit, and the fibres extend more regularly transversely across from one to the other containing wall than in the case of the Carolina chrysotile deposits. They are nearly always free from scattered iron ore and built up of tightly packed, well-oriented needles. A single vein may persist with sensibly constant width for several feet or yards, when it often tapers out more gradually or dies down to prolonged films. Very often several parallel veins accompany one another, the width of intervening country rock being subject to all kinds of variations (compare Fig. 14), and one vein frequently overlaps another or comes in at a slightly different level to maintain the general continuity of the fibre horizon when a neighbouring seam has ended. In this way the persistence of a group is kept up through the entire development along the levels. The repeated virtual coalescence of several seams of the middle group in level IV B gives a combined fibre width of 20 inches, broken by only one or two thin dark bluish clayey partings (see Fig. 15).

MIDDLE GROUP OF AMOSITE SEAMS IN THE FIRST LEVEL B SECTION, PENGE.
TO ILLUSTRATE VARIATION IN LATERAL PERSISTENCE.



Scale 1 inch = 12 inches (approx.).

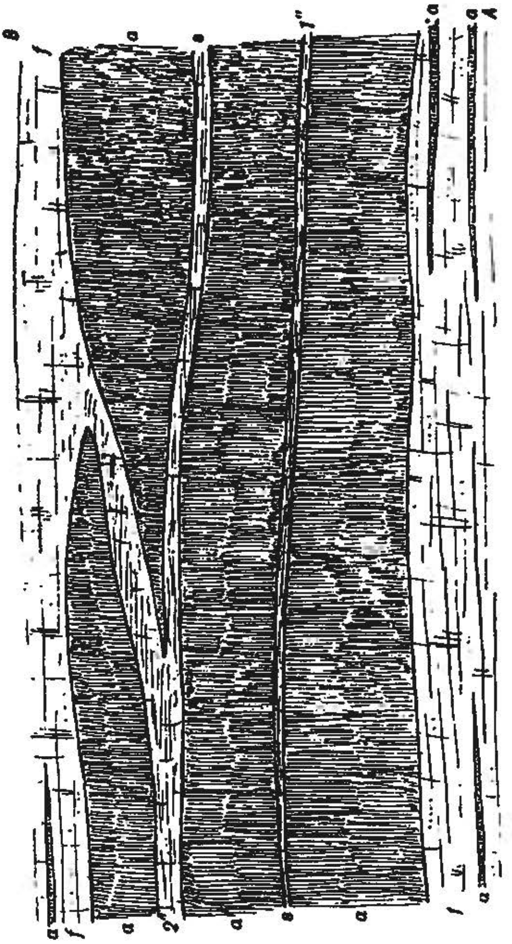
Fig. 14.

Perhaps the most striking characteristic of the Lydenburg amosite veins is the abnormal *length of fibre*, maintained not as an exceptional occurrence, but over great stretches along the principal horizon. A little over 11 inches represents the maximum hitherto observed, from which there is every gradation down to the thinnest films. At the same time in many veins the fibre is from 4 to 7 inches long, and no difficulty has been met with in maintaining the entire output up to this standard. The bulk of the Egnep supply is derived from the third and fourth levels of Section B, and an average of 6 inches over this part of the mine is justified, since the middle group consists of several veins, at least one of the constituent seams measuring over 7 inches at several places, apart from the local coalescence referred to. In this respect the Lydenburg amosite is greatly superior to the Canadian chrysotile and unique among asbestiform minerals generally.

6. *The Nature of the Fibre.*—The following remarks are supplementary to the descriptions given in Chapter I of the chemical and physical properties of amosite :—

While the old prospecting pits examined in 1907 showed the same remarkable fibre length, the material was very brittle and dirty rusty brown in colour, so as to present an altogether unpromising appearance. The developments at the present mines reveal a progressive improvement in quality from the surface downwards. The material from the highest levels is a pale brownish colour, but less brittle; although the fibres possess greater tensile strength, they are not as clean or straight nor so readily separable into very thin flexible strands as lower down; the asbestos from such sources is

SECTION ACROSS THE MAIN OR MIDDLE GROUP OF AMOSITE SEAMS, THIRD LEVEL, B SECTION, EGNEP MINE, PENGE.



AB = 30 inches. *a.* Hornblende asbestos (cross fibre). *f.* Banded ferruginous quartzitic slates. *s.* Soft dark bluish shaly partings.

Fig. 15.

classed as grade III and commands a lower price. In the second and third levels of the Egnep Mine the colours tend towards pale greyish white or ash-grey and the flexibility is superior, until in the fourth level at or near ground water the fibre assumes distinctly greater tensile strength and flexibility, can be separated easily into most delicate strands, and rubbed up into soft silky masses. The colours vary between various shades of pale green, yellowish green, pale golden yellow, and grey; some varieties from Streatham are almost pure white and comparable to chrysotile when thoroughly fiberized. This best quality is known as No. I grade and is from three to four times as valuable as grade III. Generally speaking, the fibre is quite free from mineral or stoney admixtures. No doubt the deeper colour and earthy-brown character of the fibre nearer the surface is due to oxidation and hydration of iron, of which a considerable percentage enters into the constitution.

No evidence could be so far obtained of the proximity of ground water adversely affecting the seams as regards number, width, or quality. The progressive improvement in the character of the asbestos lower down is well established. Any change in quality depending upon proximity to the present surface should be gradual, but no sign of the initial stages of deterioration are seen. Similarly there is no tendency for amosite to pass into the lavender blue crocidolite. It is very doubtful whether such a change is even likely, since the blue asbestos is frequently found already at the surface and remains unchanged on being followed underground. Cases from the northern extension of the Lydenburg fibre horizon are even known of the same lump of ironstone showing veins of both grey amosite and blue crocidolite without intermediate phases. Possibly the presence or absence of soda may underlie this distinction.

The determination of amosite as a monoclinic amphibole depends on the microscopic examination of a number of rocks exhibiting various stages of asbestiform minerals. At Penge and Streatham the commercial seams lie along the principal asbestos horizon, but throughout the succession of ironstones many further veins are found of little economic but of exceptional diagnostic importance in the determination of the fibrous mineral. Often these consist less of oriented fibre than of confused aggregates of dark brownish crystals without definite orientation. Certain other outcrops of more massively bedded softer dark greenish ferruginous rocks are crowded with scattered yellowish or greyish nests and spots of crystals, not infrequently arranged in stellate groups and distributed more evenly after the fashion of metamorphic phases. The above varieties furnish a transition from rocks with scattered feathery crystalline tufts through various stages of thin veins made up of badly oriented elongated crystals of blade-like habit to asbestiform veins and typical cross-fibre seams. They show the yellowish minerals to possess the typical lozenge-shaped outlines, prismatic cleavage, and oblique extinction up to twenty-two degrees of monoclinic non-pleochroic amphibole, while some sections show feathery wisps of most delicate fibrous growth intimately associated with larger crystals.

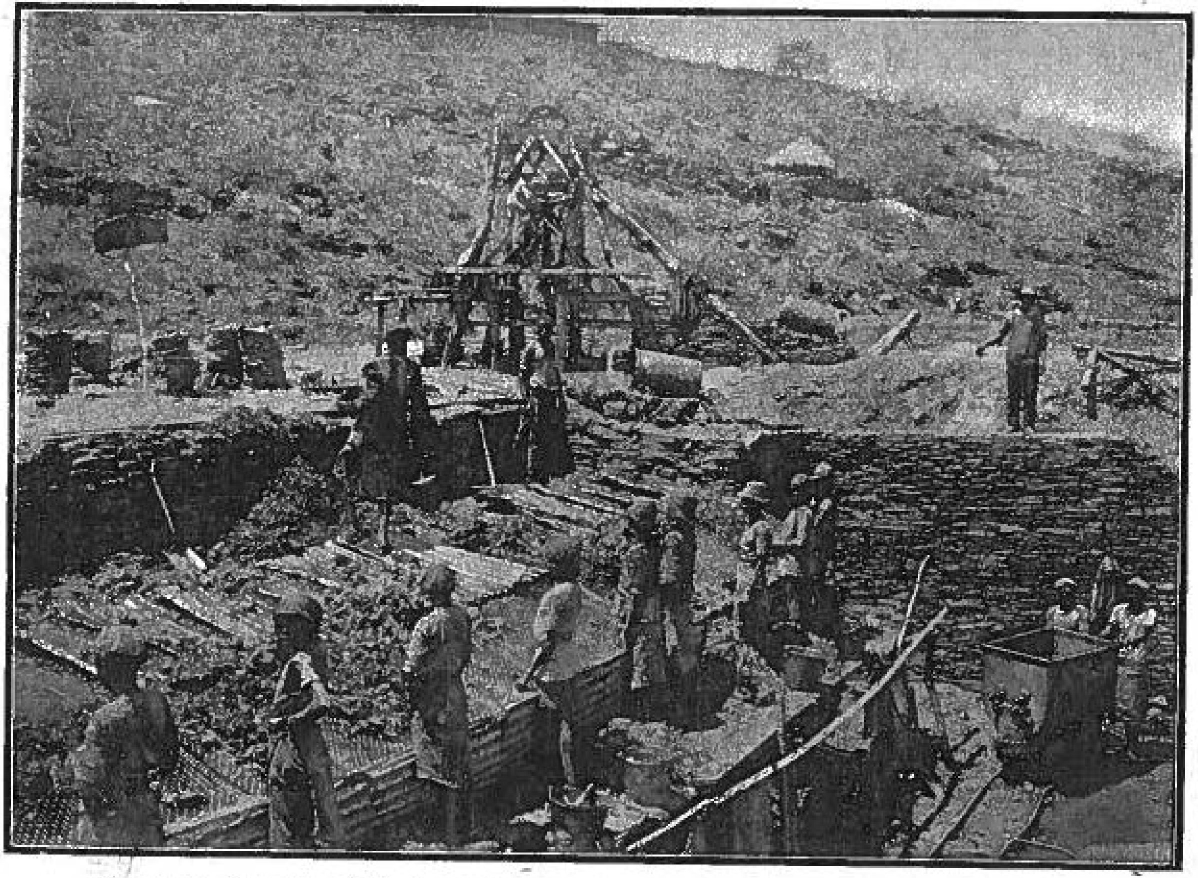


Plate XIII.—Separation of fibre lumps of Amosite preparatory to cobbing, Egnep Mine, north of Lydenburg.

7. *Vein Persistence and Available Supply.*—Even without attempting a numerical estimate of the total quantity of fibre available, development has gone far enough to justify the conclusion that very large bodies are obtainable from the Egnep and Amosa Mines, while continued prospecting has found the further extension of the principal horizon over Streatham or of other horizons on neighbouring farms, e.g. Kromellenboog.

Reference has been made to the fact that in Section B of the Egnep Mine the fibre continuity is demonstrated over distances up to 500 feet along the strike and for some 300 feet along the dip; taking the whole of this mine and Amosa Hill, over the entire slopes of which the fibre has been traced well into Streatham, a lateral persistence of very close on one mile is proved. Further north a series of trenches have demonstrated the continuity of the main groups of seams, increasing the preceding value to about one and a half miles and indicating a satisfactory condition as regards permanency, apart from additional evidence of amosite of good length on other farms in close proximity. An estimate of 6 inches for the average fibre length over Section B, allowing only for the middle group of seams, is by no means excessive, and represents 25,000 cubic feet of amosite between two successive levels only. It has also been found that along some of the stope faces the amount of waste rock did not suffice for packing in a stoping width of about 40 inches. In case of Amosa Hill, the mine surveys have indicated a tonnage of over 100,000, down to 300 feet on the dip, the furthest point reached. This figure is based on a fibre length of 6 inches, but this value is exceeded at several points.

8. *Fibre Grading and Disposal.*—From the underground workings of the Egnep Mine a hoisting shaft arranges for the lumps of fibre to be brought to a platform at the surface, over the edge of which the raw material is thrown on inclined sheets of corrugated iron and raked downwards over coarse wire screens (see Plate XIII). Smaller fragments of waste rock, together with lumps of shorter fibre, fall through the screen and are conveyed to a growing dump, which forms a valuable reserve of fibre, not made use of at present. Pieces made up of longer fibre are retained by the screen and are transferred to the adjoining principal cobbing shed, where a large number of natives are employed in cobbing, i.e. separating rock from fibre by means of square-shaped hammers, using wooden blocks for anvils. Over 100 youths are engaged in this work. The prepared fibre is next spread out for sun drying and bagged. The principle of grading is effected, not by fibre length, but depends on colour and flexibility, though with the more specialized requirements of the market more rigorous criteria for grading will most likely become necessary. At the present these are differentiated :—

First Grade, No. I Quality : Ash-grey, pale whitish grey, and very pale greenish. This is the best variety and posseses the highest flexibility and tensile strength. This grade is mainly supplied by the third and fourth levels of B Section

Second Grade, No. II Quality: Pale brownish colour or pale greyish; fibre less thoroughly flexible and supplied from the intermediate levels.

Third Grade, No. III Quality: Yellowish brown less straight fibre and not so flexible as the superior grades. It is characteristic of the upper levels.

The length of fibre ranges from about 4 to about 7 inches, and thus the entire output is spinnable.

Over the other portions of the Egnep Mine and also at the Amosa Mine are several smaller subsidiary cobbing sheds.

During the latter part of 1917 experiments were tried with a jaw rock-breaker, screening frames, rollers for cobbing, etc., but no machinery beyond that required for hoisting was in established use.

After grading and drying, the fibre is put up ready for the market in 200-℔. bags, which have to be conveyed by ox-wagon to Lydenburg Station, an average load consisting of 40 bags (4 tons). From 4s. to 5s. per bag has to be paid for this transport, which during the second half of last year absorbed some 80 wagons.

The value of the lowest grade is about £8 per ton at Lydenburg and rises to three to four times this figure for the better qualities, f.o.b. Capetown or Durban.

II. AMOSITE (PIETERSBURG DISTRICT).

It has been pointed out that the country rock of the Lydenburg amosite deposits continues unbroken north-westwards at least to Chuniespoort for a distance of some sixty miles, across the Olifants River into the southern portion of the Haenertsburg Goldfields, and thence westwards across the Malips River Valley. This section of the asbestos horizon falls into the Pietersburg District,* and includes both crocidolite and amosite veins situated in a generally similar succession near the base of the Pretoria Series. The development of these further occurrences has not yet reached the same stage as that presented by the Egnep and Amosa Mines. All the Pietersburg asbestos is again of the cross-fibre variety and restricted to that part of the Pretoria Series which underlies the Timeball Hill Quartzite, but here also an amphibole asbestos resembling amosite has been observed in the narrow zones of banded ironstones lying interbedded in the main series of dolomite (e.g. Chuniespoort area). Some of the amosite is of good quality and length, but sometimes a promising looking fibre is spoilt by scattered crystalline specks of iron ore.

The best-known localities of amosite are Uitval No. 1791, Holkloof No. 1581, and Krantzkloof No. 1786, situated in the upper portion of the Malips River basin; further occurrences also lie east of this area in the southern portion of the Haenertsburg Goldfields, and in the Chuniespoort area indications of an asbestos comparable

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* The general geology of this area is shown on Sheet No. 13 (Olifants River) of the Geological Survey. On this map the base of the Pretoria Series is drawn a little too far south and should cross the Malips River approximately through the centre of the farm Uitval No. 1791 and Pylkop No. 471.

to amosite lie in an interbedded ironstone band in the Dolomite Series close to the common boundary of Boomplaats No. 1659 and Uitloop No. 514, north of the police post.

Near the bottom of the Pretoria Series close to the base of the great succession of siliceous ironstones underlying the Timeball Hill Quartzite, amosite veins are most prominent. In the Penge–Streatham area only the lower portion of the beds below this quartzite consist of banded ferruginous rocks, but in going northwards this facies affects a gradually increasing width, until along the Beyer's Nek–Malips Drift section almost the entire series to the lowest main quartzite consists of this phase of ferruginous slate. The change is accompanied by a marked increase in thickness, amounting in the Malips River Valley to about three miles of surface outcrop and corresponding to about one-half the entire thickness of the Pretoria Series ; at the same time there is a great reduction for the Daspoort and Magaliesberg groups. Compared with the Lydenburg fibre area. with its regular or very little disturbed strata, much minor folding is seen in the Malips River section and tends to exaggerate the increased width of the banded iron stones.

The best-developed amosite veins are those of *Uitval No.* 1791, which is part of the same fibre belt including the adjoining farms *Holkloof No.* 1581 and *Krantzkloof No.* 1786. They lie some nine miles north-west of the junction between the Malips and Olifants Rivers, or about fifty miles by road from Pietersburg Station. A contemplated new road from Uitval northwards over Beyers Nek direct to Pietersburg would shorten this distance appreciably.

The Uitval workings lie low down on the southern slopes of a deep and confined short valley running approximately from west to east into the main Malips River Valley. Typical black dolomite krantzes define the north side of the Uitval Valley and banded ironstone the south side, the base of the Pretoria Series thus falling approximately along its floor, where débris of a conglomerate closely resembling Bevets, as seen at Penge, can be observed. The asbestos has been exposed on Uitval in a number of workings, either opencast or as short tunnels or drives, and spaced over about 150 feet from the floor of the valley up its southern flank. The amosite deposits take the form of cross-fibre veins interbedded in banded ironstones and dipping forty-five to fifty degrees to the south. The more promising group consists of one or two veins about 13 feet apart and restricted to a more constant horizon. The fibre is pale greyish or ash-grey amosite up to some 4 inches long, free from scattered crystals of iron ore and comparable in quality to the third or second grade of the Egnep Mine. Irregular dirty white magnesite veins are also found under conditions similar to those described above from the Lydenburg fibre area.

The persistence of this amosite horizon has been proved over about 500 yards, so that considerable quantities should be available ; developments have not yet proceeded far enough to afford reliable data for estimating the available tonnage more accurately.

Plate XIV.—Fig. 1. Bedded cross fibre vein of crocidolite in banded ironstone.
Lot 244, Malips River. (Photo. by A. W. Rogers.)

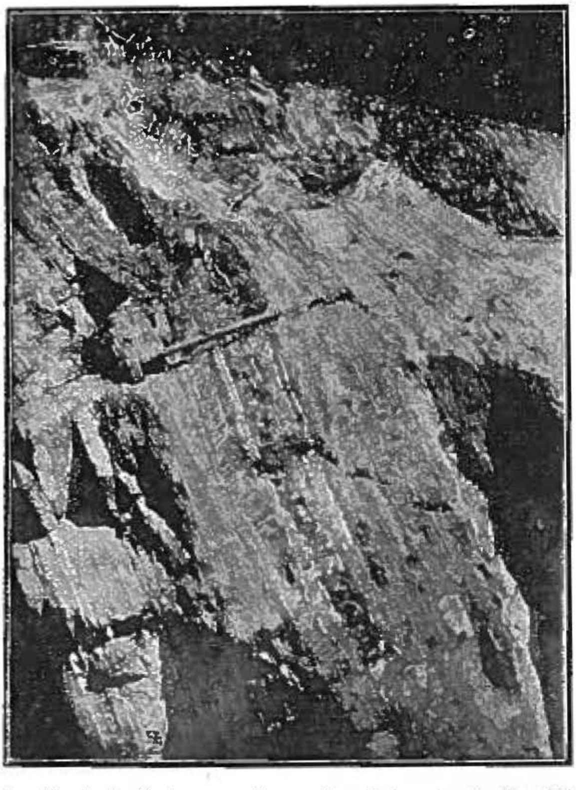

Plate XIV.—Fig. 2. Bedded cross fibre vein of Amosite in banded ironstone.
Holkloof No. 1581, Malips River Valley. (Photo. by A. W. Rogers.)

South-west of Uitval, on Holkloof No. 1581, a vein of pale bluish white cross-fibre amosite is well exposed almost in the bed of the spruit; it averages 5 inches in thickness and can be followed for over 50 feet in sharp contact against banded ironstones, which at this point present a local dip to the north (see Plate XIV, Fig. 2).

In some of the workings on Lot No. 244 on the left bank of the Malips River amosite veins also occur, but may be more conveniently considered in connection with the crocidolite deposits of the same farm (see below).

Like the amosite deposits of the Penge–Streatham area, those of Uitval and Lot No. 244 occasionally show the peculiar form of growth associated with rapid and pronounced variations in fibre length. They are referred to in connection with the "cone" and "corrugated" structures found more commonly in the Pietersburg and Cape crocidolite occurrences (see Chapter II).

III. CROCIDOLITE (PIETERSBURG DISTRICT).

Reference was already made to the fact that, whereas amosite is found right along the whole extent of the fibre belt from the Steelpoort to Chunies River, crocidolite appears to be restricted to the Haenertsburg Goldfields and Malips River portions of the Pietersburg District. Here both varieties of amphibole asbestos are associated together, sometimes in the same set of workings, so that the separate consideration of crocidolite is mainly a matter of convenience, and does not imply any fundamental difference in origin.

Crocidolite occurs in a large number of localities, including, e.g. Lot No. 244 in the Malips River Valley, or Lots Nos. 123, 126, 263, and others in the Haenertsburg Goldfields, while Molengraaff has described occurrences from Jobskop No. 589 and Riverside No. 578 (compare Bibliography No. 29). Their horizon agrees with that of the amosite from the same area; the asbestos is not necessarily confined to the lowest portion of the banded ironstone, though proximity to underlying dolomite seems to favour their occurrence, an association of possible genetic significance. Many of the veins are too thin for economic exploitation or, when of suitable fibre length, may be spoilt by scattered crystals of iron ore; prospecting operations, e.g. on Lots Nos. 244 and 123, have furnished fibre of good length and quality, free from foreign admixtures.

The deposits situated on *Lot No.* 244 have been prospected in a series of workings, mostly open-cast. This locality lies close to the left bank of the Malips River, a little way up to the slopes of the hills; the upper group of prospecting developments are some 50 yards from the south-easterly beacon, about 4 feet deep, and expose a fibre horizon about 150 feet long in a thinly bedded very hard siliceous ferruginous slate. Owing to minor folding, this slate is sometimes almost horizontal, sometimes dips up to about thirty degrees to the north or south. Several parallel cross-fibre veins of crocidolite are seen conformably interbedded, in places 3 inches thick, but usually only ¾ inch or less. They consist of tightly packed, thoroughly oriented fibre, commonly dark lavender blue, with their long axes slightly inclined to the containing walls and indistinguishable from the typical blue crocidolite asbestos of Griqualand West. In their detailed distribution, variable lateral persistence, tapering habit of termination, they show great similarity to the chrysotile veins of the Carolina or the amosite veins of the Lydenburg Districts. Any one vein rarely persists for more than a few feet or yards, and then dies out to be replaced by another one at a slightly different horizon. In places the quality of the fibre is deteriorated by disseminated iron-ore crystals.

In Chapter I an analysis of the crocidolite from Lot No. 244 is given, and this is in general agreement with other fibrous monoclinic soda amphiboles.

The country rock of the upper set of workings proved extremely hard, and the consequent slow progress of development has led to further prospecting being suspended at this point. It is not clear whether this indurated habit of the ironstone is a permanent character or merely an effect depending upon the present surface. Certain experience at other points seem to indicate that at greater depth a softening may be expected.

In the lower set of workings is a drive some 40 feet long into the hill, here revealing banded ironstone dipping thirty degrees to the south. The interbedded cross-fibre veins include both blue crocidolite and light greyish white amosite.

The fibre length reaches 3 inches, but is more often less ; here also are found the " cone " and " corrugated " structures (see Chapter II).

Besides at these two sets of workings, amphibole asbestos has been located at a number of other points in the present neighbourhood, but these discoveries are still in the early prospecting stage.

In the Haenertsburg Goldfields to the east of the Malips River further cross-fibre crocidolite veins occur repeatedly, and have more recently led to active prospecting on or near *Lot No.* 123. These are of good length and quality and show the common lavender blue colour. In exceptional cases a colour combination may be observed, e.g. on Lot No. 123. A vein about 1 inch wide, made up of cross-fibre, shows blue crocidolite over about seven-eighths of the total thickness, but this variety terminates sharply against a pale silvery-grey variety for the balance of the width without any structural modification. The resulting effect is that of two differently coloured bands in a single layer of cross-fibre asbestos. The wider one is undoubtedly crocidolite, but the thinner one has the appearance of amosite, though in the absence of more numerous analyses, it is not certain how far such variations go with changes in chemical composition. It is possible that the gradations from lavender to pale bluish grey may be conditioned by varying soda content.

In one and the same vein both the normal blue and the golden yellow asbestos, with the appearance of griqualandite, may occur. The latter has been observed as much as 3 inches thick, but the association with infiltrated quartz leading up to true "tigereye" has not hitherto been recorded.

The hard dark blue compact heavy lumps of what may be regarded as a kind of mass-fibre crocidolite, so characteristic of the dry river beds in parts of the Cape asbestos belt (potential crocidolite), may probably be compared to a very similar rock recorded so far only from one locality in the Transvaal—Lot No. 269, in the southern portion of the Haenertsburg Goldfields. No fibrous structure is visible in hand-specimen, but a thin section gives a slight indication of bedding planes and is crowded with strongly pleochroic crocidolite needles without orientation; the strongly elongated crystals exhibit the typical amphibole cleavage, and their extinction ranges from 12 to 19 degrees, with a tendency to radial arrangement from larger iron-ore crystals as centres.

CHAPTER V.

OCCURRENCES OF ASBESTOS IN NATAL.

THE only varieties of asbestos so far exploited in the Province of Natal are chrysotile and tremolite, both from Zululand.

CHRYSOTILE.

The most important occurrence of this fibre variety is at the *Sitilo Mine*, in the Tugela Valley, Zululand, between Eshowe and Krantzkop; it is best reached from Krantzkop (railway terminus) by the main road descending to the Tugela River at the Middle Drift, thence taking the Eshowe main road. The mine lies about nine miles from the left bank of the river and some twenty-five miles from Krantzkop Station. In this part of Zululand the bed rock is a hornblende schist which occupies extensive tracts of country, and is freely traversed by light coloured veins of acid rocks, in part aplite or pegmatite, but generally presenting the characters of acid granitic differentiates. Associated with this series are dark coloured basic rocks, e.g. serpentine, as well as apparently younger basic intrusions of the sill and dyke habit; the country is fairly open, though somewhat hilly, and in places well covered with bush, more specially on the Krantzkop side of the main stream.

The Sitilo Mine lies some 1500 feet above the Tugela River, close to and overlooking the old Eshowe road on the northern slopes of a short range of serpentine with bare smooth outlines. The deposit was opened up and developed by a number of adits extending up to some 200 feet into the hill and associated with high open cuttings. The largest of these is known at Cathedral Adit and forms an open-cast working extending for some 40 or 50 feet vertically down the hill; it shows the succession represented by Fig. 16, where the pale or dark green serpentine is traversed by parallel bands of light coloured finer grained aplite alternating with darker coloured hornblende schist. The asbestos lies in the serpentine on one side of the contact up to within 2½ feet of it in the form of many parallel vertical cross-fibre seams of pale yellowish green chrysotile. The longest fibre observed measured about 3 inches, but values ranging from ¼ inch to ½ inch are the rule; these taper off, die out, and come in again in the manner familiar to all chrysotile occurrences. There appears to have been a tendency for the seams to decrease in number and fibre length in proportion as the adjoining aplite band varied in thickness, but the present condition of the adits, now * to a large extent fallen in, does not allow a genetic connection between the

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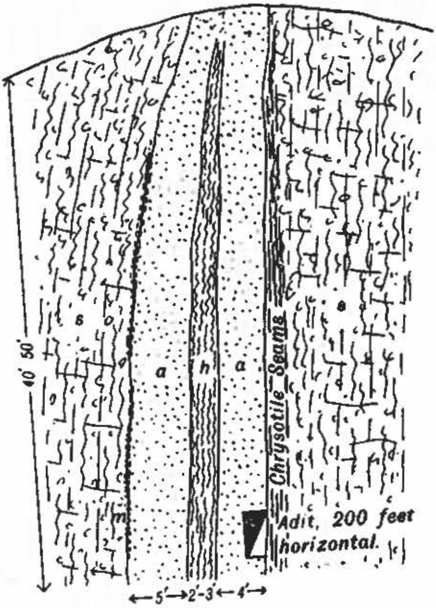
* June, 1918.

aplite and the asbestos seams to be tested. It is possible that the intrusion of the former resulted in a certain amount of fracturing of the massive basic rock in contact with it, thus providing potential lines of weakness oriented with the intrusion. In the subsequent alteration of the basic rocks to serpentine through hydration, accompanied by increase of volume, these lines of weakness behaved as potential fissures in favouring the formation of cross-fibre asbestos along lines of least pressure, as indicated in Chapter VI. No definite evidence is available as to the persistence of chrysotile in depth, though the close association of the seams with aplite suggests the continuation of the latter as a probable pre-requisite condition for the persistence of the former.

SECTION EXPOSED AT THE MOUTH OF THE CATHEDRAL ADIT,
SITILO ASBESTOS MINE, ZULULAND.



a. Evenly fine grained light grey aplite.
h. Grey banded micaceous gneissic rock.
s. Dark greenish serpentine, with groups of parallel cross fibre seams of chrysotile.
m. Thin layer of biotite.

Fig. 16.

According to Dr. Hatch,* the Sitilo chrysotile was shipped in some quantity to the English market. Apparently the output was disposed of as a whole, and it is doubtful whether a proper system of grading, based on fibre length, was maintained. In 1913 some 23 tons were produced, valued at £429, and in 1914 a further 95 tons were recovered, valued at £1697. The asbestos was of inferior quality, but found a market for the manufacture of cement slate and for steam-lagging purposes.†

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* F. H. Hatch—"Report on the Mines and Minerals of Natal," London, 1910. This includes a report on the chrysotile by Professor W. Dunstan.

† P. A. Wagner—"Asbestos," South African Journal of Ind., Vol. 1, p. 262.

In the Tugela Valley chrysotile has been also recorded from a number of other localities, e.g. the Fort Yolland area, without hitherto having led to active mining developments.

TREMOLITE.

Deposits of this variety of asbestos have been opened up in Zululand by the African Asbestos Co. and the Buffalo Asbestos Co. They lie some forty-five miles from Dundee at the nearest railway station.

The workings on the Buffalo Asbestos Co. are in the Klip River Location and best reached by the main road descending from Helpmakaar, twenty-five miles from Dundee, on the edge of the Highveld Plateau across a portion of the Buffalo River basin into Elandskraal, whence the last nine or ten miles are represented by a bad road, almost impassable to anything on wheels. The workings are open-cast and comprise a number of quarries, cuttings, and prospecting pits, situated on the lower slopes of a group of hills overlooking the right bank of the Macebeko River. These hills are made up of well-jointed soft pale green talcose rocks, in part somewhat schistose and most probably answering to very highly altered basic rocks; in their general characters they recall some phases of the Jamestown Series in the Barberton District.

The largest working shows a well-defined seam from 4 to 5 inches thick of soft pale greenish grey, sometimes more whitish, asbestiform tremolite, an analysis of which is given in Chapter I. This seam is of the slip-fibre kind and fibres several inches in length can easily be isolated; they are very soft, with a faint silky appearance, but thoroughly brittle, so as to be useless for purposes requiring spun yarn.

Several other seams of similar slip fibre can be observed, and in the general body of the country rock there is sometimes a tendency towards a fibrous structure. It is not improbable that movement along joint planes has assisted the formation of slip fibre.

A certain amount of both the talcose rock and the tremolite is being recovered and worked up at Dundee into asbestos stove bricks, so-called Buffalo jointing for steam or acid jointing, boiler lagging, and steam packing (see Chapter VII).

Certain varieties of the surrounding rocks at the Buffalo Mine approach a pure talc, and in thin pale green semitranslucent characters very closely resemble to best-quality talc bands of the Verdite Mine near Noordkaap Siding, in the Barberton District. The very striking form of "pencillated weathering" previously described from from the Noordkaap area * is also found here, and furnishes another resemblance between the present rocks and the Jamestown Series.

A little nearer to Elandskraal are the developments of the African Asbestos Co., where an open-cast working shows the same variety of pale greenish talcose rocks, traversed by a broader irregular seam of similar asbestos (tremolite ?) up to 8 inches wide and splitting up into a number of narrower veins.

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* A. L. Hall—"The Geology of the Barberton Gold Mining District," Geological Survey Memoir No. 9. Pretoria, 1918, p. 202.

CHAPTER VI.

THE GENETIC PROBLEM.

FROM the point of view of genesis the asbestos deposits exhibit the following outstanding features :—

(1) Highly perfected fibrous growth.
(2) Predominant mode of occurrence as interbedded cross-fibre seams.
(3) The law of association.

The striking fibrous habit is shared not only by all commercial varieties of asbestos, but also by other asbestiform minerals and natural crystalline material, which may not possess the additional physical properties of asbestos, so that the fibrous structure seems to depend less on the nature of the mineral than on the condition of crystallization.

The mode of occurrence as interbedded cross fibre very conspicuously predominates over slip and mass fibre in both serpentine and hornblende asbestos; in spite of the very large number of instances examined, not a single case among commercial deposits of the Union has come to the writer's notice of a definitely cross-bedded vein. This experience probably depends not only on factors controlling the development of crystalline structure, but also on the geological relationship to surrounding rocks, etc.

By the law of association is meant the restriction of one variety of fibre to the same class of country rock, chrysotile being found only in serpentinous rocks—whether consolidating directly from igneous fusion (Canada) or arising from the alteration of dolomite rocks (Carolina)—and hornblende asbestos being restricted (as in the Union) to banded ironstones.

In this way the genetic problem of asbestos is partly crystallographic, partly geological, the former aspect probably identical for all asbestos proper, the latter varying with the nature of the fibre and its geological association. It will be thus more convenient to consider serpentine and hornblende asbestos separately.

1. CHRYSOTILE.

This variety is the most widely known form of asbestos, owing to the prominent position which the extensive Canadian deposits have acquired, and most investigations of its mode of occurrence and origin have primary reference to it. Though opinions regarding its origin have been expressed by a number of observers, little definite and more detailed information is available. The more purely crystallographic aspects of the problem, based on the typical mode of occurrence of chrysotile in dunite, etc., is probably applicable also to the Carolina type of fibre occurring in sedimentary rocks, as well as to amosite or crocidolite in banded ironstones. But the geological aspect of genesis, i.e. the prevalence of interbedded cross-fibre veins, together with the law of association, has to be considered with reference to the field relationships exhibited by each variety, and the results to be deduced from the Canadian type of occurrence do not appear to the writer necessarily applicable to either the Carolina chrysotile in altered dolomite or the amphibole fibre in banded ironstone, both these varieties of country rock being of undoubted sedimentary origin.

Renewed attention has more recently been directed to the problem of asbestos formation by interesting contributions from Professor S. Taber,[*] in which use is made of the experimental method. Owing to the difficulty of reproducing natural conditions, this method can have only a limited application, and its lessons must be extended to natural cases with caution, but they seem to the writer more justifiable in the case of questions of crystal growth than in some of the problems, in the solution of which the experimented method of investigation has been applied.

Professor Taber describes an experiment where a porous cell is partially immersed in a saturated solution of copper sulphate, the latter gradually ascending through minute pores until evaporation occurs from the exposed portion of the cell. A coating of sulphate was observed to form after two days at irregular spots, developing into thin crusts and finally showing groups of short needle-shaped columns of the same material, normal to the cell surface and pushing the crust slowly outwards. Narrow cracks were found in the cell walls after about ten days, the opening becoming filled with çopper sulphate to form veinlets made up of columns or fibres with their axes oriented normal to the containing walls. An irregular parting near the centre, defined by a line of small cell fragments, shows the enlargement to proceed by growth from both sides; the growth of the crystals continued without break across the whole vein, where one side was cut off from further supplies of solution. It is pointed out that in structure and appearance these veins closely resemble those of serpentine asbestos, which may have grown out from the walls in somewhat the same manner. In considering the lessons to be drawn from experiments of this kind, Professor Taber comes to the conclusion that "the peculiar structure of asbestiform minerals is usually due to the accentuation of a normal prismatic habit and cleavage through the limitation of crystals growth by physical conditions."

Some writers [†] have questioned the justification of extending results obtained in the laboratory to natural occurrences, and pointed out the nature of the wall rock as an important factor and the possibility that the vein spaces represent shrinkage cavities. No doubt

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[*] S Taber—"The Genosis of Asbestos and Asbestiform Minerals." Bull. Amer. Inst. Min. Eng., 1916, pp. 1973–1998, and "The Growth of Crystals under External Pressure." *Amer. Journal of Science*, 1916, p. 532–556.

[†] Bull. Amer. Inst. Min. Eng.. 1917, and Sc. Progress, January, 1918.

the moral from experiments has its limits, but the analogy seems too close to be altogether without more general significance. In the great majority of cases chrysotile occurs in large masses of intrusive serpentine or allied magnesian rocks, and their final consolidation from igneous fusion and further cooling down render volume changes very probable, so that shrinkage cavities are conceivable. In other cases chrysotile occurs in sedimentary rocks, to which the former conditions of vein formation along open fissures can hardly apply. It is extremely difficult to conceive a large number of such openings in case of the very numerous asbestos seams, specially in the banded ironstones of the Cape or Lydenburg fibre areas, where individual veins maintain a thickness of 6 inches and more over several hundred feet.

The genetic problem of chrysotile has been more recently discussed in greater detail by R. P. D. Graham * with reference to the Canadian occurrences, where it is concluded that " siliceous magnetic waters, rising along fissures in the cooling and contracting peridotite, have soaked into the rock on either side and brought about its serpentinization. . . . Owing to the tendency for the fissures to open, the pressure was not uniform from all directions, and the growing crystals were able to develop only in the direction of least pressure, normal to the fissure. . . . As succeeding layers or films, farther and farther removed from the original fissure, became completely serpentinized, the crystals continued to grow outward, because it was only at their extremities that they were in contact with fresh supplies of material, and also because the lesser pressure normal to the walls aided their growth in this direction " (pp. 195–196).

The view that the veins represent deposits in open fissures through the agency of circulating solutions attracted early attention and appears a simple conception. The discontinuity implied by this theory has been accounted for by the contraction and cooling down of igneous rock, by subsequent movement, by volume changes due to serpentinization, etc. The possibility of the existence of open spaces offers many difficulties from a mechanical point of view. It has been shown † in Southern Quebec that the chrysotile veins may occupy as much as 10 per cent. and more of the rock, and are disposed in all directions, sometimes with a continuity 100 feet long. In the veins of the same asbestos in the Grand Cañon, Arizona, interbedded seams are maintained for at least 150 feet. In case of the exceptionally long fibre of the Lydenburg District, where, as pointed out above, an average of 6 inches is maintained over long distances to be measured in hundreds of feet, and sometimes rises by coalescence of several seams to a combined width of over 20 inches, the difficulty of a mechanical conception of open fissures appears to the writer insuperable. It may be possible that some veins have arisen

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* R. P. D. Graham—" Origin of Massive Serpentine and Chrysotile Asbestos, Black Lake. Thetford Area, Quebec." Eco. Geol. XII, 1917, pp. 154–202.

† J. A. Dresser—" Prel. Rep. on the Serpentine and Associated Rocks of Southern Quebec." Geol. Sur., Canada, Memoir No. 22, 1913.

thus, but an exclusive or even predominant mode of origin of this kind it would be almost impossible to conceive. The very common association of chrysotile—the best-known fibre variety—with massive serpentine as igneous rocks units has probably been the reason why the occurrences of chrysotile in altered limestones has not yet received much attention, and the same remark would appear to apply to amphibole asbestos in banded ironstone. On the theory of open fissures, the widespread distribution of so many seams of crocidolite and amosite throughout the very extensive Cape and Transvaal fibre belts postulates an enormous number of open spaces in sedimentary rocks, and it is not easy to understand why they are restricted to only one type of rock and do not sometimes remain in other sediments.

Within the Union no commercial occurrence of chrysotile has so far been found in the normal or Canadian type of association, i.e. in a massive basic rock due to igneous fusion, but only in altered sediments; this is also true of all South African crocidolite and amosite. This ultimate derivation from sedimentary rocks is most probably founded on a geological basis different from that obtaining in igneous bodies.

The descriptions in Chapter III have shown that the Carolina chrysotile deposits are distributed exclusively with reference to an intrusive diabasic sill, which is directly overlain by altered and serpentinized dolomite. The veins of asbestos never occur in the sill, only in the dolomite above—at a fairly constant distance up to 3 or 5 feet from the igneous rock. In every case where fibre has so far been found, the underlying sill also occurs, but the converse is not always the case. The lower contact has nowhere been definitely exposed, but the association of fibre with the sill holds good throughout the belt. The asbestos seams become more numerous and better established in proportion as the dolomite has a more pronounced altered appearance, and all veins are of the interbedded cross-fibre type. This mode of distribution, the constant distance from the intrusive sill, and also the chemical aspects strongly indicate a genetic connection between the chrysotile and the underlying intrusive sill, depending upon metamorphic effects. It is unlikely, on the other hand, that fibrous serpentine resulted directly from the intrusion as a product of contact metamorphism. Serpentine appears invariably to depend for its formation on pre-existing magnesian silicates, such as pyroxene or olivine. so that it is more probable that the immediate effect of intrusion was the formation of such silicates; these were subsequently altered into serpentine. The chemical basic for these changes is furnished by the dolomite itself; this, in the Carolina occurrences, is associated with siliceous layers. The material requisite for the formation of magnesian silicates, as a familiar expression of contact metamorphism of carbonate rocks by molecular rearrangement *in situ*, is thus supplied by the country rock itself. Silica in this is not distributed more uniformly, like in a body of massive peridotite (as silicates), but along certain layers only. in a general trend conforming to the direction of bedding, so that the distribution of the ultimate fibre seams would be rather as interbedded than as irregular cross veins. The subsequent change to serpentine requires the agency of water and is accompanied by a considerable increase in volume. This water may have been of magmatic or meteoric origin, but the small scale of the intrusive and the general impression that there is a tendency for the fibre length to decrease as development is carried further underground suggest meteoric sources of supply. It might be argued that the expansive strain set up by increase in volume resulting from hydration is counterbalanced by increasing rock pressure further in, so that a limit would be reached to the conversion of metamorphic silicates into serpentine, but the workings have not gone far enough to show what becomes of the contact zone above the sill, when the fibre deposits have altogether ceased.

The volume changes accompanying the formation of serpentine give rise to a considerable expansive strain, not necessarily nor even likely to lead to open fissures, but more probably only amounting to potential fractures, disposed in conformity with the more or less linear distribution of zones of metamorphosed dolomite along the direction of bedding. The striking structural contrast between thoroughly oriented chrysotile fibres and the apparently massive serpentine in contact with it is much lessened when the latter is examined in thin sections, which also reveal a fibrous structure, but without orientation, and more recently it has been shown that there is no marked difference in specific gravities between chrysotile and massive serpentine, if special precautions are taken.* It appears, therefore, that massive serpentine is a kind of mass-fibre chrysotile, only differing from true chrysotile in structural degree. But the potential fractures, more or less oriented in the alignment of future cross-fibre seams for reasons already indicated, give rise to unequal pressure, which affects solubility, so that deposition takes place along the direction of least pressure. Along the potential fractures crystals lying more nearly in the line of least pressure, i.e. at right angles to the fracture, will become elongated, while those lying more or less across this direction will have their solubility increased so as to be redeposited along the ultimate fibre orientation. This process, continued long enough, would finally lead to seams of chrysotile of the interbedded cross-fibre type.

The preceding reflections lead to the following summary statement of a working hypothesis :—The Carolina chrysotile originated ultimately from the intrusion of a basic sill into dolomite rocks, which were subjected to contact metamorphism, resulting in the formation of magnesian silicates. The latter were subsequently converted into serpentine by hydration from probably meteoric waters ; the expansive strain consequent upon increase in volume due to hydration caused potential fractures—not open fissures. The interbedded disposition of the seams rests on the sedimentary nature of

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* R. P. D. Graham, *loc. cit.*, pp. 186–189.

the dolomite, while crystallization *in situ* under unequal pressure tends to develop oriented fibres in the direction of least pressure from massive serpentine possessing a fibrous habit, but with fibres not yet aligned. The expansion strain determines the minimum pressure to be directed at right angles to the alignment of potential fractures, themselves trending with the direction of beddings.

The above view of the derivation of the Carolina chrysotile from the metamorphism of dolomite suggests the possibility of further veins being found at the lower contact of the sill, where no thorough prospecting appears to have been carried out up to the present.

Most probably a parallel case to the above asbestos occurrence is afforded by the recent chrysotile discovery near Chuniespoort, where interbedded cross-fibre veins also occur in dolomite and are underlain by an intrusive sill. The country rock of the fibre deposits is a light coloured finely granular dolomitic marble, in which lies a band of dark dirty greenish serpentine carrying chrysotile veins and in contact above with more obviously metamorphosed dolomite.

The genetic problem of the Carolina and Chuniespoort chrysotile is probably analogous to that presented by the serpentine of Mountville, described by Merrill.[*] Here a massive dolomite with siliceous layers contains veins and nodules of partly fibrous serpentine, derived from a diopside with considerable increase in volume.

A striking similarity in geological conditions is apparent between the Carolina type of fibre occurrence and that described by Noble and Diller from the Grand Cañon, Arizona.[†] In the Algonkian succession of Asbestos Cañon is a sill of diabase with crystalline limestones above and below; these carry bands and nodules of serpentine with chrysotile veins, specially over a horizon from 3 to 15 feet under the sill, but only where the strata have been invaded by the intrusion; these minerals are not found where the sill lies between shales, neither do they occur in the igneous rock itself. It is pointed out that the serpentine is of contact metamorphic origin, connected with the invasion of the limestone by the diabase. Diller regards the serpentine surrounding the veins as derived from some mineral in the limestone and not from the diabase. The fact that these Algonkian rocks are magnesian and in places siliceous, in form of chert bands and nodules, and that the general trend agrees with the direction of bedding, are further analogies with the Carolina fibre belt. Diller concludes against deposition in open spaces in favour of replacement of serpentine in planes of weakness and lays stress on the development of asbestos from igneous intrusion.

In three separate localities it can thus be shown that chrysotile may occur in altered sediments of dolomitic character within the metamorphic influence of basic intrusions, so that the development

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[*] G. P. Merrill—"On the Serpentine of Mountville, New Jersey." Proc. U.S. Nat. Mus., Vol. II, 1888, pp. 105–111.

[†] L. F. Noble—"Contribution to the Geology of the Great Cañon." "The Geology of the Shimuno Area." Amer. Jl. Sc., 1910, pp. 577-522. J. S. Diller—"The Types, Mode of Occurrence, and Important Deposits of Asbestos in the United States." Bull. 470, U.S.G.S., 1910, pp. 576–519.

of the same fibre variety, in each case under identical geological conditions, is scarcely accidental, but justifies the conclusion of community in origin.

Persistence in depth has an obvious bearing on the economic outlook of asbestos deposits, and in this respect the genesis and geology of each occurrence are of special importance. In case of the Canadian type, Cirkel refers to the recent location of chrysotile at a depth of 400 feet in the shaft of the Black Lake Chrome and Asbestos Co., and concludes that the fibre deposits are not shallow and that workable seams may probably extend down to several thousand feet.[*] In the opinion of Dresser,[†] the depth of chrysotile deposits is conditioned by the form assumed by the parent rock of the serpentine, being limited to the thickness of a sheet or laccolith invading older rocks, but possibly continuing to an indefinite depth in case of an intrusive mass. Serpentinization is, by the same author, regarded as a deep-seated process, not depending on the action of the atmosphere. In describing Tasmanian occurrences, Twelvetrees[‡] also inclines to the opinion that chrysotile persists in depth.

The preceding views are concerned only with the Canadian type of habit, and by no means necessarily apply to those cases where a derivation from sedimentary rocks is involved. The mode of origin suggested for the latter depends upon the metamorphism of dolomite from a basic sill, so that at first sight it would appear that the fibre deposits ought to continue underground, so far as the intrusion persists and remains in contact with the same kind of siliceous carbonate rocks. On the other hand, the direct action of the igneous rock appears more likely to have been restricted to the formation of the contact metamorphic magnesian silicates, from the subsequent hydration of which serpentine was formed; there is nothing in the Carolina fibre area to show that this serpentinization was a deep-seated process and the necessary water was more probably of meteoric than of magmatic origin. An examination of the developments on Goedverwacht seems to show some indication that fibre of better length and quantity lay nearer the present surface; at the end of the earlier period of activity on Diepgezet, where the deposits were opened up for a greater distance along the dip than elsewhere, the impression was also left of a limited persistence in depth.

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[*] F. Cirkel, *loc. cit.*, p. 100–102.

[†] J. A. Dresser—"Mineral Deposits of the Serpentine Belt of Southern Quebec." Tran. Can. Inst., Vol. XII, 1909, p. 203.

[‡] W. H. Twelvetrees—"Asbestos at Anderson's Creek," Geol. Sur., Tasmanie Min. Res. No. 4, Hobart, 1917, p. 25.

2. CROCIDOLITE AND AMOSITE.

Essential Identity of Origin.—Both these varieties of asbestos are monoclinic amphiboles, which may be regarded essentially as ferrous silicates with a high percentage of ferrous iron and a fairly large amount of soda in case of crocidolite. The limited analytical data available for amosite show that soda may or may not occur here also. Furthermore, both varieties have been found only in banded ironstone, that term including, for the purposes of the genetic problem, not only the black magnetic variety, but also the brownish jaspery rocks and allied ferruginous siliceous sediments generally. Lastly, both types of fibre lie in the same geological series and exhibit identical mode of occurrence as interbedded cross-fibre veins, with the same minor variations in structural detail recurring in many localities over a wide stretch of fibre area. It is therefore concluded that the general mode of origin is identical for both, and in the nature of the case of special significance for the Union of South Africa, which holds the record in size of asbestos area and crocidolite output.

Restriction to the Same Type of Country Rock.—Previous chapters have shown that one or the other variety of hornblende asbestos occurs all along the basal portion of the Pretoria Series from the Steelpoort River to Chuniespoort, but only in banded ironstone, whether in the Pretoria Series proper or in thin bands of the same rock interbedded in the underlying Dolomite Series. Throughout the Cape fibre belt crocidolite is found in the banded ironstones of the Lower Griqua Town Series over a very large tract of country, and the recent discovery of another amphibole asbestos comparable to amosite near the base of the Pretoria Series in the Zeerust District further emphasizes the marked restriction of such asbestos to a certain class of country rock only.

General Similarity in Composition of Amphibole Asbestos and Country Rock.—Apart from the special questions raised by the soda and magnesia contents (referred to below), the chemical composition of crocidolite and amosite with the large predominance of iron is somewhat of the kind which a bulk analysis of the country rock would most probably present. If, therefore, amphibole asbestos may originate from ferruginous sediments, like the Carolina chrysotile is derived from dolomitic sediments, i.e. not by the introduction of material wholly chemically foreign to its country rocks, but by a kind of reconstitution of essential constituents already supplied by the surrounding strata, its peculiar distribution, sharply restricted to ferruginous siliceous ironstones, is a natural result of its mode of origin.

Lateral Variations in the same Horizon and Changes subsequent to Deposition.—Owing to the special attention devoted to the problem of asbestos genesis as applied to the Canadian type of chrysotile with its familiar derivation from igneous rocks, the possible origin from sediments of the little studied amphibole asbestos may be difficult to realize; the strata including the latter deposits of the Union, are certainly of great age, and may therefore have undergone more profound changes since their deposition. This is very likely correct to some extent, notably, perhaps, in the amount of subsequent silicification, but it is worth while to examine to what extent lateral variations of the same horizons in the Pretoria Series indicate changes of facies leading to material chemically adapted to the formation of crocidolite and amosite and what is the interrelation between the series as developed in the Transvaal and Cape Colony.

For the purposes of this discussion the different rocks making up the Pretoria and Griqua Town Series may be grouped into shales, quartzite, and banded ironstones.

Underlying the Timeball Hill Quartzite in the Eastern and North-Eastern Transvaal is a great succession of unaltered soft shales and slates, which exhibit a steady change in lithological characters to banded ironstones; the latter predominate almost exclusively along the Haenertsburg–Malips Drift section of the Pietersburg District, while a few miles south of the Steelpoort River a monotonous series of thoroughly argillaceous rocks is found. Where exactly the change occurs it is impossible to say, since it is completed gradually, though fairly rapidly, and appears to set in along one horizon sooner than another, but is first noticeable a little south of the Steelpoort River, where the shales become sandy, and, after crossing that stream, acquire, through a large proportion of ferruginous slates, some of the character of banded ironstones. Sometimes these variations lead to massive ferruginous slates, sometimes they develop a banded habit through alternating layers of variable iron and silica content. From the Steelpoort River northwards an increasing width is thus affected, until over the Malips River neighbourhood almost the whole succession up to the base of the Timeball Hill Quartzite has changed into thinly bedded dark coloured banded ironstone. Amphibole asbestos has not so far been found where the rocks are still in their normal argillaceous condition. Lateral variations of the same kind can be followed in the ferruginous Timeball Hill group of quartzites, which along the type section west of the Capital present some features of sedimentary contemporaneous iron ores, but gradually lose this character when traced from the Delagoa Bay railway northwards, until along the Olifants River the ferruginous habit is completely lost, only a single quartzite without iron remaining. Another very striking variation is shown by the so-called Ironstone Band underlying the Daspoort Quartzite; this band is only a few yards thick at the Capital, but undergoes an enormous increase in thickness towards Rustenburg and Zeerust, where it gives rise to groups of hills; it overlies the amygdaloidal andesite corresponding to the Ongeluk Volcanic Series of Griqualand West, and most likely represents the Upper Griqua Town Series of that area. Again, from Pretoria a band of ferruginous sandy shales is slowly developed in a westerly direction along the base of the Pretoria Series.

Type Facies in the Upper Division of the Transvaal System and their Interrelation.—The uppermost division of the Transvaal System therefore presents the following type facies:—The *Pretoria Facies* with predominant shales and quartzite to the virtual exclusion of shales and quartzite, only found as very minor occurrences. This passes eastwards into an intermediate stage—the *Haenertsburg Facies,* with a strong development of banded ironstones over the lower half of the series only, while it passes westwards into another intermediate stage—the *Zeerust Facies,* where banded ironstones are strongly marked immediately over the amygdaloidal andesite in a position closely analogous to that of the Upper Griqua Town Series of the Cape Province, but also appear again almost at the base of the series. A considerable stretch of country separates the Transvaal border from the Molopo River in the Bechuanaland Protectorate—as far as known the most northerly limit of the Griqua Town facies; very little is known about the geology of this stretch, partly owing to extensive surface deposits, but the gradual transition of the Pretoria into the intermediate Zeerust facies with its locally more distinct Griqua Town features, combined with the established passage of shales into banded ironstones from the Pretoria into the Haenertsburg facies, justify the belief that the great predominance of ferruginous siliceous sediments over Griqualand West is an extreme accentuation of a progressive lateral variation in conditions of sedimentation. The great increase in thickness of the ironstone band from Pretoria westwards and its position above the amygdaloidal andesite, which always maintains a very definite horizon over a wide stretch of the series in the Transvaal Province, allow a correlation with the Upper Griqua Town Series to be suggested with some confidence. The apparent elimination in the Cape of the entire succession overlying this ironstone band implies lateral changes not really any greater than those already referred to, and is not more remarkable than the striking contrast between the Magaliesberg horizon in the Dullstroom neighbourhood, where the four or five separate quartzites with associated shales give rise to the various ranges of the Steenkampsbergen, some twenty miles across, and round Koedoekop, south of Haenertsburg, where the same group has dwindled down to a surface width of only three-quarters of a mile.

The preceding remarks lead to the conclusion that, in furnishing material suitable for the formation of amphibole asbestos, lateral variations from shales into banded ironstones consequent upon altered conditions of sedimentation may represent a genetic factor at least as, if not more, important than changes occurring subsequent to deposition.

The Preliminary Conclusion.—Hence a preliminary conclusion is that, before crocidolite and amosite can be found, the future country rock of the veins must have provided layers of essentially the same composition as regards iron and silica. But this statement is incomplete, otherwise amphibole ought to occur in other ironstone, e.g. the Ironstone Band below the Daspoort Quartzite, etc.

The Question of Soda.—It is considered that the further restriction of the genetic problem arises from the special requirements of soda and magnesia. All crocidolite analyses show a percentage of soda to the maximum of 7·71 per cent., and an analysis of the freshest amosite contains the same constituent to the extent of 2·12 per cent. It is very difficult to arrive at any satisfactory conclusion as to the source of the soda, and the introduction from outside sources of alkaline material upon the scale demanded by the large number of widely distributed asbestos veins is impossible to realize, specially as there is no indication of rocks likely to furnish such a supply. It is more probable that the soda is original and dependent upon special—perhaps brakish water—conditions of deposition.

The Problem of Magnesia and Association of Dolomite.—The second requirement is magnesia, which enters into eight out of the nine available analyses of crocidolite and into all these of amosite to the maximum of 6·14 per cent. The close proximity of the seams to the underlying Dolomite is a constant experience in the Lydenburg and Pietersburg asbestos deposits; and is again exemplified by the Zeerust occurrence; this association is scarcely accidental and becomes specially marked, where in a greater succession of banded ironstones the seams tend to keep to the base of the series (Malips River); it indicates the underlying dolomite as the probable source of the magnesia. In case of the Lower Griqua Town Series, a possible closer genetic connection with the limestones of the Campbell Rand Series is less apparent, since the crocidolite veins seem to be spread out over a greater vertical range. Attention has been called in Chapter II to the rather more marked prominence of crocidolite deposits on the eastern edge of the Asbestos Mountains and Kuruman Hills nearer the top of the Campbell Rand carbonate rocks, and to the possibility of a further set of workings along the Khatu Khosis group of hills being merely a repetition of the same set of fibre horizons due to the synclinal structure. A personal visit to these parts of the Cape fibre belt has left the impression of the crocidolite veins being more numerous and prominent nearer the base (Wonderwerk, Warrendale) than further to the west (Crawley). These considerations, coupled with the more clearly marked restriction of amphibole asbestos to the top of the Dolomite Series in the Transvaal incline the writer to the view that the association is more genetic than accidental. It appears not to be without significance in this connection that no records of crocidolite from the Upper Griqua Town Series exist. The influence of the underlying dolomite on the lowest beds of the Lower Griqua Town strata, owing to the partial removal of carbonate material by solution, has been referred to above, and the wider circulation of magnesian waters through a greater thickness of banded ironstones would amount to a difference in degree only. Professor Van der Riet's analyses of the Campbell Rand limestones furnish evidence of their magnesian character.*

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* Annual Report. Geol. Commission of Cape Colony for 1908, p. 85.

The Question of Contact Metamorphism.—Given the requisite material with the additional requirements of magnesia and soda, the genetic problem is further complicated by the question of metamorphism peculiarly prominent in the North-Eastern Transvaal, where the intrusion of the great Bushveld Plutonic Complex on a reginal scale has permitted the asbestos horizon to come within the outer contact zone. Before a genetic connection can be established, it has to be shown that the intrusion is of a large enough order, that the asbestos horizon falls within the aureole and that the mineralogical changes are within the metamorphic capacity of the agent.

In several previous publications the first point has been sufficiently demonstrated, and it has also been shown, independently of any inferences based on asbestos distribution, that over the Lydenburg fibre area the Pretoria Series has been profoundly altered from the edge of the Bushveld Complex down to the Timeball Hill Quartzite, while further north the aureole extends down to the base of the series or even a short distance into the Dolomite. In the Lydenburg asbestos area the beds resting on this quartzite are thoroughly altered chiastolite or staurolite slates, and it cannot be supposed that the effect of the Bushveld intrusion was completely arrested at the quartzite ; that it extends some way below the latter is indicated by further altered slates, where the banded ironstones do not yet exclusively prevail. In Chapter IV it was shown that the same amphibole which forms interbedded amosite seams in the principal asbestos horizon in strongly banded rocks has also been found in neighbouring strata as irregularly scattered crystalline tufts. But this special habit yields a rock of strongly contact metamorphic appearance, and is characteristic of more thickly bedded phases with more uniformly ferruginous character, where the requisite composition for an iron amphibole is maintained, not along certain layers only, but rather from point to point. In general habit there is a strong resemblance to chiastolite slate, apart from differences in the body of the rock. The writer is not prepared to admit that thermal metamorphism must involve transference of foreign material, except under very abnormal circumstances and quite locally (e.g. Potgietersrust xenoliths), but that, as a general rule, the kind of metamorphic mineral formed depends mainly on the nature of the original sediment. Where a siliceous ferruginous sediment falls into an outer belt or contact metamorphism, the formation of a ferrous silicate amphibole is just as typical as that of an aluminium silicate, like chiastolite, in argillaceous rocks. The conclusion that the particular massive phase with scattered iron amphibole is a true contact rock is supported by the further experience that its horizon—traced into the pure shale facies—freely develops typical chiastolite slate while under the influence of the same intrusion (Zeerust), and that in the highest beds of the Dolomite further north of the Penge area an actinolite appears in the carbonate rocks, so that an amphibole, low in iron and rich in lime, once more shows the contact mineral to go with the nature of its parent sediment.

These remarks show that the three requirements for a genetic connection between the Bushveld intrusion and the presence of iron amphibole are satisfied.

In spite of this result, the evidence up to the present available is not sufficient to show whether, given the right material, contact metamorphism alone is a necessary and sufficient condition for the formation of amphibole asbestos, since only a few localities are concerned on this agent, i.e. the Lydenburg and Pietersburg fibre area, and most probably also the recent asbestos occurrence in the Zeerust District, while in the Cape fibre belt there is no counterpart to the Bushveld intrusion.

In the Cape no evidence is available at the surface of an igneous intrusion on a scale and with effects comparable to the Bushveld Complex, yet the geological conditions of the country rock are so much like those of the Transvaal hornblende fibre belt that the conclusion of similar genetic conditions is impossible to resist. If there is a hidden igneous agent, it is very remarkable that signs of its effects should nowhere be traceable. Those characteristically contact metamorphic phases, alluded to above as occurring round Penge, have not so far been met with in the Cape fibre belt, and the only variety which might possibly be of analogous origin is the very exceptional occurrence over Enkelde Wilgeboom described in Chapter II. Contact metamorphism alone may thus have had, and probably did have, a contributory share, but it is not considered to be the major cause of asbestos formation, as far as crocidolite and amosite are concerned.

Necessary and Sufficient Genetic Conditions.—In the writer's view, the two necessary and sufficient genetic conditions for the formation of crocidolite and amosite under the modes of occurrence prevailing in the Union are (*a*) the presence of sediments of ferruginous and siliceous characters containing along certain layers soda as an original constituent, and (*b*) their association with rocks capable of supplying magnesia. Both these conditions are satisfied by the banded ironstones and their underlying dolomitic rocks, wherever crocidolite or amosite have so far been found.

In the Transvaal contact metamorphism has been a contributory cause, but its effects were, perhaps, restricted to certain rocks only, and played a minor part as regards cross-fibre veins, though it is not unlikely that its combination with the mode of origin prevailing in the Cape fibre area accounts for the very remarkable restriction of unique fibre length to the north-eastern Transvaal.

In the Cape asbestos belt this agency has most likely to be altogether eliminated and the two fundamental conditions have their full play, the same remark also applying to fibre occurrences in those narrow belts of banded ironstone that lie outside the Bushveld aureole some way down in the Dolomite Series.

Modus Operandi *leading to Interbedded Cross-fibre Veins.*—Turning from the geological aspects to the fibre veins themselves, there is little doubt that their interbedded character expresses the sedimentary origin of the country rock, in which a composition suitable for asbestos is distributed in layers rather than across the succession. Waters carrying magnesia, and probably also some lime in solution, and travelling along bedding planes would induce recrystallization in those layers which have the requisite composition, i.e. proper relative proportion of iron oxide and silica, and soda, etc., by a process of molecular rearrangement, not necessarily caused by contact metamorphism, though perhaps assisted by it ; this would depend not on open fissures, but on growth *in situ*. Where such waters did not meet with beds of suitable composition, magnesian material, not absorbed by asbestos formation, may now be represented by the irregular veins of magnesite sometimes met with, as alluded to in Chapter IV. The first stage in the formation of an interbedded cross-fibre vein will, therefore, be the development of crystals of iron amphibole along certain layers only, but without orientation ; in other words, mass-fibre crocidolite and amosite would precede the cross-fibre habit. In case of a mineral like amphibole with its great inherent tendency to develop a prismatic habit, specially perhaps when originating otherwise than from igneous fusion, the crystals are likely to assume a more or less elongated habit. Those needles which are oriented more nearly at right angles to the bedding planes will, in their continued growth, exert a certain amount of pressure against the containing walls ; that crystals can exert a very considerable pressure during growth is well established. Owing to the mutual interference of growing crystals, an unequal pressure is developed, greatest in a lateral direction ; this affects solubility and causes removal of amphibole from the sides and its redeposition in the direction of elongation more nearly along the cross-fibre orientation, where the pressure is least, owing to the tendency of the enclosing wall to be lifted by the most favourably disposed crystals. Other factors may aid oriented growth, such as unequal pressure arising from volume changes depending upon differences of specific gravity between fibre and country rock or supply of solution from one side only (or at unequal rates), since the majority of veins are limited on one side by a straight line, but the locus of the opposite fibre terminations is a wavy line.

Intermediate Stages of Development.—The preceding mode of origin ought sometimes to lead to intermediate stages. These occur, though very rarely, in the Cape fibre area, but, taking the Transvaal into account also, they are more frequent than an examination of the Cape asbestos belt alone would lead one to suppose. In the latter case they have been noticed on Claradale, Wonderwerk, Koegas, etc., and are referred to as potential crocidolite in Chapter II ; this is the mass-fibre stage of the future cross-fibre vein. In the Lydenburg area they are fairly common, being specially noticeable round Penge, etc. A comparison of a large number of instances shows connecting links from thin yellowish brown layers containing scattered elongated crystals of amosite without orientation through others showing, in addition, very irregular stringers or patches of more or less thoroughly oriented amosite up to fully developed cross-fibre seams. Between these intermediate stages and the heavy dark blue layers, referred to as potential crocidolite, there appears to be no essential difference in kind; the different appearances of the rocks are mainly due to the contrast between blue crocidolite and yellowish brown amosite and variations in fineness of crystal growth. The heavy dark blue potential crocidolite of the Cape has also been observed south of Haenertsburg.

The Genesis of Chrysotile compared with that of Hornblende Asbestos.—The mode of origin of the Carolina chrysotile is thus similar to that of crocidolite or amosite, in so far as all these varieties are intimately derived from sediments, dolomitic in the former, but ferruginous and siliceous in the latter. Whereas in case of chrysotile the origin is finally due to contact metamorphism, in case of hornblende asbestos that agent has only a contributory effect. As regards the formation of interbedded cross-fibre veins, the bedded disposition is in both types of fibre an expression of their derivation from sediments, but the important factor of changes in volume owing to hydration does not arise to the same extent in amosite or crocidolite, owing to the comparatively small amount of water of constitution.

Indications that the fibrous mineral was deposited in open fissure exist neither in the serpentine nor the hornblende asbestos occurrences.

The Experimental Analogy.—In spite of the objections, referred to above, which might be raised against applying the lessons of laboratory investigations, the remarkably close imitation of asbestos vein structure in Professor Taber's experiments cannot be ignored. The divisional planes of thinly bedded ironstone could, perhaps, be regarded as taking on the function of the capillary pores in the porous cell, and solutions circulating along bedding planes could represent the copper solution, from which the cross-fibre veins were found, though in nature the bulk of the required material already exists in the country rock. Finally the " cone " and " corrugated " structure, described in Chapter II, would correspond to the effects of pressure exerted after prolonged growth and to the rupturing of the cell walls during the artificial reproduction of cross-fibre veins.

Summary.

The foregoing discussions are not claimed as a solution of the problem presented by asbestos genesis, since our information is still incomplete in more than one respect, notably so in further analytical data regarding amosite and the composition of the country rocks, but they lead to the following summary statements, which may be regarded as signposts pointing out the probable roads to complete truth :—

(1) Crocidolite and amosite originate from sediments having pronounced ferruginous and siliceous characters under certain attendant conditions.

(2) The first of these conditions is the presence of soda ; the second is the supply of magnesia.

(3) The conditions are satisfied by the banded siliceous ironstones in the lower part of the Pretoria Series of the Transvaal or in the Lower Griqua Town Series of the Cape Province, both in association with underlying dolomite, the soda being more likely an original constituent depending upon special conditions of sedimentation.

(4) The interbedded habit is an expression of the stratified variations in composition of the sediments.

(5) The formation of amphibole asbestos is due to recrystallization as growth *in situ* of material of suitable composition and in the presence of magnesian waters—not by lateral secretion in open fissures.

(6) Contact metamorphism plays no part in the Cape fibre belt ; the Lydenburg and Pietersburg fibre area falls within the outer aureole of the Bushveld Plutonic Complex, and the effects of the latter are reflected in certain phases of ferruginous sediments near the main-fibre horizon, but the unique fibre length restricted to the aureole of the North-Eastern Transvaal may indicate the co-operation of contact metamorphism in enforcing the mode of formation summarized in (5).

(7) Unequal pressure arising from mutual interference of growing crystals, possibly also volume changes, unequal supply of solution, and the common tendency of amphibole to develop prismatic habit, i.e. special or limited physical conditions of growth—determine the cross-fibre habit.

(8) The progressive development may proceed from the sediments through " potential " asbestos, allied to mass fibre, to the cross-fibre habit.

Persistence in Depth.—The question how far the deposits of crocidolite and amosite may be expected to persist underground has not yet assumed, nor is it likely to assume in the near future, any economic bearing. In the Cape belt large resources of fibre are available, so to speak, next door to the surface, and while the actual number of seams may, perhaps, be fewer in the Transvaal hornblende asbestos districts, this is easily made up for by the unique fibre length. Up to a depth of not less than 300 feet on the dip there is no indication of any deterioration in fibre length or seam number, neither has the presence of ground water level been attended by adverse results of this kind.

The mode of origin here suggested and the experience so far available are distinctly in favour of persistence in depth.

CHAPTER VII.

INDUSTRIAL ASPECTS AND USES.

THE commercial value of asbestos depends upon the combination of certain properties—satisfactory as regards number, kind, and degree—mainly physical, which are probably in part at least an expression of a chemical composition varying between fairly narrow limits for each variety.

The principal properties valued in the industry are :—

Tensile strength
Flexibility.
Fineness of fibre.
Incombustibility.
Length of fibre.
Acid and alkali resisting capacities.
Sea-water resisting capacity.
Elasticity.
Non-conductivity of heat or heat-insulation capacity.
Electric insulating power.
Colour.

The above order is approximately that of relative importance, though, in consequence of the many and increasing varieties of uses to which the fibre is now put, this order varies for different classes of manufactured articles ; no doubt flexibility and tensile strength are of prime necessity for many articles, while length of fibre is of exceptional importance where yarn has first to be spun. In still other cases special stress is laid on acid and sea-water resisting properties or on heat-insulating capacity, e.g. in the manufacture of flexible boiler covering and other uses in mercantile or naval marines. whereas colour is of less importance, provided other desiderata are satisfied.

For these reasons not every fibre requires all the above properties to be present in the same degree for commercial purposes. Moreover, the different varieties show a good deal of variation in some of their characters, and this holds good even for an asbestos from one fibre area, e.g. some amosite from the Lydenburg District is a good deal more elastic in some veins than in others, and in the Cape asbestos belt there is a noticeable difference in the fleeciness or perfection of fibrous structure between the Southern and Northern Sections ; where colour is an essential factor, the deposits within the Union offer a fairly wide choice, while the recent developments of amosite show what a great range in fibre length is available in hornblende asbestos.

Other things being equal, that variety will be the most valuable one which combines the greatest number of the most highly prized properties, each in the required degree.

Given a fibre of suitable quality, many other industrial factors have to be considered in its profitable disposal in the world's markets; these include questions of labour supply, transport to railhead, shipping costs, etc., and last but not least, the more or less keen competition with other sources of supply. The discussion of these lies outside the scope of the present pages.

During the last ten years or more the number of exploited asbestos occurrences has considerably increased, and several of these have an appreciable share in the world's output, though Canada, as the most important producer, still easily maintains its lead with something like 80 per cent., after which come Russia and the United States, but more recently Rhodesia has been developing an increasing output. Of the world's production during 1910 and 1911, the Cape accounted for only 1·2 per cent., but since that date the combined output for the Union has markedly increased, owing to the contributions from new fibre areas in the Transvaal (see Chapter VIII).

An accurate estimate of the present outlook of this industry within the Union is specially difficult, if not impossible, on account of the peculiar shipping and other problems arising out of the world situation to-day; these are likely to continue for some time after the present upheaval.

For many years *chrysotile* has held a leading position in the market, due to a combination of several fortunate factors. The persistence of extensive deposits has been proved in the Province of Quebec, and their exploitation has now been well established for a longer period; the improved methods of preparation for the market depend upon machinery for cobbing, sieving, drying, grading, etc., while its exceptionally high flexibility and infusibility have secured for it a firm hold in the industrial applications, in which American manufactures have been specially to the front. Thus, Canada has come to be looked upon as the most reliable source of chrysotile, which can be trusted to furnish large and continuous supplies of well-graded fibre, to which manufacturers can adapt their machinery in accordance with the particular qualities of this asbestos.

As regards acid and sea-water resisting capacity, tensile strength, elasticity, and fibre length, however, chrysotile is inferior to crocidolite or amosite.

Up to the present the Union's share in the world's chrysotile output has been negligible.

Crocidolite.—The preceding remarks indicate that, before another variety of asbestos can be disposed of in the markets, manufacturers must be satisfied that this offers some special properties wanting in the fibre they have been accustomed to rely on, that continuous and large supplies can be drawn upon, and, lastly, that the deliveries are being kept up to the standard of the sample. Crocidolite possesses several such properties, which render it superior to chrysotile for certain applications, i.e. greater tensile strength and elasticity, superior heat and electrical insulating capacity, greater acid and sea-water resisting properties, and marked superiority in fibre length.

It is often stated that chrysotile is the most valuable variety of asbestos, but it has to be remembered that, owing to the large and well-regulated output from the Canadian mines, as compared with the irregular and small output of crocidolite, the latter has never been an important factor in the asbestos markets, notwithstanding its superiority in the physical properties just referred to. Yet the price of 1 to 2 inch crocidolite stood at £70 per ton in the European market in 1913–14, a figure seldom reached by chrysotile. Had there been a production comparable in bulk and regularity to that of the Canadian fibre, amphibole asbestos would probably have been a much greater factor in the world's market. This remark also applies to amosite, the new iron amphibole of the Transvaal.

In the exploitation of crocidolite the Union of South Africa has a practical monopoly, since Western Australia so far only contributes a small quantity. The Cape Asbestos Co., established since 1893, has had a long uphill fight to obtain for crocidolite the recognition it deserves, and the keen competition in the world's market led to the establishment of their own factories in England, Hamburg, and Turin, with a sister company in France. They are the largest manufacturing concerns for articles derived from crocidolite, and the great bulk of the Cape blue output is absorbed by them, largely from their own mines, but also by purchase from other workings. Thus only a proportion of the combined yield from the Cape fibre area has been able to compete in the open market.

While in the Southern Section of the Cape fibre belt the predominance of the mines directly under the Cape Asbestos Co., with their long experience in the exact requirements of their factories. has led to well-established principles of development, e.g. methods and criteria of grading, the Northern Section round Daniels Kuil and Kuruman, where smaller companies and syndicates have more recently been opening up further deposits, is not always as advanced in the preparation of the fibre for the market. This result is due in part to the fact that the seams are, as a rule, not sufficiently persistent to admit of more systematic underground mining, so that the peculiarities of the contract system of labour have greater play, but it is also the case that the methods of grading are sometimes less thorough or less carefully applied; the danger thus arises that an order may not come up to the standard of the sample. This is to the detriment, not only of the producer concerned, but to the fibre area as a whole, a result specially deplorable in case of an industry in its youth, which has only recently begun to get a footing in the market.

An important aspect of the Cape asbestos industry is the greater fibre length. Although the Canadian output is so large, in 1915[*]

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[*] During 1916, the total Canadian chrysotile output amounted to 118.246 short tons, of which 5,414 (equivalent to 4·5 per cent., are represented by "crude" fibre.

only some 4 per cent. of it is represented by fibre over ¾ inch long and only 1·4 per cent. by fibre over 1 inch in length; the great bulk of the output—roughly, 95 per cent.—is made up of shorter chrysotile, worth up to £11 per ton. Therefore, for the manufacture of yarn, only a fraction of the world's chrysotile output is available, in spite of the probability of improved methods tending to lower the limit of spinnable length and of additional supplies more recently coming in from Rhodesia. Taking ⅜ inch as the extreme limit of spinnable length, at least 80 per cent. of the Union's crocidolite output would be serviceable for yarn. In this respect the Cape industry has a distinct advantage over Canada, a remark equally applicable to the crocidolite deposits of the Malips River area in the Pietersburg District of the Transvaal. It even seems doubtful whether sufficient spinnable chrysotile would be available to cover the many directions in which the uses of fibre goods depending on yarn might be extended (see below). It may be pointed out in this connection that, according to Cirkel,* investigations in the United States regarding the safety drop curtains, supposed to have been made of asbestos, have shown that in many cases very little asbestos was used, the material employed being heavy jute, linen, cotton sheeting, or canvas.

Thus it may be summarily emphasized that, in spite of the commanding position of chrysotile in the world's markets, crocidolite may be expected to secure an increasing share in the manufacture of asbestos goods by virtue of its having several properties in a superior degree, while the discussion in Chapter II has shown very large quantities to be available. Closer co-operation among the younger producing concerns in parts of the Cape fibre belt, with special reference to greater care in grading operations, would probably remove some of the difficulties of persuading manufacturers to give these new fields a more extended trial.

Amosite, the new iron amphibole asbestos of the eastern and north-eastern Transvaal, was born into the world of the fibre industry only some four years ago, and as the latest and the least-known arrival has had difficulties to contend with probably as great as those which at first surrounded the manufacture of blue asbestos goods. Though known at least as far back as 1907, it remained more or less a mineralogical curiosity for some time, since its chemical composition differs markedly from chrysotile, whereas its ash-grey or pale brownish appearance recalls neither serpentine asbestos nor crocidolite. However, during the last two years or so large contracts have been placed in America and Japan, and promising inquiries have been received from France and England. In the United States amosite has been used in the manufacture of motor-car brakes. A beginning has also been made in the local manufacture of amosite building material.

The most striking property is fibre length, in which respect amosite is without a rival, values very close to the average of 6 inches being maintained over considerable distances, as more fully explained

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* Chrysotile Abestos, 2nd ed., Ottawa, 1910, p. 252.

in Chapter III, where large quantities of such long material were shown to be available. When it is remembered that the price of chrysotile and crocidolite rises very considerably with fibre length, this superiority of amosite is a powerful factor in its favour, provided other essential properties are satisfied in the required degree. The experiments of Dr. Versfeld, referred to in Chapter I, have shown that, as regards incombustibility, amosite is superior to crocidolite, and in tensile strength, flexibility, sea-water and acid resisting properties it is at least equal to the latter variety. Some of the most recent developments have yielded a golden yellow and an almost pure white fibre, both of very soft unctuous feel and very finely fibrous; the writer's examination of these did not reveal any appreciable inferiority to chrysotile as far as flexibility is concerned. Though more information is wanted as to the behaviour of amosite when tested under the conditions prevailing in the manufacture, the experience so far available justifies the hope of a great future for the new asbestos variety.*

The superior fibre length maintained for the entire output, combined with the much more regular mode of occurrence along a fairly definite horizon traceable over great distances, as previously described, enable these amosite veins to be developed by more systematic methods of underground mining, a distinct advantage in regulating a steady supply. At the same time the well-known fact that in the case of the more familiar asbestos varieties, fibre exceeding 2 inches in length makes up only a very small proportion of the output may have added to the difficulties in convincing manufacturers of the capacity of the new fibre area to furnish supplies sufficiently large and regular to justify the erection of spinning machinery adapted to such an exceptional length.

Compared with the very extensive Cape blue asbestos belt, the Lydenburg and Pietersburg amosite fields occupy a distinctly smaller area, but this is compensated for by the newer discoveries occurring in much more massive seams and as more markedly concentrated deposits in less scattered localities, while the distances to railheads compare very favourably with those to be contended with over the greater portion of the Cape fibre belt.

In the very great variety of *uses* to which chrysotile is being put in the manufacture of asbestos goods, the Union of South Africa with its trifling output of serpentine asbestos is not directly concerned to any large extent, except in so far as such adaptations affect the competition with similar articles based on the use of crocidolite and amosite. A study of the astounding variety and

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* According to information supplied by the Imperial Institute a larger sample of amosite, submitted to technical tests, showed that the asbestos could be spun into yarn and woven into cloth, which could be used for any purposes, such as the working of asbestos matresses.

high perfection of articles now turned out by manufacturers of asbestos goods is most instructive to any one interested in fostering a local fibre industry, but a discussion of such aspects would lead too far here. It may be pointed out, however, that the great bulk of the industrial applications is in connection with building material, and in 1910 it was estimated that in the near future fully 75 per cent. of all asbestos produced in the world will go into asbestos slates and shingles, of which one Austrian factory alone produced 70,000,000 square feet in a single year. The expansion of this manufacture has led to an increasing number of factories all over the world, requiring very great quantities of cement, so that some manufacturers have established their own cement works.

The manufacture of blue asbestos goods from crocidolite of the Union is still carried on almost exclusively overseas, and in this industry the Cape Asbestos Co. has given a strong lead by demonstrating the long and varied list of articles that can be successfully manufactured from this fibre and brought to a high state of perfection. These include asbestos cloth, rope, felt, yarn, tape, and belting, etc., depending upon spun material, as well as various kinds of packing, millboard, slates, tiles, preparation for electrical insulation, etc., some of which are prepared in combination with other material, such as cement.* The superiority of crocidolite in its sea-water or acid-resisting properties and heat-insulating capacity has a great practical application in navies and mercantile marines as flexible boiler and steam-pipe coverings, so much so that its exclusive use has been enforced in the German Navy, thus replacing chrysotile articles; such adaptations are in use on the locomotives of the South African Railways. An enormous economy is effected by preventing the radiation of heat and the condensation of steam resulting therefrom; since under normal circumstances only about one-tenth of the heat energy in the steam is available for producing power, a considerable saving in fuel, increase of power and efficiency, and more comfortable working conditions are secured.†

A beginning has also been made with the *manufacture of asbestos goods within the Union.*

The *Iron, Concrete, and Asbestos Manufacturing Co.*, close to *Durban*, turn out slates and tiles by means of a complete up-to-date plant; in these Portland cement and a lower grade blue asbestos from Kuruman are the main ingredients, with or without iron oxide as colouring matter. The articles find a use as roofing slates, for ceilings, and in the construction of portable buildings, etc.

More recently the *Asbestos Manufacturing Syndicate, Ltd.*, have established a factory at *Salt River*, near Capetown, where machinery, originally imported for the manufacture of tiles from sawdust and

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* For further details see P. A. Wagner, 46, p. 265.

† Cirkel *loc. cit.*, p. 255.

cement, has been adapted for making roofing tiles. These are made from ground amosite from the Lydenburg or Pietersburg Districts and Pretoria cement, together with red colouring matter, etc. The same concern is also manufacturing a flooring composition, in which the same ground asbestos is used, in combination with magnesite, kieselguhr, etc.

Messrs. *J. Wilson & Son*, Doornfontein, are turning out roofing tiles manufactured from cement and crocidolite from the northern section of the Cape Asbestos Belt or amosite from the Lydenburg District.

The *Premier Asbestic Company*, Johannesburg, use a coarsely fibrous tremolite from the farm Corea, in the Zoutpansberg District, for the preparation of boiler lagging.

The *Buffalo Asbestos Company*, Dundee, use tremolite from the Klipriver Location in Zululand, in the manufacture of asbestos stove bricks, buffalo jointing for acid or steam jointing, boiler lagging, and steam packing.

The attempts to establish a local industry for the manufacture of asbestos articles are sometimes looked upon with the kind of prejudice which one meets in other endeavours to start new industrial developments, for reasons which need not be discussed here. No doubt the initial cost of installing the necessary machinery is a serious matter when the demand for a new class of goods cannot yet be accurately estimated. A large proportion of this demand is likely to come from the building trade, and the fact that certain imported asbestos tiles, by cracking or otherwise, have not come up to expectations has, perhaps, increased an existing prejudice, although in other countries the manufacture of slates, tiles, etc., has been well established for a number of years and shows a great increase, as pointed out above. A very important branch of the oversea industry is that of corrugated roofing, for which a large market ought to arise, specially in South Africa, for the locally made article; the very great advantages of heat insulation offered by corrugated asbestos roofing must not be lost sight of.

Though under the most favourable circumstances the South African market is likely to be moderate, the great proportion of spinnable fibre in the Union suggests the possibility of largely increasing the local market by extended uses rather than by the replacement of chrysotile in established applications. This remark applies to crocidolite, but even more strongly to amosite, and increases the prospects of an export trade. As regards length of fibre, the Union deposits are in a strong position, for the available quantity of exceptionally long spinnable fibre has recently become very much greater, and the important advantages of this factor, combined with quantity, may open fields of utility which could not be contemplated when, as pointed out above, the world's annual output of fibre over

$\frac{3}{4}$ inch in length only amounted to a few thousand tons, most of which was absorbed in the manufacture of yarn and packing. Discussing the great possibilities of asbestos cloth, Cirkel states that the demand for this class of goods for certain purposes has never yet been supplied, due largely to the initial cost of the requisite machinery, but also to the anticipated difficulty of obtaining a regular and uniform supply of crude chrysotile (i.e. fibre over $\frac{5}{16}$ or $\frac{3}{4}$ inch in length) enabling the production of this cloth to be maintained without interruption.* Though these remarks were made about 1910, there is nothing to show that the proportion of crude fibre chrysotile has been materially increased to-day, so as to approach the exceptionally strong position now reached by the Union with its large proportion of spinnable crocidolite and amosite.

There would appear to be a considerable opening for these, and specially for amosite with its long flexible and strong fibre in the manufacture of tents, motor-car hoods, sun-blinds, wagon sails, tarpaulins, sun helmets, saddle girths, lawn tennis nets, and many other purposes to which cotton, linen, and hemp are put, these materials being subject to rapid decay in the condition to which they are exposed ; most of these applications should find a good market in South Africa with its open-air conditions of life. Not only would such articles be practically everlasting as regards decay, but their relative incombustibility and low heat conductivity would mean further advantages ; the same remarks apply to asbestos cordage, asbestos cotton waste, etc.

The circumstances under which the property of incombustibility is subjected to the severest tests in asbestos goods are exceptional, and although chrysotile holds the first position in this respect, amosite, as pointed out in Chapter I, possesses the same property in a high degree and is less fusible than crocidolite. The field of utility depending on the preceding factor has been much restricted by the small output of spinnable chrysotile available. Here one may mention aprons for cooks, stokers, and other factory workers, chemists, etc., and fire-proof screens, drop curtains, and so forth.

The analyses so far made of amosite show some approximation to crocidolite, so that tests are desirable to ascertain whether the former may not be equally serviceable for flexible boiler covering or for applications designed to keep perishable solids and liquids at the proper temperature during transport and storage. In this connection asbestos stockings and blankets may be mentioned. In bullet-proof mattresses the long elastic fibre of amosite suggests another application.

The specially fleecy variety of crocidolite from the Northern Section of the Cape fibre belt would, perhaps, find a use for hospital wool, or, if colour is essential, the pale grey or almost pure white variation of amosite, which easily assumes a woolly consistency, could be applied. Such uses are suggested as jackets for pneumonic patients, since the relatively low heat required for sterilization does not destroy the capacity for easy fiberizing.

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* Cirkel, *loc. cit.*, p. 251.

CHAPTER VIII.

STATISTICAL INFORMATION.

THE following table contains the output of asbestos for the several Provinces since Union, based on the returns given in the Annual Reports* of the Government Mining Engineer :—

ASBESTOS OUTPUT FOR THE UNION OF SOUTH AFRICA (SHORT TONS).

YEAR.	CAPE COLONY.		TRANSVAAL.		NATAL.		UNION TOTAL.	
	Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.
		£		£		£		£
1910†..	680·25	10,598	10·5	165	2·5	38	693·25	10,801
1911...	1,253·5	20,765	—	—	13	74	1,266·5	20,893
1912...	1,217·3	18,822	—	—	3	60	1,220·3	18,882
1913...	937·5	15,599	—	—	24·2	429	961·7	16,028
1914...	1,160·4	18,657	30·1	1,430	—	—	1,190·5	20,087
1915...	2,082·9	33,166	55·5	2,733	—	—	2,138·4	35,899
1916...	4,227·8	74,293	407·3	8,490	20·6	287	4,655·7	83,070
1917...	2,999	49,445	3,192·5	37,486	28	393	6,219·5	87,364
Totals..	14,558·65	241,385	3,695·9	50,304	91·3	1,281	18,345·85	263,024

The writer is indebted to Mr. Rundle Olds for information of the detailed annual output of the Cape Asbestos Co., from which the following table has been compiled :—

CROCIDOLITE OUTPUT FROM THE CAPE ASBESTOS COMPANY'S MINES.

Year.	Long Tons.	Remarks.
1895..............	1,352·45	
1896..............	31·25	Output affected by Rinderpest and Transport.
1897..............	41·20	
1898..............	122·75	
1899..............	218·55	
1900..............	72·45	Closed down owing to war conditions.
1901..............	31·30	
1902..............	46·05	
1903.	245·65	
1904..............	379·85	
1905..............	502·55	
1906·.............	239·20	
1907..............	367.45	
1908..............	952·35	
1909..............	1,147·60	
1910..............	646·05	
1911..............	413·50	Reduction due to bad markets.
1912..............	642·70	
1913..............	539·30	
1914..............	680·50	
1915..............	1,735·55	
1916..............	1,098·40	
1917..............	1,186·05	
Total........	12,063·20	

---

* The Annual Report for 1917 distinguishes between output (sales and shipments) and actual production; owing mainly to present abnormal shipping conditions the latter exceeds the former, and amounted during 1917 to 4,033·672 short tons for the Cape, 4,592·9 for the Transvaal, and 39·5 for Natal.

† Last seven months.

SUMMARY AND CONCLUSION.

The outstanding features regarding the mode of occurrence and distribution of asbestos within the Union may be summarized as follows:—

1. The *Union of South Africa* contains asbestos deposits of very considerable extent and holds the world's record as regards varieties of fibre, while it occupies the leading position as a crocidolite producer; in areal extent the crocidolite belt of the Cape Province is the largest asbestos area of any kind hitherto recorded.

2. The *fibre varieties comprise* the following, enumerated in approximate order of abundance:—Crocidolite, amosite, chrysotile, and tremolite. As commercial sources these varieties are distributed: In the Cape, crocidolite; in the Transvaal, crocidolite, amosite, tremolite, and chrysotile; in Natal, chrysotile and tremolite. The Free State has not so far furnished any asbestos deposits.

3. *Crocidolite* or "*Cape Blue*" is the best-known and longest developed variety in the Union, its occurrences having been exploited practically without interruption since 1892; in this work the Cape Asbestos Co. (established 1893) has maintained a strong lead.

The *crocidolite belt* in the *Cape* is restricted to the north-western parts of the Province (mainly Griqualand West) and reaches as a narrow strip of country from a point some twenty miles south of Prieska in a general northerly direction across the Orange River through Griquatown, Daniels Kuil, and Kuruman at least as far north as Tsenin on the Mashowing River. It measures some 250 miles in length, with a maximum width of over 30 miles. This distribution coincides with the Lower Griqua Town Series, now correlated with the Pretoria Series as the highest division of the Transvaal System; it consists of a great thickness of thinly bedded ferruginous siliceous slates or banded ironstone, to which the crocidolite is confined in the form of many strictly interbedded cross-fibre seams, ranging from the exceptional maximum of about 5 inches downwards; most of the seams consist of lavender blue fibre from ¼ inch to 1 inch in length.

Crocidolite in this belt occurs at a very large number of localities more or less over the entire area, but often—especially in the northern part—in closer proximity to the underlying limestones of the Campbell Rand Series. Two sections of the fibre are recognized: the southern section, comprising the oldest and most important workings (on the Orange River) round Westerberg and Koegas, the local headquarters of the Cape Asbestos Co.'s mines; the northern section extends from the neighbourheed of Daniels Kuil northwards through Kuruman (including the Asbestos Mountains and the Kuruman Hills), where the deposits have been opened up since about 1910 by a number of smaller producers.

Mining developments usually proceed by means of open-cast workings, sometimes extending a little underground on the dip; this is more especially the case in the northern section, whereas in the southern some of the mines are by now worked on more systematic lines to deeper levels (Westerberg).

In the *Transvaal crocidolite* is restricted to the north-eastern part of the Province, situated east of Chuniespoort and embracing portions of the Haenertsburg Goldfields. Here the interbedded cross-fibre seams occur in the basal portion of the Pretoria Series close to the underlying Dolomite, in ferruginous siliceous slates, practically indistinguishable from the banded ironstones of Griqualand West, and consist of the same lavender blue fibre as in the Cape belt, with sensibly the same dimensions as regards width. Though known since 1905, they have been opened up only during the last two or three years, and their exploitation is still to a large extent in its initial stages.

4. *Amosite* has so far been found in the *Transvaal* only. It apparently forms a new variety of asbestos as a monoclinic ferrous silicate amphibole with or without soda. It is found at a number of localities in the Lydenburg and Pietersburg Districts over a narrow strip of country extending from the Steelpoort River north-westwards through Sekukuniland at least as far as the Malips River and Chuniespoort through a distance of some sixty miles over an average width of about three miles. Amosite is an ash-grey or pale brownish mineral, occurring as interbedded cross-fibre seams in the same banded ironstones of the basal portion of the Pretoria Series (close to the underlying Dolomite) in which the crocidolite in the Haenertsburg Goldfields is found. The length ranges from the not uncommon value of 11 inches downwards, but the principal amosite horizon in Sekukuniland is strongly characterized by thick seams, very frequently from 4 to 7 inches wide over considerable distances. This asbestos was known as far back as 1907, but its systematic development only began some three or four years ago, and the main deposits, now well opened up in the Egnep and Amosa Mines on the right bank of the Olifants River, reveal large quantities of this unique fibre length.

5. *Chrysotile* forms a commercial occurrence so far in the *Carolina District* of the *Transvaal* only, where several farms—some twenty-five miles east of Carolina—show a persistent fibre horizon almost at the top of the Dolomite within a few feet of an intrusive diabasic sill and over a distance of some two to three miles along the strike. This asbestos forms cross-fibre seams interbedded in altered dolomite and ranging from the very rare maximum of 7 inches downwards. Seams in the neighbourhood of ½ inch in thickness are the common experience. They have been worked at intervals for a number of years, but, compared with the crocidolite and amosite reserves, the supply is distinctly more limited; the fibre has the familiar brilliant white appearance of the best chrysotile, is of superior quality, and closely resembles Canadian chrysotile.

In *Natal chrysotile* is found in Zululand near the Middle Drift over the Tugela River, where it has been exploited at the Sitilo Mine: here one finds cross-fibre seams in dark greenish serpentine and disposed vertically along and very close to the contact with an aplite intrusion.

6. The remaining asbestos—*tremolite*—has been worked in *Natal*, where the Buffalo Asbestos Co. have opened up a number of slip-fibre seams, several inches thick, in pale greenish talcose rocks on the Klipriver Location of Zululand, some forty-six miles from Dundee. The same variety has also been exploited in the *Zoutpansberg* District north of Mara Siding.

7. As regards *mode of origin*, the crocidolite and amosite seams are most probably derived from ferruginous sediments carrying some form of soda as an original constituent, not by lateral secretion along open fissures, but by growth *in situ*, the constant presence of magnesia being probably genetically connected with the proximity to underlying dolomitic beds.

The Transvaal chrysotile seams are also derived from the alteration of sediments, due to the subsequent serpentinization of magnesian silicates resulting from the thermal metamorphism of siliceous dolomitic rocks consequent upon a basic intrusion. This mode of origin is probably identical with that of the chrysotile deposits from Grand Cañon, Arizona, to which the Carolina chrysotile (and also an occurrence of the same asbestos at Chuniespoort) show a remarkably close resemblance.

On the other hand, the Sitilo deposits of Zululand appear more closely analagous to the Canadian type of deposit, due to the serpentinization of massive igneous rocks of ultra basic characters.

The preceding chapters have shown that the Union possesses great reserves of asbestos, and the remarkable increase in the total output during the last four years or so, in spite of the almost complete disorganization of oversea markets and shipping conditions, is a striking feature.

While Canadian chrysotile—of which only a small fraction is spinnable—still maintains a leading position in supplying raw material for the asbestos industry, the superiority of crocidolite for certain articles of manufacture has brought about its successful use in a variety of goods turned out by the European factories of the Cape Asbestos Co.

Both crocidolite and amosite are available in large quantities, and these are greatly superior to Canadian chrysotile in the spinnability proportion, which amounts to some 70 per cent. in case of Cape blue, while no difficulty has so far been experienced in keeping the entire amosite output of spinnable length.

The present international economic situation has seriously interfered with a regular production and disposal of fibre from the Union, so that the successful efforts to establish a local manufacturing industry of asbestos goods are specially welcome. Such factories exist at Salt River near Capetown, Durban, Johannesburg, and Dundee, in which crocidolite, amosite, or tremolite (with its country rock of talc) are adapted to various uses; among these the requirements of the building material and engineering trades claim first attention, e.g. roofing tiles, flooring composition, boiler lagging, etc. Such increased activities react favourably on the local cement industry and stimulate the exploitation of the Union's mineral resources in other directions.

The suitability of Cape blue for the manufacture of goods requiring spun fibre has long been well established, and recent experiments carried out under proper technical conditions have demonstrated that amosite can also be fiberized and adapted for yarn production.

The marked industrial revival now apparent in many directions of South African effort, the proof that the more important fibre deposits of this Dominion possess the requisite commercial advantages of quality and quantity, the many further uses to which such asbestos—with its very high proportion of spinnable fibre—might be extended (as pointed out above), and, lastly, the successful establishment of several local asbestos factories, entitle one to the belief that a wide and increasing field of utility awaits our deposits.

In this beneficial result the growing self-consciousness of a South African nationality will not have been the least important factor.

APPENDIX.

While this volume was in the Press, a further three analyses of amosite—from Penge—became available; the writer is indebted to Mr. T. H. B. Wayne for permission to publish them.

These analyses are by Messrs. Gulick, Henderson & Co., of Pittsburg, Pennsylvania, and are tabulated below under I to III. It is not certain how the samples were taken for analysis, but the high percentage soluble in HCl in case of analysis I, as well as the large amount of lime and magnesia, strongly point to oxidation or carbonation and allied secondary changes. The marked increase in FeO is associated with a decrease in Fe_2O_3, in soluble proportion, and in percentages of CaO and CO_2. Probably the freshest fibre contains iron in the form of FeO only, as suggested by the tendency towards brilliant white colours at the lowest depths.

After allowing for carbonation and calculating Fe_2O_3 as FeO, one obtains the results given under IA, IIA, IIIA; the similarly recalculated analysis III in the table given in Chapter I is added as IV. These adjusted values are very fairly consistent:—

	I.	II.	III.	IA.	IIA.	IIIA.	IV.
SiO_2	36·20	49·48	47·68	44·72	50·85	48·27	51·09
Al_2O_3	—	·68	tr.	—	·69	tr.	—
Fe_2O_3	12·08	8·16	4·84	—	—	—	—
FeO	24·27	30·09	36·00	43·41	38·37	40·84	39·67
MgO	8·50	6·77	6·20	5·88	6·95	6·04	4·03
CaO	5·56	·88	tr.	—	—	tr.	—
Na_2O	·15	·20	·28	·19	·21	·283	2·15
CO_2	8·40	·56	·21	—	—	—	—
H_2O (comb.)	4·70	2·74	4·50	5·81	2·81	4·55	3·05
	99·86	99·56	99·71	100·01	99·88	99·98	99·99
Sol. in 5% HCl	30·00	8·40	8·50	—	—	—	—
Length of Fibre	6·5″	6·5″	8·5″	—	—	—	—

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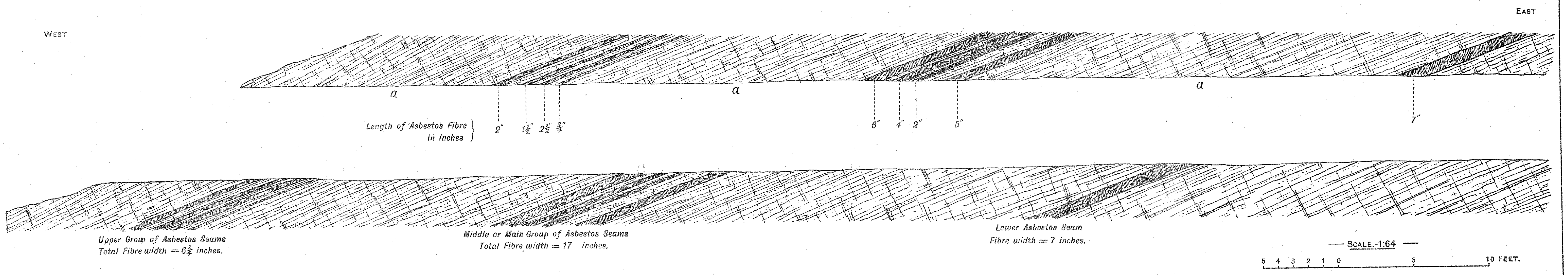
INDEX.

[Note.—The names of farms with the district in which they are situated are printed in italics.]

Memoir No. 12. PLATE XV.

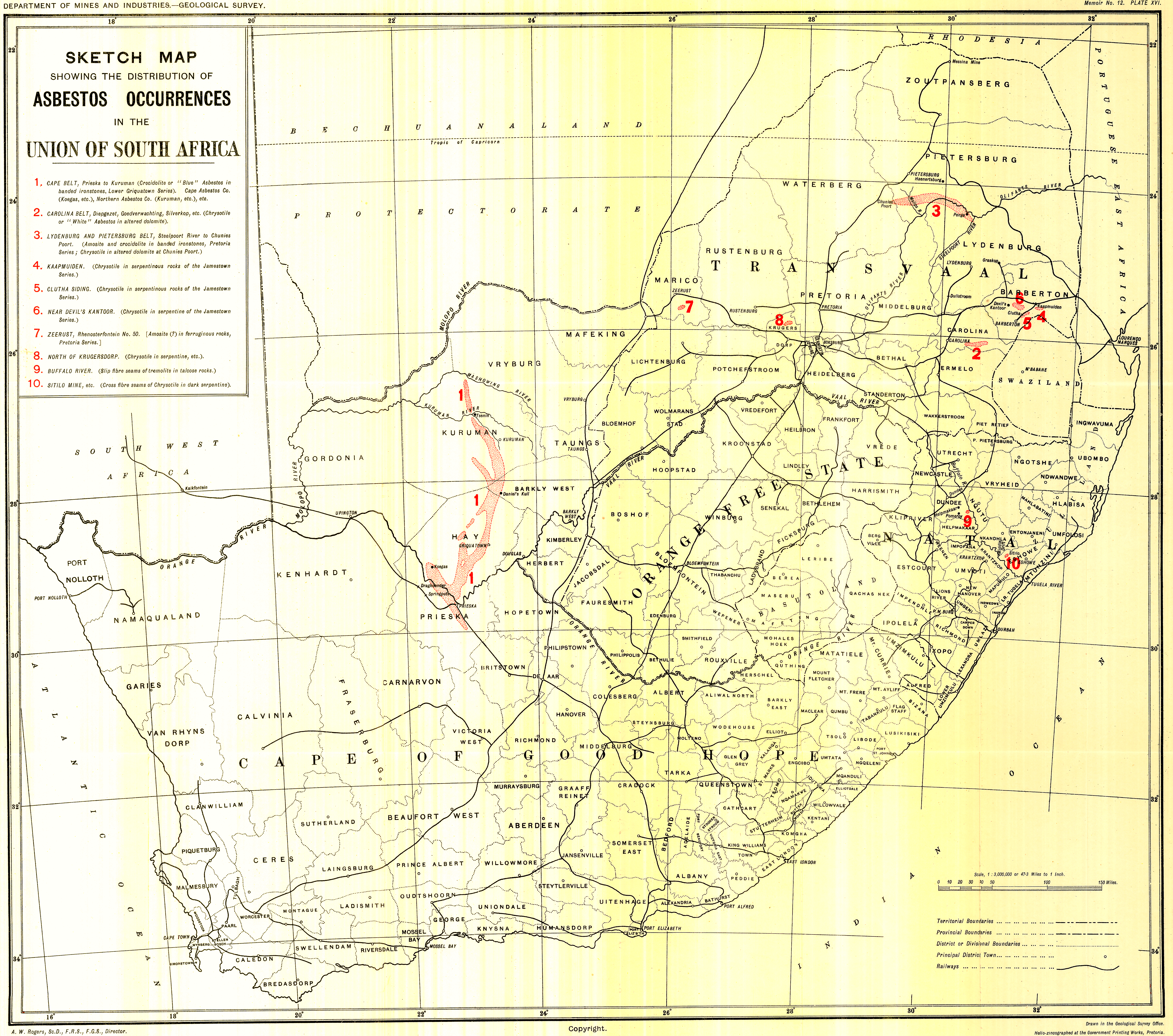
SECTION ALONG FIRST LEVEL, "B" SECTION, PENGE, SHOWING THE DISTRIBUTION OF ASBESTOS VEINS.

a = Ferruginous siliceous slates and softer shaly layers. Dip = 20°.



UNION OF SOUTH AFRICA.
DEPARTMENT OF MINES AND INDUSTRIES.—GEOLOGICAL SURVEY.

Memoir No. 12. PLATE XVI.



SKETCH MAP
SHOWING THE DISTRIBUTION OF
ASBESTOS OCCURRENCES
IN THE
UNION OF SOUTH AFRICA

1. *CAPE BELT, Prieska to Kuruman (Crocidolite or "Blue" Asbestos in banded ironstones, Lower Griquatown Series). Cape Asbestos Co. (Koegas, etc.), Northern Asbestos Co. (Kuruman, etc.), etc.*
2. *CAROLINA BELT, Diepgezet, Goedverwachting, Silverkop, etc. (Chrysotile or "White" Asbestos in altered dolomite).*
3. *LYDENBURG AND PIETERSBURG BELT, Steelpoort River to Chunies Poort. (Amosite and crocidolite in banded ironstones, Pretoria Series; Chrysotile in altered dolomite at Chunies Poort.)*
4. *KAAPMUIDEN. (Chrysotile in serpentinous rocks of the Jamestown Series.)*
5. *CLUTHA SIDING. (Chrysotile in serpentinous rocks of the Jamestown Series.)*
6. *NEAR DEVIL'S KANTOOR. (Chrysotile in serpentine of the Jamestown Series.)*
7. *ZEERUST, Rhenosterfontein No. 50. [Amosite (?) in ferruginous rocks, Pretoria Series.]*
8. *NORTH OF KRUGERSDORP. (Chrysotile in serpentine, etc.).*
9. *BUFFALO RIVER. (Slip fibre seams of tremolite in talcose rocks.)*
10. *SITILO MINE, etc. (Cross fibre seams of Chrysotile in dark serpentine).*

Scale, 1 : 3,000,000 or 47·3 Miles to 1 Inch.

Territorial Boundaries	— - - — - - — - -
Provincial Boundaries	— - — - — -
District or Divisional Boundaries	…………………
Principal District Town	○
Railways	∼

A. W. Rogers, Sc.D., F.R.S., F.G.S., Director.

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