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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, M.A.; Sc.D.; F.G.S. (Assistant Director)

(Second Edition)

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

Price 7s. 6d.

THE GOVERNMENT PRINTER, PRETORIA
1930

7333—19/8/30—1,500.

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Plate I (Frontispiece).—Portion of the Malips Drift Asbestos Mine's workings (Egnep, Ltd.), showing a thick seam of amosite interbedded in banded ironstone. Photo by F. E. Wright.

THE SECRETARY FOR MINES AND INDUSTRIES,
PRETORIA.

SIR,

I have the honour to submit the manuscript of the second edition of the Memoir on the Asbestos Deposits in the Union written by Dr. A. L. Hall.

Twelve years have passed since the first edition was issued, and the steady increase in the output of asbestos gives assurance that the future of the industry promises well. This development has afforded opportunity for the collection of much information of importance, and the present edition of the memoir has three new chapters in addition to new chemical analyses, text figures, and plates, while the other chapters have been largely rewritten.

The first edition has been out of print for some time, and it may be expected that the second will be of even more use to the industry than the first proved to be.

I have the honour to be, Sir,

Your obedient servant,

ARTHUR W. ROGERS,
Director, Geological Survey.

Geological Survey Office,
Pretoria, 6th August, 1930.

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At End of Volume.

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INTRODUCTION TO THE SECOND EDITION.

During the 12 years that have passed since the first edition of this work appeared, the Asbestos Industry of the Union has made very considerable progress; thus the value of the asbestos output has risen from £87,364 for the year 1917 to £497,393 during 1929.

Apart from general economic factors in the international asbestos situation, such as the greatly increased varieties of uses to which the fibre is now put and the consequent greatly increased demand, some of the main elements that have contributed to the marked advance in our asbestos industry are : The discovery and successful exploitation of the rich and high-grade crysotile deposits near Kaapsche Hoop in the Barberton District, the steady progress in the development of the phenomenally rich amosite occurrences in the Penge section of the Lydenburg District, and the discovery, stimulated no doubt by the increasingly successful activities of the industry in the areas referred to, of a large number of fibre deposits not only of chrysotile in various parts of the Transvaal, but also of amosite along many miles of strike from Penge northwards to Chuniespoort, the latter constituting what is commonly referred to as the Pietersburg Asbestos Fields. The manufacturers' final—though tardy—recognition, that amosite, while less valuable than "white" or "blue" asbestos, is yet suitable for many industrial purposes, has also been an important factor in stimulating the industry. Finally, the decision of some of the largest manufacturing concerns to obtain a solid footing in the Union's asbestos fields, has had the welcome effect of securing more systematic and sustained mining developments in certain sections of our fields, while implying a substantial measure of confidence in their permanency and value. Incidentally this policy has provided small producers with a local market; this applies with special force to the Cape Asbestos Belt.

Several of the more recent developments referred to above, e.g. the chrysotile discoveries in the Barberton District and most of the fibre deposits within the Pietersburg Asbestos Fields occurred after the original edition of this memoir was published. This is now out of print. In view of the great development of the industry in many directions, as already pointed out, a more or less complete revision had to be undertaken, based on repeated examinations of all the major and nearly all the minor fibre occurrences in the Union, including the recent and promising discovery of chrysotile on Havelock's Concession in Northern Swaziland. The extensive mining developments carried out in the Pietersburg Fields and in the Kaapsche Hoop area have added some important details to our knowledge of the geology of those regions—as well as of the genetic problem—as shown in the following pages.

Several new quantitative analyses have been specially made for the new edition, and the writer is greatly indebted to the Government Chemical Laboratories, Johannesburg, for the careful manner in which this important work has been carried out.

In addition to the acknowledgments made in the first edition, the author is glad of this opportunity of recognizing—in connection with the new edition—with sincere appreciation the valuable assistance received from the late J. W. S. Beatty (New Amianthus Mines, Ltd.), the late Mr. F. Bennetts [Munnik-Myburgh Asbestos (Kaapsche Hoop), Ltd.], Mr. J. H. P. Bilbrough (Seelig Asbestos Mines, Ltd.), Mr. J. F. Bourhill [Munnik-Myburgh Asbestos (Kaapsche Hoop), Ltd.], Mr. Bramley (Island Asbestos Co.), Col. A. J. S. Brown (Pietersburg Asbestos, Ltd., and Montana Mine), Mr. Brown (Pietersburg Asbestos, Ltd.), Mr. E. G. Bryant, B.Sc. (Prieska), Mr. J. G. Bunney (Egnep, Ltd., Penge), Mr. H. D. Castle (Havelock Mine), Mr. E. C. Clarke (Kalkkrans Asbestos, Ltd.), Mr. F. W. Clements (Josefsdal Mine), Mr. H. B. Cowlhan [Northern Asbestos Mine (Pty.), Ltd.], Mr. Davidson (Egnep, Ltd., Amosa Mine), Mr. J. Dixon (Egnep, Ltd., Penge), Mr. Du Toit (S.A. Consolidated Asbestos, Ltd.), Mr. W. Dyke Poynter (formerly Mining Commissioner at Pilgrims Rest), Mr. W. E. G. Fitzpatrick (Havelock Mine), Mr. G. F. Fourie (formerly Claim Inspector, Pietersburg), Mr. H. Friedman (S.A. Consolidated Asbestos, Ltd.), Mr. H. N. Fuller (New Amianthus Mines, Ltd.), Mr. Furniss (Asbestocement Manufacturing Co., Johannesburg), Mr. J. S. Hancock (Chunies Asbestos Co.), Mr. Harrison (Nauga Asbestos Co.), Mr. M. Haskel, Mr. Howes [Northern Asbestos Mines (Pty.), Ltd.], Mr. A. H. Jenkins (Chunies Asbestos, Ltd.), Mr. C. J. N. Jourdan (Inspector of Mines), the late Mr. A. T. Judge, Mr. J. Kable (African Asbestos Trust, Ltd., Kalkkloof), Mr. G. Kent (Johannesburg), Mr. H. L. Kirkman [Dominion Blue Asbestos Mines (Pty.), Ltd., Montana Mine], Mr. W. D. Kirkman [Dominion Blue Asbestos Mines (Pty.), Ltd., Kuruman], Mr. V. Kässner (Sterkspruit), Mr. J. D. Marquard (Inspector of Mines, Bloemfontein), Mr. Donald McBean and Mr. W. McBean (Egnep, Ltd., Malips Drift Mine), Mr. G. McBean (Johannesburg), Mr. T. J. McFarlane (New Amianthus Mines, Ltd.), Mr. G. de Merillac (Cape Asbestos Co., Blackridge), Mr. H. Norris, Mr. Nortier (Seelig Asbestos Mines, Ltd.), Mr. J. E. Robison (Central Asbestos Mines of S.A., Ltd), Mr. Rundle Olds (Cape Asbestos Co., Koegas), Mrs. K. H. Rodley (Kaspersnek), Mr. Schechter, the late H. Seelig (Seelig Asbestos Mines, Ltd.), Mr. L. B. Schwabe [Northern Asbestos Mines (Pty.), Ltd.], Mr. Steyn [Northern Asbestos Mines (Pty.), Ltd.], Mr. R. B. Saner, Dr. B. Schlesinger, Mr. Stott (Griqualand Exploration and Finance Co., Elandsfontein), Mr. G. H. Trevelyan (formerly Mining Commissioner at Pietersburg), Mr. v. d. Berg (Standard Asbestos Co., Ltd.), Mr. D. S. v. d. Merwe (Mining Commissioner at Pietersburg), Mr. v. d. Merwe (Havelock Mine), Mr. J. M. Vine (formerly Deputy Assistant Commissioner, Piggs Peak), Mr. E. H. White (Claim Inspector, Pietersburg), Mr. Whittaker (Johannesburg), and Mr. A. E. Young (London African Tin Syndicate, Ltd.).

Special recognition is due to the Cape Asbestos Co. (including Egnep, Ltd), and to Messrs. Turner & Newall, Ltd. [Dominion Blue Asbestos Mine (Pty.), Ltd., New Amianthus Mines, Ltd., and Montana Mine], for affording all facilities for the examination of their various workings. The author is very specially indebted to Mr. A. K. Parrott, Field Assistant of the Geological Survey, who rendered valuable help in the field.

INTRODUCTION TO THE FIRST EDITION (1918).

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 amphibole—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. McBean, 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 sixty 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 the Union gradually came well to the front with its extensive belt of crocidolite asbestos in the Cape Province, followed a few years later by the discovery of chrysotile deposits in the dolomite east of Carolina, and of enormous quantities of amosite—an ash grey amphibole asbestos of exceptionally great fibre length—in the Lydenburg district; then came the discovery and gradually increasing exploitation of very rich chrysotile deposits in the Barberton district, until finally the proved extension of the Lydenburg deposits northwards to Chuniespoort added the Pietersburg asbestos fields as a further source of large quantities of amosite.

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 " 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 general composition $(MgFe)O$, SiO_2 :—

Anthophyllite.

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

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—

$$NaFe, (SiO_3)_2, FeSiO_3.$$

Soda is an invariable constituent of this amphibole.

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 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, of the total world production of asbestos of all kinds, 70 per cent. (during 1928) came from the province of Quebec, so that Canada leads in the world's supply and since all her product is chrysotile, this variety still holds the premier position among the varieties of asbestos.

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.

Varieties of Asbestos Found within the Union of South Africa.

As far as the Union is concerned, workable asbestos deposits comprise :—*Chrysotile, crocidolite, amosite, anthophyllite* and *tremolite*. Of these the anthophyllite and tremolite occurrences are of minor importance, the former having so far been discovered under economic conditions in the Zoutpansberg District only (Korea), while the latter occurs in Natal and in a few localities elsewhere.

For many years *crocidolite* has been produced in appreciable quantities from the Cape Asbestos Belt and its production continues steadily; a small output of the same fibre also comes from the Pietersburg Fields.

The Union's earliest production of *chrysotile* came from the Carolina District, where it was found in a country rock of altered dolomite; this source has hitherto proved economically disappointing. In about 1916 occurred the highly promising discoveries of chrysotile in the serpentines of the Jamestown Series near Kaapsche Hoop in the Barberton District, which are now furnishing a very satisfactory production.

Amosite.—The marked difference of the fibre, which was found in the banded ironstones in the Lydenburg District (Penge), when compared with the characteristic lavender-blue colour of " Cape Blue " asbestos, in particular its high proportion of very long fibre, physical appearance in white, pale brownish, silvery grey, ash grey or extremely delicate greenish tints, and last but not least, its definite establishment in the markets of Japan, United States, etc., made it desirable to have a distinctive name, primarily for commercial purposes. For these reasons the writer in 1918 * proposed the term *Amosite,* derived from the word *Amosa,* made up from the initial letters of the phrase " Asbestos Mines of South Africa," the company which originally exploited the farms in the Lydenburg District (Penge), etc., where this fibre was first located in 1907, thus taking cognizance of local conditions and the priority of the North Eastern Transvaal in this new fibre variety.

Subsequent work has shown (Bibl. No. 58) that amosite is a rhombic amphibole, exceptionally rich in iron, and forming part of the Anthophyllite-Gedrite series of amphiboles. While it might therefore be

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* See No. 27 in the bibliography at the end.

held that the term "amosite" has no claim to denote a distinct mineral species, the composition of this fibre is intermediate between that of normal anthophyllite and normal gedrite, so that there appears some justification in retaining "amosite" as a definite member of the rhombic amphibole series. In any case, since the name is now well understood in the industry as referring to a special type of fibre, technically distinct in many respects from chrysotile and crocidolite, the term is here retained.

Note.—The term *Montasite* has recently been registered as a trade name to denote a fibre of very superior quality found in the Montana Mine of the Pietersburg Fields. Its mode of occurrence in the banded ironstones, physical characters and chemical composition (see Table No. 5 below) show that montasite is identical with amosite, of which it represents merely a very finely fibrous variety; thoroughly fiberized montasite has a very beautiful almost white appearance, and is liable on cursory examination, to be mistaken for chrysotile.

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 slight 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.

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 initital difficulties. According to Professor H. T. Barnes (No. 9, 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

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 Maritzburg Museum is an example of asbestos (chrysotile?) from Umsinga, Natal, with the extraordinary length of 43 inches; it is most probably slip fibre. In the Carolina District exceptional cases of 6½ inches have been observed free from stony or other partings and consisting of continuous high-grade fibre; such cases are, however, very rare and constitute an almost negligible percentage in the output. Lengths varying from a quarter to three-quarters of an inch are the common rule, and of the total Canadian output during 1915 only 4 per cent. was fibre exceeding ¾ of an inch in length, while that over 1 inch only amounted to 1.4 per cent. During 1928 the Canadian chrysotile output† was 273,235 short tons; of this amount the proportion of longer fibre (Crude No. 1, Crude No. 2, and Crude Run of Mine) totalled 3,997 short tons, equivalent to 1.09 per cent. A similar experience is met with in the Union's chrysotile mines, not excluding the rich deposits of the New Amianthus Mines, where the bulk of the production is milling fibre. In the other direction there is every gradation down to the faintest films 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 colouration acquire the dead white colour and consistency of purest cotton or silk when worked up in the lands. Lumps of high-grade

* These numbers refer to the bibliography at the end.

† Bibliography No. 4, p. 47.

chrysotile not infrequently exhibit a very delicate sea green or olive green tint and are translucent at their edges.

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 whether the highest grades of crocidolite and amosite fibre are always 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 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. 22, 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 accurately to weight 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 appears negligible; further information on the relative specific gravities of serpentine and chrysotile is given in Chapter IX.

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 Table No. 1, computed from eleven separate analyses published in Cirkel's monograph (No. 9, 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.

TABLE No. I.—*Composition of Chrysotile.*

	Union of South Africa.			Rhodesia.			Canada.	Italy.
	I. Barberton New Amianthus.	II. District. Munnik-Myburgh.	III. Carolina.	IV. Shabani.	V. Gath.	VI. Victoria.	VIII.	VIII.
SiO_2	40·05	40·75	41·9	40·96	42·20	38·58	40·49	40·30
Al_2O_3	1·90	·90	Nil	1·70	1·59	3·21	1·27	2·27
Fe_2O_3	1·60	1·30	Nil	—	—	—	2·53	·87
FeO	·40	·60	Nil	2·44	1·76	2·53		
CaO	·15	—	·5	—	—	2·90	—	—
MgO	38·35	41·0	36·3	38·73	38·70	38·87	41·41	43·37
Na_2O	·25	·35	2·71	·10	·16	—	—	—
K_2O	·15	Trace	—			—	—	—
H_2O (110°C)	16·60	1·90	18·00	2·70	1·84	—	14·06	13·72
Ignition		13·45		13·37	13·75	14·10		
TOTAL	99·70	100·25	99·41	100·00	100·00	100·19	99·76	100·53

I.—Long Fibre, Ribbon Line, Amianthus, Ltd., Southern Joubertsdal No. 99, near Kaapsche Hoop; analysis by Government Chemical Laboratories, Johannesburg. II.—Long Fibre, Grade IXL from No. 4 Main Workings, Munnik-Myburgh Asbestos, Ltd., near Kaapsche Hoop; analysis by H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg. III.—High Grade Fibre, Diepgezet (in dolomite) east of Carolina; analysis by C. Gardthausen, Geological Survey. IV.—Chrysotile, Shabani Asbestos Mine, Southern Rhodesia. V.—Chrysotile, Gath Asbestos Mine, Southern Rhodesia. VI.—Chrysotile, Victoria, Southern Rhodesia. VII.—Canadian Fibre; mean of eleven analyses, given in Cirkel's Memoir on Chrysotile, Ottawa, 1910, p. 31. VIII.—Chrysotile from Italy, given in Cirkel's Memoir, p. 31.

Of the chrysotile in the Union, Table No. 1 gives three analyses. Two of these (Nos. I and II) agree very closely with the average composition of Canadian fibre (No. VII), while in the third case (Carolina No. III) there is also a close agreement, except for the high percentage of soda (2·71 per cent.). This result is unusual, though Hintze (*Handbuch der Mineralogie*) quotes several instances of serpentine containing that constituent, and in Graham's paper (Bibl. No. 22, 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. There is a consistent and high percentage of water of constitution; the probability that this feature controls flexibility (at any rate in the case of chrysotile) has been already referred to.

Crocidolite.

General.—This interesting mineral* was first noted by Lichtenstein during his travels in South Africa, 1803 to 1806, when he collected a heavy massive blue mineral in the Orange River valley near Prieska; this is most probably identical with the material described as "potential crocidolite" in the first edition of the present memoir. In 1815 Klaproth (Bibl. No. 44) gave an analysis (see I in Table No. 2) of Lichtenstein's material, naming it "Blau-Eisenstein." Subsequently, Stromeyer and Hausmann in 1831 (Bibl. No. 69A) published analyses (II and III in Table No. 2) of a fibrous blue mineral and proved its identity with Blau-Eisenstein; they referred to it as "asbestiform crocidolite," a term built up of two Greek words meaning "Flaky" or "Woolly Stone." The conclusion that this mineral is characterized by much ferric iron is due to Doelter (Bibl. No. 13A).

Physical Properties.—Crocidolite is a monoclinic hornblende, possessing (like chrysotile) a highly pronounced *fibrous structure*, but is easily distinguished from all other asbestos by its highly characteristic *lavender blue* colour. The cause of this distinctive colouration is not definitely known; the light gray colour of the chemically almost identical amosite (with a consistently much lower soda content) suggests that the blue colouration of crocidolite depends upon its invariably higher percentage of soda. It has also been suggested, during the discussion of a recent paper by Jourdan (Bibl. No. 37), that the colouration is due to a ferrous compound.

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

* The so-called "crocidolite" in the jeweller's trade is a highly altered silicified brown variety, to which the name "Tiger Eye" is here applied.

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 were 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 three-quarters (and below) are the more common rule.

The *tensile strength* of crocidolite is distinctly greater than that of chrysotile, and experiments made with a cylinder $^{1}/_{100}$ inch in diameter show that a considerable weight can be supported. Cirkel (No. 9, 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. 9, 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.

The specific gravity, according to Dana, varies from 3·20 to 3·30.

Much information on the nature of crocidolite, in particular with regard to its *optical properties,* will be found in a recent paper by M. A. Peacock (Bibl. No. 58), giving the results of a most valuable and detailed investigation of South African amphibole asbestos, based on material collected by Prof. Palache, a member of the Shaler Memorial Expedition which visited this country during 1922.

One instructive conclusion arising from Peacock's close study of the optical properties is that in the crocidolite from the Cape and Greenland the extinction angle is zero; this does not agree with the data usually, given, which describe the extinction as 18° to 20°. This conclusion bears out the reference contained in the Annual Report of the Cape Geological Commission (Bibl. No. 67, p. 86) to needles of crocidolite found by Rogers near Prieska, in 1908, in which the extinction is only a few degrees. (See below.)

Chemical Properties.—Crocidolite is a monoclinic amphibole with a very low extinction angle; it is essentially a metasilicate of iron, containing a large percentage of both ferric and ferrous iron, the former usually slightly in excess of the latter, according to the more recent analyses. Soda is an essential constituent ranging from about 4 to 7 per cent., while magnesia, lime, and alumina are low. According to Peacock (Bibl. No. 58) the composition is given by the formula: $3H_2O$, $2NaO$, $6(Fe,Mg)O$, $2Fe_2O_3$, $17SiO_2$. The accompanying Tables Nos. 2 and 3 give a large number of analyses of crocidolite from the Cape Province and two from the Transvaal (Pietersburg Fields); in the earlier ones the iron content is returned wholly as ferrous iron, while in the latter ones the consistent presence of much ferric iron is demonstrated.

TABLE No. 2.—*Composition of Crocidolite.*

	Cape Province.								Transvaal.	
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	50·00	50·81	51·64	52·11	51·89	52·11	51·1	51·22	56·27	59·40
Al_2O_3	—	—	—	1·01	—	—	—	—	—	—
Fe_2O_3	—	—	—	20·62	19·22	20·26	—	—	—	14·40
FeO	40·50	33·88	34·38	16·75	17·53	16·51	35·8	34·08	33·78	15·10
MgO	—	2·32	2·64	1·77	2·43	1·88	2·3	2·48	1·67	3·40
CaO	1·50	·02	·05	—	·40	·75	—	·03	1·70	·55
Na_2O	5·00	7·03	7·11	6·16	7·71	5·79	6·9	7·07	3·92	4·05
Moisture	—	—	—	—	—	—	—	—	—	·10
Combined Water	3·00	5·58	4·01	1·58	2·36	3·53	3·9	4·50	—	3·25
TOTAL	100·00	99·81	99·85	100·00	101·69	100·83	100·00	99·48	99·84	100·25
Including		·17 Mn_2O_3	·02 Mn_2O_3		·15 K_2O			·10 Oxide of Mn		
Sp. Gr.	3·20									

I. Analysis by Klaproth (Bibl. No. 44); this is the so-called "Blau-Eisenstein," collected by Lichtenstein, near Prieska.
II. and III. are "Krokydolith," analyses by Stromeyer (Bibl. No. 69A).
IV. Analysis by Doelter (Bibl. No. 13A).
V. Analysis by Renard (Bibl. No. 60).
VI. Published by Chester and Cairns (Bibl. No. 8A).
VII. Quoted in Cirkel's monograph (Bibl. No. 9; from Jones' treatise (Bibl. No. 36).
VIII. Quoted by Cirkel from De Larrarent (De Lapparent?—Bibl. No. 9).
IX. Crocidolite from the Malips River, east of Pietersburg; analysis by Hahn.
X. Crocidolite from Pietersburg Asbestos, Limited, east of the Malips River· analysis by Government Chemical Laboratories, Johannesburg.

TABLE NO. 3.—*Composition of Crocidolite* (continued).

	Cape Province.									
	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.	XX.
SiO_2	52·30	54·50	52·90	52·60	50·50	50·65	52·85	51·94	50·71	50·66
Al_2O_3	—	—	—	—	—	—	2·00	·20	Nil	·04
Fe_2O_3	17·50	21·00	17·10	17·75	20·20	18·55	17·10	18·64	20·45	17·05
FeO	17·30	13·10	16·40	18·70	15·40	17·85	18·00	19·39	17·41	17·05
MgO	4·25	2·85	4·55	2·30	3·65	2·30	1·75	1·37	2·28	1·99
CaO	·80	·90	·65	·85	·80	·75	·85	·19	·15	·01
Na_2O	4·55	4·05	3·90	4·40	4·40	5·70	4·90	6·07	5·75	5·15
K_2O	—	—	—	—	—	—	—	·04	·07	·09
Moisture	·80	1·05	·45	·30	1·05	·80	·70	·31	·96	·15
Combined Water	3·00	2·90	3·90	3·20	4·15	3·70	2·55	2·58	2·50	2·62
TOTAL	100·50	100·35	99·85	100·10	100·15	100·30	100·70	100·73	100·28	100·40

XI to XVII.—Crocidolite, analyses by Government Chemical Laboratories, Johannesburg. (Bibl. No. 37.) XI. Dark lavender blue from Hurley (Kuruman District). XII. Lighter blue fibre from Amy's Hope (Kuruman District). XIII. From Klipvlei (Barkly West District). XIV. From Blaauwputs (Prieska District). XV. Light blue fibre, Arcadia Mine (Kuruman District). XVI. Dark blue fibre from the Westerberg Mine (Prieska District). XVII. From Blackridge (Hay District).

XVIII.—Fine blue fibrous crocidolite from Kliphuis, north of Prieska. Analysis by H. E. Vassar (Bibl. No. 58).

XIX.—Incipient or Potential Crocidolite, slightly iron-stained; same locality; analysis by H. E. Vassar (Bibl. No. 58).

XX.—Acicular crocidolite, slightly iron-stained; same locality; analysis by H. E. Vassar (Bibl. No. 58).

Analysis X (Table No. 2) to Analysis XVII (Table No. 3) are of special interest since they were made with the object of ascertaining whether there are variations in composition corresponding to differences in physical properties (Jourdan, Bibl. No. 37). Mr. Jourdan states:—

" . . . . . Every shade of lavender-blue was represented, from the lightest to the darkest, and there was, so fas as outward appearances went, a great variety of fibre.

" Some varieties yielded, even without being teased out, a soft silky-like product, others appeared to be harsh and stiff and yet on teasing yielded an equally silky product, while some fibres again appeared to be more broken than those from anywhere else.

" These variations in colour and in the physical appearance suggested to the writer that there might be some variation in the chemical analyses of these different fibres, and that this variation might have a bearing on the value of the crocidolite in industry. . . . .

" It is interesting to note the consistency in the analysis of the seven samples from the Cape Province, which came from points so far apart as Amy's Hope, some 60 miles north of Kuruman, and Blaauwputs in Prieska. The colour varied from a very dark lavender blue to a light blue, almost a French grey. The fibres varied from being very harsh to that of an extremely soft silky texture.

" Now while it is clear that there is a variation in the spinning properties of the fibres of the eight samples, No. 7 [analysis XVI] is said to be the best, there is no evidence to show that the chemical analyses have any bearing on these properties.

" No. 3 from the Pietersburg District [analysis X] differs quite appreciably from the others, the silica content being rather higher and the iron oxide contents lower.

" There is no evidence that this variation affects this fibre in any way. That which is produced to-day at depth from the surface is to all outward appearances as good as most of the blue asbestos from any other parts . . . ."

Table No. 4 gives analyses of crocidolite that has suffered more or less profound alteration, through the infiltration of silica, hydration and other chemical adjustments. Here belong the highly silicified crocidolite known as Tiger-eye, the altered variety called Griqualandite, etc. (Chapter II.)

TABLE No. 4.—*Altered Crocidolite from Cape Province.*

	I.	II.	III.	IV.	V.	VI.	VII.
	Tiger-eye.	Bluish.	Blue.	Brown.	Brown.	Griqualandite.	Yellow.
SiO_2	93·05	93·43	97·27	94·45	57·46	56·75	11·80
Al_2O_3	·66	·23	—	—	—	—	1·00
Fe_2O_3	4·94	2·41	—	4·50	37·56	37·64	75·92
FeO	—	1·43	1·67	—	—	1·09	·21
MgO	·26	·22	—	—	—	·10	·46
CaO	·44	·13	·15	—	—	—	Trace
$Na_2O + K_2O$	—	—	—	—	—	—	·61
Combined Water	·76	·82	·76	·80	5·15	4·96	9·63
TOTAL	100·11	98·67	99·85	99·75	100·17	100·54	99·63*
Sp. Gr.	—	—	2·69	2·684	3·05	3·136	—

I. and II.—Renard and Klement (Bibl. No. 60).
III. and V.—Wibel and Neelsen (Bibl. No. 80).
IV.—Rammelsberg (Bibl. No. 59A).
VI.—Softer alteration product, Hepburn (Bibl. No. 34A).
VII.—Highly altered crocidolite, easily rubbed down to a yellow powder; analysis was communicated to the writer by Mr. Ronald Starkey.

* Includes CO_2......37 per cent.

AMOSITE.

Physical Properties.—This rhombic aphibole is the latest addition to the varieties of commercial asbestos, and was discovered in 1907 in Sekukuniland; it is characteristic of a definite horizon in the north-eastern Transvaal, where it invariably lies in the banded ironstone formation. It has been stated to occur—quite exceptionally—also in the same formation within the Cape Asbestos Belt (Bibl. No. 43). In the Pietersburg Fields amosite is sometimes very intimately associated, within the same seam, with crocidolite, to which it is also very closely related chemically.

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, in case of the Lydenburg Fields, all of which is spinnable.

Smaller strands of amosite, tested by hand manipulation, show an *elasticity* and a *tensile strength* little inferior to crocidolite, while the flexibility approaches that of chrysotile. One 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 superior heat resisting quality of amosite may perhaps depend on the lower soda content as compared with crocidolite.

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.

Detailed information on the *optical properties* is given in the paper by Peacock already referred to. (Bibl. No. 58.)

In the first edition amosite was described as a monoclinic amphibole. A recent examination of a large series of occurrences taken from 17 different seams distributed over some 60 miles of strike within the Pietersburg and Lydenburg Districts from the Steelpoort River to Chuniespoort show the fibre to extinguish uniformly straight, thus confirming Peacock's determination of the orthorhombic character of amosite.

Chemical Properties.—Amosite is a rhombic ferrous silicate hornblende characterised by a high percentage of ferrous oxide and low amount of alumina, thus being intermediate between anthophyllite and gedrite. Soda is not always present, but invariably distinctly less than in the case of crocidolite. Lime is low in amount, except in the Kalkfontein fibre (analysis IX of Table No. 5). Magnesia is a constant constituent and, on the whole, more abundant than in crocidolite. According to Peacock (l.c.) amosite may be represented by the same general formula as crocidolite, viz., by the three molecules :—R_2O_3. $RO.SiO_2$; $R_2O_3.R.O.\ 4SiO_2$ and $RO.SiO_2$.

In the accompanying Table No. 5 are shown 8 analyses from Penge and Streatham, the principal economic localities, and " montasite " from the Montana Mine in the Pietersburg Fields is represented by two analyses, which clearly correspond to those of amosite. The high amount of lime in analysis IX is apparently abnormal.

TABLE No. 5.—*Composition of Amosite.*

	I.	II.	III.	IV.	V.	VI.	VII	VIII.	IX.	X.	XI.
	Penge.	Penge.	Penge.	Penge.	Penge.	Penge.	Penge.	Streatham.	Kalkfontein.	Montana Mine.	Montana Mine.
SiO_2	49·72	53·34	50·24	36·20	49·48	47·68	47·35	49·10	47·04	57·8	54·00
TiO_2	—	—	—	—	—	—	Trace	—	Trace	—	—
Al_2O_3	5·72	9·35	—	—	·68	Trace	4·20	—	7·02	·95	Trace
Fe_2O_3	—	—	7·80	12·08	8·16	4·84	3·34	—	2·43	4·15	Trace
FeO	37·00	34·35	32·00	24·27	30·09	36·00	36·60	43·86	26·10	28·1	36·70
MnO	—	—	—	—	—	—	·28	—	·15	—	—
MgO	3·77	·74	3·96	8·50	6·77	6·20	5·80	6·14	4·96	5·25	3·90
CaO	1·65	1·59	Trace	5·56	·88	Trace	·77	·46	10·84	·45	1·10
Na_2O	—	—	2·12	·15	·20	·28	Trace	—	Trace	Trace	Nil
K_2O	—	—	—	—	—	—	Trace	—	Trace	·75	Nil
Moisture	—	·62	—	—	—	—	·35	—	·45	·70	·80
Combined Water	2·29	—	—	4·70	2·74	4·50	1·25	—	1·05	2·3	3·00
Ignition	—	—	3·00	—	—	—	—	—	—	—	—
P_2O_5	—	—	—	—	—	—	·04	—	Trace	—	—
S	—	—	—	—	—	—	·05	—	·05	—	—
O_4	—	—	—	—	—	—	Nil	—	Nil	—	—
CO_2	—	—	—	8·40	·56	·21	Trace	—	·10	—	—
TOTAL	100·15	99·99	99·12	99·86	99·56	9·71	100·03	99·56	100·19	100·45	99·50
Sol. in 5% HCl	—	—	—	30·00	8·40	8·50	—	—	—	—	—
Length of Fibre	—	—	—	6·5 in.	6·5 in.	8·5 in.	—	—	—	1·00 in.	1·75 in.

I. and II.—Third-grade brownish amosite from near the surface; analysis by Hahn. III.—Best quality "white" asbestos from IV Level, B. Section, Egnep Mine; analysis by C. Gardthausen. IV. to VI. are three analyses of amosite by Messrs. Gulick, Henderson & Co., Pittsburg, Penn. VII.—Analysis by W. H. and F. Herdsman, given by Peacock (Bibl. No. 58). VIII.—Second quality amosite; analysis by Hahn. IX.—Amosite, Cape Province; analysis by W. H. and F. Herdsman, given by Peacock (L.c.). X.—Montasite from the Pietersburg Fields; analysis by H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg. XI.—Amosite, Montana Mine; analysis by S. Bilbrough & Co., Johannesburg.

The following useful comparison of the properties of the three most important varieties of asbestos is given by R. B. Ladoo, formerly Mineral Technologist to the Bureau of Mines, Washington and given in his treatise "Non-Metallic Minerals, Occurrence—Preparation—Utilization," First Edition, New York, 1925:—

Comparison of Properties of Chrysotile, Crocidolite and Amosite.

Property.	Chrysotile.	Crocidolite.	Amosite.
Fibre length (usual maximum)..	1½ to 2 inches	1½ to 3 inches	7 inches.
Tensile strength................	High.........	Higher than chrysotile	Good.
Flexibility.....................	High.........	High.........	Good.
Fineness of fibre..............	Very fine.....	Fine.........	Fine.
Resistance to heat.............	Good, but becomes brittle	Poor; fuses to a glass	Good, but becomes brittle.
Resistance to acids, alkalies and sea water	Poor.........	Good.........	Good.
Electrical-insulating value.......	Fair to good..	Good.........	—
Heat-insulating value...........	Good.........	Good for moderate heat	Good.
Spinnability....................	Excellent.....	Fair..........	Fair.

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 steampipe 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. 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.

Tremolite has also been found at many other localities within the Union, but in the form of slip fibre, associated with various types of igneous formations as country rock.

ANTHOPHYLLITE.

Deposits of this class of fibre have so far been found only in one locality, i.e., on the farm Korea in the Zoutpansberg District, associated with basic magnesian rocks (see Chapter VII). Anthophyllite is a rhombic iron magnesia bearing hornblende, and on Korea the mineral is grayish white in colour, has a low tensile strength, while the fibrous structure is distinctly less perfect than is the case in chrysotile, amosite, or crocidolite.

The chemical composition is given in Table No. 6 which indicates a member of the Anthophyllite Gedrite group—partly altered—and low in alumina, thus belonging to the anthophyllite end of this series :—

TABLE No. 6.—*Analyses of Anthophyllite.*

	Korea. I.	*N. Transvaal.* IA.	*Moravia.* II.
SiO_2	52·05	58·83	57·39
TiO_2	trace	—	—
Al_2O_3	·45	·51	2·04
Fe_2O_3	·65	·73	·42
FeO	4·30	4·85	6·53
MgO	29·50	30·73	29·08
CaO	3·85	—	·69
Na_2O	trace	—	—
K_2O	1·15	1·29	—
CO_2	5·50	—	—
Water 110° C.	·40	·45	—
Combined Water	2·40	2·77	2·56
	100·25	100·16	—

I.—*Fibrous Anthophyllite, Korea,* Zoutpansberg District. Analysis by H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg.

IA.—*Analysis I,* after absorbing all CaO into $CaCO_3$ and the balance of CO_2 into $MgCO_3$, and recalculating to 100.

II.—*Greenish White Fibrous Anthophyllite,* from Moravia. Hintze, Vol. II, p. 1185.

SUMMARY OF DISTRIBUTION.

Primarily for the purposes of convenient reference, the main facts in the distribution of the asbestos deposits are summarized in Table No. 7, which shows at a glance what varieties are found in each province, including Northern Swaziland, and how each kind of fibre is distributed

TABLE No. 7.—*Summary of Asbestos Distribution in the Union and Northern Swaziland.*

	Cape Province.	Transvaal Province.	Natal Province.	Northern Swaziland.
Chrysotile (in serpentine).	—	In the Jamestown Series, round Kaapsche Hoop [and East of Carolina: Kalkkloof, Sterkspruit, etc.]. [North of Krugersdorp.] [Zoutpansberg District (near Messina, etc.)]. [Round Kaapmuiden, Malelane, etc., in the Barberton District.] [Doornkraal in Northern Potgietersrust District.]	[Eshowe, round Krantzkop, Fort Yolland, Zululand, etc.].	On Havelocks Concession, South of Barberton.
Chrysotile (in altered dolomite)	—	[In the Dolomite of the Transvaal System, East of Carolina, Diepgezet, Rietfontein, etc.; similarly near Graskop; Kaspersnek; Dullstroom; near Chuniespoort and Eastwards.] [In altered dolomitic rocks at top of Magaliesberg–(Edendale.)]	—	—

Crocidolite (in banded ironstone)	From south of Prieska to north of Kuruman, through some 250 miles of strike. Most extensive asbestos field on record	Pietersburg District from the Malips to the Olifants River, through 45 miles of strike	—	
Amosite (in banded ironstone)	—	Pietersburg and Lydenburg District, from Chuniespoort to the Steelpoort River, through 60 miles of strike. [N.W. of Warmbaths.] [Marico District, S.S.E. of Zeerust.] [Messina.]	—	—
Tremolite (in various basic igneous rocks)	—	—	[Zululand · Klip River Location, Macebeko River Valley, etc.]	—
Anthophyllite (in basic igneous rocks)	—	[Korea, west of Waterpoort Siding, Zoutpansberg.]	—	—

over those regions. All the principal occurrences of commercial importance are listed, as well as all minor deposits, the latter being shown in brackets.

While the term " minor deposit " has been interpreted as liberally as possible, the table is not to be regarded as a complete picture of all asbestos occurrences hitherto recorded; those localities which represent nothing more than useful collecting ground for mineral enthusiasts have been excluded. It is also more than probable that additional discoveries will be made, too late to be included in this summary.

The sketch map (Plate XXXVII) at the end of the volume shows the situation of the principal fibre deposits listed.

Northern Swaziland is included on account of the recent important discoveries of chrysotile in that area, situated very close to the border of the Union; no commercial deposits of asbestos are recorded from the Orange Free State.

CHAPTER II.

DEPOSITS OF ASBESTOS IN THE CAPE PROVINCE.

(Crocidolite or Blue Asbestos).

WITHIN the limits of the Cape Province the only variety of asbestos exploited is crocidolite, commonly referred to as "Cape Blue," found in cross fibre seams interbedded in the banded ironstones of the Lower Griqua Town Series of the Transvaal System.

As explained above, the presence of this mineral was first noted by Lichtenstein, during his travels in South Africa 1803-1806, while in the Orange River Valley near Prieska. The analysis of Lichtenstein's material is given in I of Table No. 2. The name crocidolite ("Woolly stone") was proposed by Hausmann in 1831 (Bibl. No. 69A).

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, extended in recent years northwards through Daniels Kuil to Kuruman and beyond.

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 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

* 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.

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 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 Plate III) from its left to its right bank, one enters Griqualand West, made up of the Divisions of Hay, Hopetown, Herbert, Kimberley, and Barkly West. 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 2,000 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* (4,264 feet above sea-level), north-west of Kuruman; *Gamohaan* (5,277 feet above sea-level), west of Kuruman; *Chee* (5,800 feet above sea-level), south of Kuruman; *Gakarusa* (6,070 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 average nine miles; 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 asbestos workings have arisen in this part of the fibre belt; the most important of these belong to the Dominion Blue Asbestos Mines (Pty.), Ltd., a subsidiary company of Turner & Newall, Ltd.

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. These figures show 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 considerable amount of evidence, these gradual changes in facies from the Cape to the Transvaal types of the Series are important in connection with the distribution of crocidolite or amosite in the two Provinces (see Chapter IX).

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.

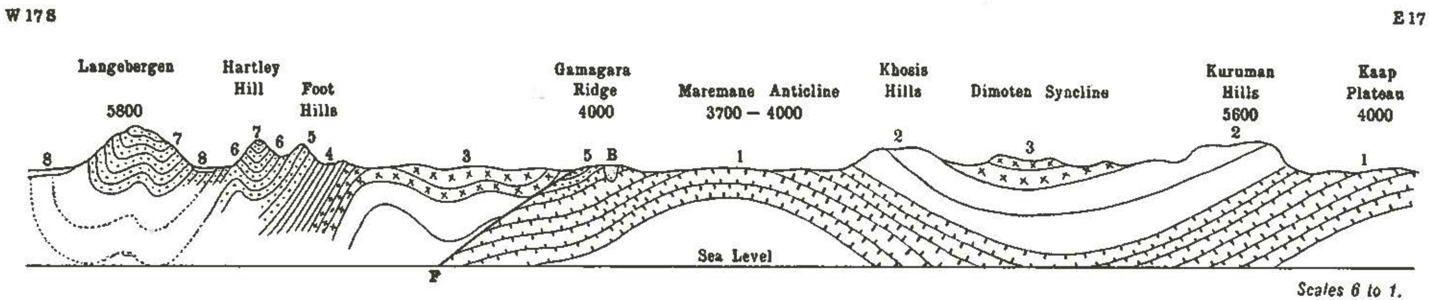
The *Lower Griqua Town Series* forms a great succession of more thinly bedded ferruginous rocks, and it is in them that the crocidolite occurs as interbedded cross fibre veins. A little north of Griqua Town, where the beds are less disturbed than elsewhere, the thickness amounts to 2,500 feet.

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 5,000 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 the 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.

Section from the Kaap Plateau to the Langebergen, Kuruman District, Northern Cape Province. Distance 66 miles.



1. Campbell Rand Series.
2. Lower Griqua Town Beds.
3. Middle Griqua Town or Ongeluk Beds.
4. Upper Griqua Town Beds.
5. Lower Matsap Beds.
6. Middle Matsap Beds.
7. Upper Matsap Beds.
8. Surface sand, etc.

B. Blink Klip Breccia.
F. Paling Fault.

(After A. W. Rogers.)

Fig. 1.

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 grop (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 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 cynclines 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 obtaind from the Annual Reports of the Geological Commission of Cape Colony (Bibl. No. 64, pp. 180-188).

Many examples of more or less pronounced minor folding (as distinct from the regional folds illustrated in Figure 1) occur more or less throughout the entire asbestos belt, but are on the whole rather more pronounced in the southern (Prieska-Koegas) than in the northern (Daniels Kuil–Kuruman) section, and it is the exception to find a uniform dip over workings of any extent. Such types of minor folding as are illustrated on Plate IX are widespread and very common, not only here, but also in the banded ironstone formation of the Pietersburg asbestos fields (Plates XXIV, XXV, and XXVII), thus emphasizing the very close similarity in the geology exhibited by this series in the widely separated Cape crocidolite and Transvaal amosite belts.

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 a few places the basal beds of the Lower Griqua Town Series (quite close above the underlying dolomite) are locally very much disturbed by minor folds or sharp contortions, and much broken up. These features were first described by Stow (Bibl. No. 68, p. 655) and more recently in the reports of the Cape Geological Commission (Bibl. No. 64, p. 166; No. 66, pp. 35-37); they are intimately related to a peculiar formation known as *Blink Klip Breccia,* which owes its name to a markedly brecciated character, associated with abundant clusters or small pockets and scattered flakes consisting of lustrous spangles of specularite (micaceous hematite); the most striking outcrop is Blink Klip Kop, some 3 miles north-east of Postmasburg, which attracted the attention of Burchell as far back as 1822 (Bibl. No. 8) and is also referred to by Stow. The breccia consists of thoroughly angular fragments of banded ironstones, chert, etc. identical with the material making up much of the Lower Griqua Town Series, and set in a matrix of silica or hematite. The rock is richer in iron ore than the normal ironstone of the country, and is often almost wholly composed of hematite, while preserving the banding and outlines of the original fragments. The Campbell Rand limestone surrounding the Kop lies undisturbed almost up to its contact with the more or less highly folded and broken breccia. On its north-eastern side the feature presents a large irregular cave due to natives searching for specularite; its floor lies some 80 feet below the level of the surrounding limestone.

The same highly ferruginous breccia has also been recorded from Ramaje's Kop on Mount Carmel, north of Daniels Kuil, where some small outliers of the Lower Griqua Town Series cap several low but conspicuous hillocks east of the Asbestos Mountains, also from Blockhouse Hill at Daniels Kuil.

The section on the east side of Blockhouse Hill has been described (Rogers *l.c.*) as showing the dolomitic limestones dipping gently toward the west, and overlain by a thin band of highly disturbed 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.

Stow (Bibl. No. 68) regarded the breccia as of detrital origin, and Passarge (Bibl. No. 57) explained it as cemented surface debris, but Rogers has clearly shown (Bibl. No. 64, p. 178) that the formation is due to the collapse of the basal beds of the Lower Griqua Town Series into hollows or fissures resulting from the solution of the underlying dolomite. This explanation is borne out by the general impression left on examining similar appearances in some of the asbestos workings on the eastern edge of the main range of the Asbestos Mountains (e.g. Warrendale, south of Daniels Kuil).

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.

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 its 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.

Many shades of *colour* are met with, but pale yellow, brownish black, bluish and red predominate, largely depending upon the state of oxidation and hydration of the abundant iron ores present. In several places, e.g. round Koegas or on Hurley north of Daniels Kuil, the country rock of the crocidolite seams shows vivid electric blue layers (" *Hurley Blue* ") some of which correspond to the so-called " potential " crocidolite, described below. Only one or other of these colour types is generally seen in a given outcrop, and a mixture of bands with strong colour contrast, such as the assocation 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.

Mineralogically, the banded ironstones consist essentially of *quartz* and iron ores, with locally crocidolite in the varieties described below. Quartz is the most abundant constituent, in very small original grains, or concentrated along interbedded cherty bands, formed of a clear more or less evenly fine grained mosaic, which may represent crystallization of the more siliceous bands under " mild metamorphic conditions " (Peacock, *l.c.*, p. 247). The fibrous form of quartz is characteristic of " tiger-eye " (see below). The *iron ores* are represented by *hematite* or hydrated hematite (with its various alteration products, and *magnetite;* almost invariably the ferric iron constituent is without crystal outlines, but in the peculiar forms referred to below as " cone structures " one sometimes finds cone-like masses of fibrous iron ore penetrating into a seam of crocidolite. Magnetite is sometimes found in small octahedra scattered through the layers of banded ironstone (or chert) as in the cherty layers on Tolo, 37 miles due north of Prieska, but far more frequently it is concentrated along certain layers arranged with the bedding planes, often as a thin veneer of an asbestos seam along its contact with the country rock; it is also found disseminated through an asbestos layer (the latter habitat is fairly common in the crocidolite from the Pietersburg Fields). Where magnetite predominates, dark colours prevail, but where the iron ores are more thoroughly oxidised (hydrated) into limonite, or where hematite is present, brown, yellow and red colours are found. It is probable that the magnetite—which does not show the characters of original detrital material, originated through recrystallization from ferric oxide. *Carbonate of iron* has also been recorded locally.

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.

In many asbestos workings *nontronite* has been observed in thin films of dirty greenish yellow material coating bedding and joint planes of the banded ironstone series. Such films rarely exceed ⅛ of an inch in thickness, and have a general appearance not unlike green shale, with an unctuous feel. Nontronite is clearly a decomposition product, being a hydrated silicate of iron with the composition Fe_2O_3, $3SiO_2$, $5H_2O$, characteristic of the zone of weathering, so that it is more commonly found in the altered brownish siliceous banded ironstone than in the little altered bluish shaly facies of that formation. In the Lydenburg Asbestos Fields it is also found (Chapter V); it is most abundant in the Pietersburg Fields (e.g. in the workings of Chunies Asbestos, Ltd., or in those of the Northern Asbestos Company, etc.). In the last-named Fields, its close association with amosite seams and its characteristic appearance have led the native mind to the designation " Asbestos Dung."

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 microcrytsalline 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 [illegible] 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 rhomb-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.

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, shales, limestone, chert,* etc., 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 crytsalline limestone; one of the shaly bands measures as much as 100 feet in thickness. Softer fine-grained sandstones also occur in the Krantz-fontein 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, Klooffontein, 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

* Bibl. Nos. 64 and 66.

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.

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 IX. 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.

According to Peacock (*l.c.*) the *banded ironstones were formed* as " chemical precipitates deposited in an extensive marine basin "; this conclusion is based on their " typical non-detrital character and unique simple chemical composition." According to the same author, the mode of origin of the Lake Superior ironstones of North America is " not directly applicable to the South African problem."

In connection with the view put forward in the first edition, and also adopted by Peacock, that the fibrous hornblende in the banded ironstones originated more or less wholly from the material contained in these sediments, their *chemical composition* is of exceptional interest. The following new analyses are given in Peacock's paper, and shown in the accompanying Table No. 8; at the bottom of this table the composition is given in terms of constituent minerals. A comparison of Table No. 8 with the composition of crocidolite shown in Tables No. 2 and No. 3 reveals some important features bearing on the genesis of the fibre (see Chapter IX).

TABLE No. 8.—*Composition of Banded Ironstone. Cape Province.*

	I.	II.
SiO_2	45·50	43·85
TiO_2	trace	trace
Al_2O_3	1·52	1·44
Fe_2O_3	44·16	47·88
FeO	4·63	trace
MnO	·57	·00
MgO	·42	·35
CaO	trace	trace
Na_2O	trace	trace
K_2O	trace	trace
H_2O +	2·30	5·55
H_2O −	·60	·35
P_2O_5	·05	·06
SO_4	0·00	0·00
CO_2	·12	·35
S	0·00	0·00
TOTAL	99·87	99·83
Quartz (SiO_2)	45·50	43·85
Hydrated Alumina (Al_2O_3. H_2O)	1·80	1·67
Ferric Hydrate ($Fe_2.O_3$ H_2O)	20·11	52·33
Hematite (Fe_2O_3)	13·60	·80
Magnetite (FeO. Fe_2O_3)	17·90	0·00
Magnesite (MgO. CO_2)	·24	0·67
Magnesium Phosphate (MgO. P_2O_5)	·09	0·10

I.—Banded Ironstone, from Prieska Kopje. (Fine-grained, barren, magnetite quartzite.) Analysis by W. H. and F. Herdsman.

II.—Ironstone from Kliphuis (Cryptocrystalline ferruginous chert adjacent to Crocidolite Seam.) Analysis by W. H. and F. Herdsman.

VARIETIES OF CROCIDOLITE.

All the asbestos occurrences within the Cape fibre belt lie in the banded ironstones,* both in the yellow jaspery types and in the banded darker coloured or bluish, sometimes magnetic ironstones, though on Prieska Commonage the mineral has also been observed in a ferruginous limestone. All the asbestos that is being exploited in this area is crocidolite, which appears to be the only variety of fibre known from these sediments.

Deposits of amosite in the Cape fibre belt have not come under the writer's direct observation, but according to information obtained from Mr. E. G. Bryant, this type of asbestos occurs on Middelwater, Klipfontein, and Naauwte. In a recent paper by Kirkman (Bibl. No. 43) reference is also made to fibre resembling amosite in the Cape crocidolite belt.

* The term *Garingklip* is locally applied to banded ironstone carrying asbestos.

The different forms in which crocidolite is found are conveniently classed as follows, approximately in their approximate order of abundance :—

(1) *Crocidolite Proper.*—This is the commonest kind and is made up of densely packed lavender blue fibres, usually very regularly oriented, and giving rise to interbedded cross fibre seams; this is the so-called " Cape Blue " of the trade.* It has the 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) *Tiger-eye 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 Wonderwerk, Hurley, etc., 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 (e.g. round Koegas), or among the gravelly surfaces elsewhere, belong to this same variety of potential crocidolite, and was probably the form in which the

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* The term *Spykerdraad* is locally applied to good quality blue asbestos, which can be broken up into springy fibre bundles, and fiberised into finely fibrous material.

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.

A series of thin sections of potential crocidolite (specially prepared for this edition) show no essential difference in microscopic characters between the heavy dark bluish lumps found, e.g. in the detritus of the dry water courses round Koegas and the very hard vivid blue type of ferruginous slate so common in some of the asbestos mines (Westerberg, Hurley, south of Kuruman, etc.); these rocks are thoroughly compact, heavy, and very hard, so that their thin sections in some cases remain almost opaque, while others are seen to be composed almost wholly of very minute strongly pleochroic vivid blue short needles of crocidolite, arranged without any orientation in mass fibre form; where a groundmass can be resolved, it appears to be chert.

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 sediments.

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 and Pietersburg Districts, where a greater variety of connecting links are found. The fact that one is there dealing with amosite as well as crocidolite does not imply any essential difference, since the country rocks in both areas are so nearly identical, while both fibre varieties are amphibole very closely similar in chemical composition.

It is very interesting to note that as long ago as 1907 the writer found potential crocidolite in the Pietersburg District (between Tubex and the Malips River) indistinguishable from that of the Cape Belt.

The terms "*incipient*" and *mass fibre crocidolite*" are practically identical with the meaning of "*potential crocidolite.*"

(5) *Needle-Crocidolite.*—This is a convenient term to denote the mode of occurrence of crocidolite in conspicuous needle-shaped crystals; on the whole this variety is rare. It occurs e.g. on Enkelde Wilgeboom near Prieska, and in a few other localities within the Cape fibre belt, but is fairly common in the Pietersburg Asbestos, Ltd., crocidolite workings east of the Malips River. In the variety here designated "needle-crocidolite," the mineral forms straight fine elongated very dark blue to almost black needles up to the length and thickness of

an ordinary pin, but usually shorter and thinner. These occur either plentifully disposed at random through the banded ironstone, or, as commonly the case in the Transvaal locality referred to, they are restricted to a narrow layer in the ironstone, within which the needles may lie at all azimuths, or may show a certain degree of orientation. In its relatively coarse habit and ready visibility to the naked eye, " needle crocidolite " is thus in strong contrast to the habits described as " potential crocidolite " and " Crocidolite proper."

Needle crocidolite was first described from localities situated some seven miles below stream from Prieska on the north side of the Orange; here, over Wilgeboom Dam and Enkelde Wilgeboom, typical blue crocidolite proper is abundant, but there are also rocks full of almost black or very deep blue long slender needles, but without the fibrous habit of true crocidolite, nor occurring as interbedded cross fibre seams. These are the varieties referred to in the Thirteenth Annual Report of the Geological Commission of Cape Colony (Bibl. No. 67, p. 86), 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 1/5 inch long, arranged without orientation; in another there is a tendency to orientation along a common direction inclined about thirty degrees 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 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 resmblance to crocidolite proper is seen in general habit and intense pleochroism, but the extinction only amounts to a few degrees.

In Tables No. 2, 3, and 4 will be found analyses of all the above varieties.

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

* The term *Vaalgaring* is sometimes used when referring to a very pale lavender coloured variety of crocidolite.

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 fibre* becomes harsh to the touch, but, in spite of its 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 lower 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 appears to express stages in the genesis of asbestiform minerals from ferruginous sediments arising from conditions operating at a time anterior to the present physiography.

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 fibre occurs in many and scattered outcrops found over a very large number of farms. In the northerly section of the belt crocidolite has been found both in the easterly branch defined by the Kuruman Hills and in the westerly limb of the Dimoten syncline in the Khatu Khosis Hills.

Only a certain proportion of these occurrences have led to economic developments; the earliest workings belong to the southern section, where some of the older mines nearer the Orange River have been active since about 1893. Since that date, the number of asbestos mines has steadily increased and activity gradually extended northwards into the Daniels Kuil–Kuruman Section and even beyond Kuruman.

List of Crocidolite Localities.

Cape Province.

The following list of crocidolite-bearing localities has been compiled from all available sources of information; it is mainly intended to show the wide distribution of the fibre over many points, and does not claim to be exhaustive, neither does the inclusion of a particular name in this list necessarily imply that asbestos is found at that locality under economic conditions:—

Name.	*District.*	*Remarks.*
Amyshope	Kuruman	Near Tsenin, 50 miles N.W. of Kuruman.
Bestwell	Kuruman	30 miles S.W. of Kuruman.
Billinghurst	Kuruman	19 miles N.W. of Daniels Kuil.
Blaauwboschkuil O. 380	Hay	15 miles N.E. of Niekerkshope.
Blaauwboschpoort O. 349	Hay	9 miles S.S.W. of Niekerkshope.
Blaauwhoogte	Prieska	Same as Kliphuis.
Blaauwputs O. 340	Hay	15 miles N. of Prieska.
Botallick	Vryburg	135 miles W. of Mafeking.
Bradfield A. 31	Hay	22 miles N. E. of Postmasburg or 10 miles S.W. of Daniels Kuil.
Brakpoort Annexe	Prieska	6 miles N. of Prieska.
Blackridge	Hay	See Breckenridge.

Name.	*District.*	*Remarks.*
Breckenridge O. 192....	Hay...........	36 miles (direct) N.N.E. of Koegas.
Brettby................	Kuruman......	24 miles N.N.W. of Daniels Kuil.
Buisvley...............	Prieska........	11 miles N.W. of Prieska.
Bultfontein O. 327......	Hay...........	8 miles S.E. of Koegas.
Burgersdale O. 356.....	Hay...........	8 miles S. of Niekerkshope.
Carrington.............	Kuruma.......	8 miles S.W. of Kuruman.
Carn Brea.............	Prieska........	See Keikamspoort.
Clifton.................	Vryburg.......	88 miles N. of Kuruman.
Crawley................	Kuruman......	22 miles N.W. of Daniels Kuil.
Cubbie.................	Kuruman......	18 miles S. of Kuruman.
Crown Hill.............	—	20 miles N. of Daniels Kuil.
Deal..................	Vryburg.......	115 miles N. of Kuruman.
Doornfontein A. 64.....	Barkly West...	22 miles N.N.E. of Postmasburg.
England...............	Kuruman......	23 miles N.W. of Kuruman.
Enkelde Wilgeboom.....	Prieska........	10 miles N. of Prieska; 18 miles S.S.W. of Niekerkshope.
Elandsfontein O. 395...	Hay...........	16 miles S.S.W. of Griqua Town.
Eldoret................	Kuruman......	25 miles N.W. of Kuruman.
Fairholt...............	Kuruman......	7 miles W. of Kuruman.
Fair View.............	Kuruman......	22 miles N. of Daniels Kuil.
Farm A. 111...........	Barkly West...	23 miles N. of Daniels Kuil.
Fonteintje.............	Prieska........	12 miles N. of Prieska.
Gamohaan.............	Kuruman......	9 miles N.N.W. of Kuruman.
Gamopedi..............	Kuruman......	Gamopedi Native Reserve, 25 miles N. of Kuruman.
Geelbeksdam...........	Prieska........	32 miles N.W. of Prieska.
Gathlose Native Reserve	—	See Khosis.
Glen Allen.............	Prieska........	9 miles W. of Prieska.
Groenwater............	Hay...........	12 miles N.E. of Postmasburg, Groenwater Native Reserve.
Grootboom.............	Hay..........	9 miles S.S.W. of Griqua Town.
Groot Naauwte O. 339..	Hay...........	15 miles S.W. of Niekerkshope.
Halifax................	Vryburg.......	110 miles N. of Kuruman.
Happy Valley..........	Kuruman......	23 miles S. of Kuruman.
Heuningvley Native Reserve	Vryburg.......	100 miles N. of Kuruman.
Hopefield M. 114.......	Hay...........	16 miles N. of Griqua Town.
Hounslow O. 323.......	Hay...........	2 miles N.W. of Koegas.
Hove..................	Vryburg.......	110 miles N. of Kuruman.
Hurley.................	Kuruman......	20 miles N.N.W. of Daniels Kuil.
Kaffirskrantz O. 379....	Hay...........	8 miles N.E. of Niekerkshope.
Kalkfontein............	Prieska........	14 miles N.W. of Prieska.
Kalkgat................	Prieska........	20 miles N.W. of Prieska.
Kameelfontein O. 338...	Hay...........	13 miles S.W. of Niekerkshope.
Kameelpoort O. 368....	Hay...........	4 miles S.E. of Niekerkshope.
Keikamspoort..........	Prieska........	15 miles S.E. of Prieska.
Khosis.................	Kuruman......	28 miles N.W. of Daniels Kuil.
Klein Kaffirkrantz O. 379	Hay...........	See Kaffirskrantz.
Klein Naauwte O. 346..	Hay...........	15 miles S.W. of Niekerkshope.
Kliphuis O. 359........	Prieska........	6 miles N. of Prieska.
Klipfontein O. 381......	Hay...........	12 miles N.E. of Niekerkshope.
Klipnek................	Hay..........	12 miles N.E. of Niekerkshope.
Klipvley...............	Barkly West...	52 miles S. of Kuruman.

Name.	*District.*	*Remarks.*
Koegas O. 324	Hay	30 miles W. of Niekerkshope.
Kramersfontein	Barkly West	50 miles S. of Kuruman.
Krantzfontein O. 358	Prieska	9 miles N. of Prieska.
Krantzhoek O. 396	Hay	14 miles S.W. of Griqua Town.
Kwakwas O. 318	Hay	5 miles N.E. of Koegas.
Lambley	Kuruman	6 miles W. of Kuruman.
Langley	Kuruman	11 miles S.W. of Kuruman.
Langsrust	—	—
Leelykstaat O. 320	Hay	9 miles N.W. of Koegas.
Leguko	Kuruman	30 miles S.W. of Kuruman.
Lovedale	Prieska	18 miles S.E. of Prieska.
Maipin	Kuruman	40 miles from Kuruman.
Mansfield	Kuruman	18 miles S. of Kuruman.
Mauratanche	Kuruman	25 miles from Kuruman.
McCarthy	Kuruman	50 miles S.W. of Kuruman.
Middelwater	Prieska	20 miles N.W. of Prieska.
Mount Vera	Kuruman	20 miles N.W. of Kuruman.
Naauwpoort O. 144	Hay	10 miles N.E. of Niekerkshope.
Nauga	Prieska	22 miles N.W. of Prieska.
Nauga East	Prieska	26 miles N.W. of Prieska.
Newcastle	Kuruman	18 miles S. of Kuruman.
Orcadia	Kuruman	Gamopedi Native Reserve; 40 miles N. of Kuruman.
Oudeplaats	Barkly West	4 miles S.W. of Daniels Kuil.
Owendale A. 32	Hay	9 miles S.W. of Daniels Kuil.
Penwith O. 211	Hay	37 miles N.W. of Griqua Town; 31 miles S.W. of Postmasburg.
Perth	Vryburg	80 miles N. of Kuruman.
Pomfret	Vryburg	130 miles N.W. of Vryburg.
Prieska Town Lands	Prieska	—
Pypwater O. 321	Hay	5 miles N.W. of Koegas.
Redlands	Prieska	Redlands Siding; 18 miles S.E. of Prieska.
Rietfontein = Westerberg. Old name of original farm	Prieska	32 miles N.W. of Prieska.
Riverside	Prieska	About 5 miles W. of Prieska.
Riries	Kuruman	18 miles N.W. of Kuruman.
Rooidam	Prieska	7 miles S.S.E. of Prieska.
Rooisand O. 345	Hay	10 miles S.S.W. of Niekerkshope.
Sardinia	Kuruman	25 miles from Kuruman.
Schaapnek	Prieska	6 miles N. of Prieska (part of Kliphuis).
Skietfontein A. 106	Barkly West	10 miles N.W. of Daniels Kuil.
Spion Kop	Hay	30 miles S.S.W. or Griqua Town.
Stilverlaats O. 314?	Hay	12 miles N.N.W. of Koegas.
Stofbakkies	Prieska	3 miles from Prieska.
Stoffelsrust	Prieska	14 miles S.E. of Prieska.
The Kloof	Hay	7 miles N.E. of Niekerkshope.
The Willows	Prieska	25 miles from Prieska (part of Nauga).
Vaalkop O. 345	Hay	12 miles S.S.W. of Niekerkshope.
Warrendale A. 31?	Hay	10 miles S.S.W. of Daniels Kuil.
Wəsterberg	Prieska	32 miles N.W. of Prieska.
Wilgebooms Dam O. 348	Prieska	12 miles N. of Prieska.

Name.	*District.*	*Remarks.*
Wonderwerk............	Kuruman......	21 miles N. of Daniels Kuil.
Woodstock.............	Kuruman......	12 miles S. of Kuruman.
Zaragabie..............	Prieska........	About 4 miles W. of Prieska.
Zeekoeneus.............	Hay...........	10 miles S. of Niekerkshope.

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 the majority of the Cape Asbestos Company's workings, as well as many 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 from Griqua Town in the south, to Tsenin, some thirty miles north of Kuruman, and further north. 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.

It is interesting to note—as possibly having some genetic significance—that a large proportion of fibre localities, in both sections, lie not far above the top of the underlying dolomite, e.g. close to the eastern edge of the Asbestos Mountains (see Chapter IX).

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

In this section, which includes the oldest productive mines, crocidolite occurs at a very 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 on the north side of the Orange River, i.e. in Griqualand West (Hay Division).

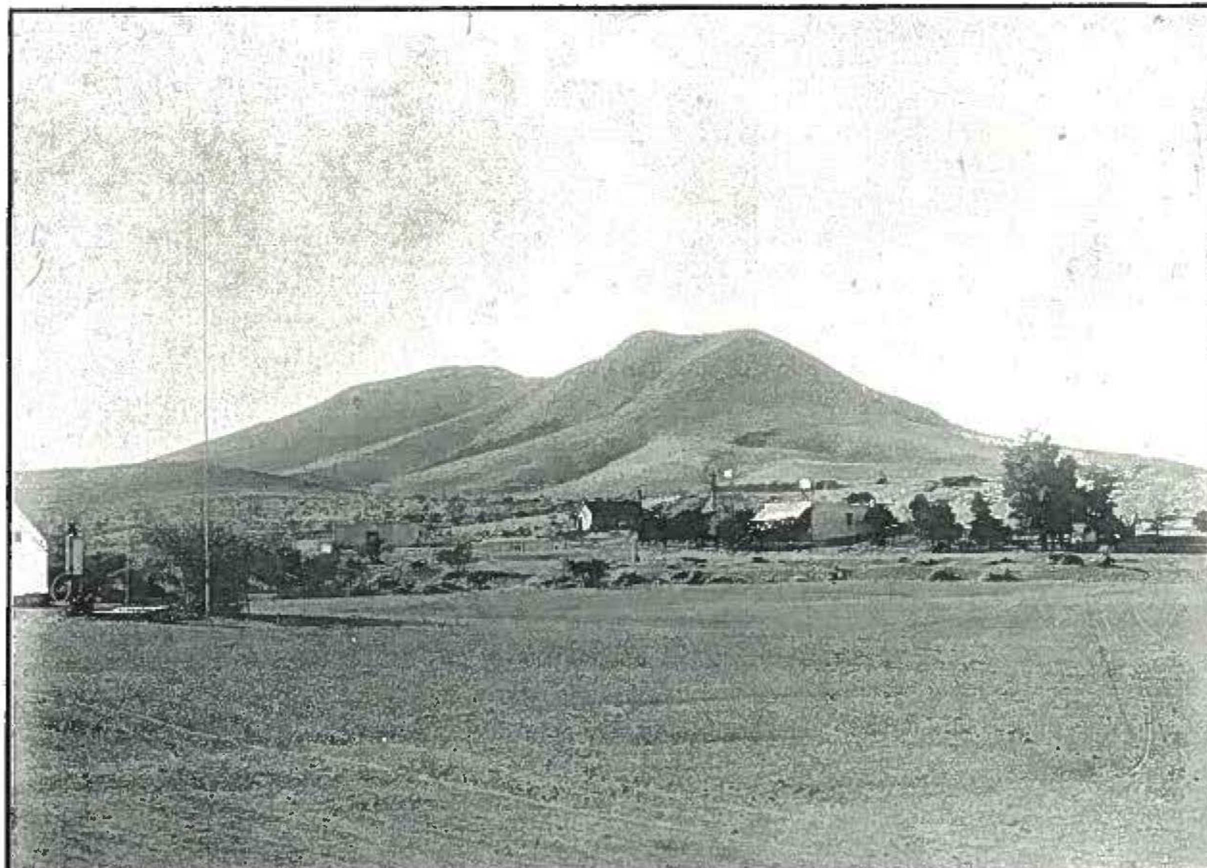


PLATE II.—*General View of Koegas,* the headquarters of the Cape Asbestos Co., showing typical smooth hills due to banded ironstones of the Lower Griquatown Series.

Producing Concerns.—It is very highly characteristic of the whole of the Cape fibre belt, that the asbestos deposits are not more or less concentrated at a few localities, and there available in large amounts, but scattered over many miles of strike, so as to occur on many farms, and on each one in moderate quantities only. This feature has tended to lead to fibre recovery at many points (though on a rather modest scale). Soon after the Cape Asbestos Company—who are the pioneers in tapping the Cape asbestos deposits—began operations about 1893 in the Koegas neighbourhood, the search for, and recovery of, crocidolite was carried gradually northwards, at many localities, the owner finding it in many cases a useful side line to produce a little fibre. In this way arose quite a number of minor producers. The eventual successful conclusion of the long uphill fight to gain for crocidolite a permanent footing in the world's asbestos markets stimulated further developments which extended the productive field still further north, right to beyond Kuruman.

The natural result of this form of mining activity—carried on at numerous widely scattered points, in the majority of cases by small producers, working their own particular methods—became apparent in a certain lack of co-ordination in grading schemes, inadequate market preparation, etc. During recent years there has been a notable improvement in this respect, brought about to some extent by a better appreciation of the importance of uniform quality, and also by a tendency for the important concerns to bring additional and promising propositions under their own control. To-day the successful establishment of the larger companies is of great value to the smaller producers in enabling them to dispose of their output, which has to satisfy requirements definitely laid down, at convenient local centres.

The conditions outlined above make it very difficult to give a list of " producers " that is complete and holds good for any length of time, specially when some of the asbestos exploitation is carried on only at intervals. Appendix 2 (at the end) shows the producers as given in the Annual Report of the Government Mining Engineer for 1929.

During that year the greatest production of crocidolite in the Southern Section was that of the *Cape Asbestos Company,* carried on at several localities with Koegas as its headquarters. Among other concerns may be mentioned the *Nauga Asbestos Co.* (Prieska District) and the *Griqualand Exploration and Finance Company* (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.

There is a good deal of similarity in the mode of occurrence right through the fibre belt and the general experience obtained from a few typical localiites holds good in most of the essential respects for the whole fibre belt. More often than not, several seams are found in a working face; they are interbedded with the banded ironstones and are parallel to one another. The seams are comparable to thin lenses, the length and width of which are many times their thickness. Their intersections with the walls of a drive thus appear as long narrow bands agreeing with the strike, and disposed in conformity with the dip, of the country rock. Very commonly a given seam will gradually die out, sometimes in a few feet, but in other cases it may persist for many yards before petering out, when, as a rule, a second seam will arise at another point in the section, and so carry on the fibre continuity.

The *methods of development* are, specially in the hands of the smaller producers, those of simple open cast workings, i.e., comparatively shallow pits, but not infrequently these are supplemented by drives and cross-cuts, or may be extended at other levels, until the whole lay-out can be fairly described as " underground workings."

The deposits are opened up in a more thorough manner on some of the *localities worked by the Cape Asbestos Company*, whose present production comes from the following farms:—Westerberg, Koegas, Klein Naauwte, Buisvley, Glen Allen, Klipfontein, Nauga East, Kameelpoort, Hounslow, Kliphuis, Keikamspoort (or Carn Brea), and Blackridge—all in the southern section. The same company also produces from the farms Botallack and Pomfret in the Vryburg District north of Kuruman.

The most thoroughly opened up and also the oldest mine is Westerberg, which together with Koegas and Nauga East produced 498 long tons of fibre during 1929. In this total the contributions from Koegas and Nauga East are small, Westerberg being a steady producer of between 30 and 40 long tons per month. (See Table No. 16 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.

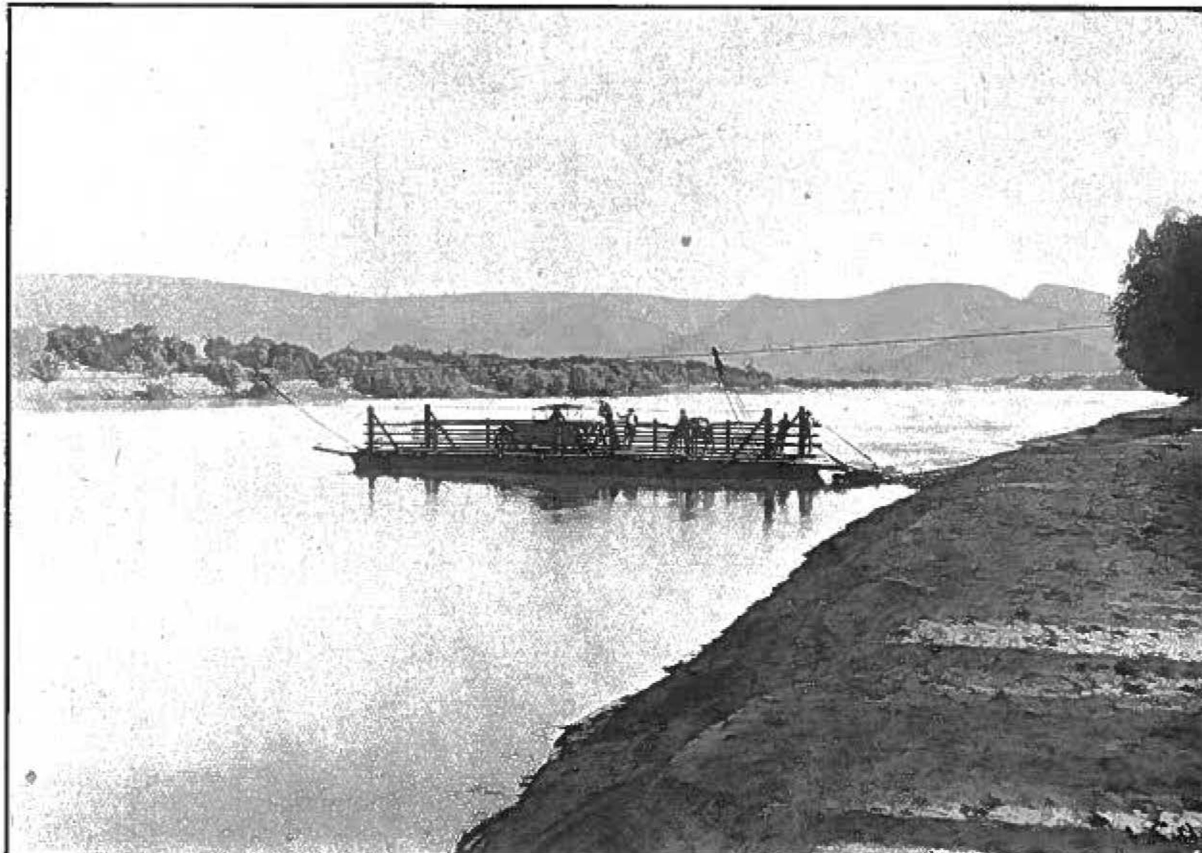


PLATE III.—*Looking down the Orange River near Koegas;* in the background the crocidolite carrying hills of the Lower Griquatown Series, in Griqualand West.

The mine was opened up first by surface trenchings (see Plate IV), 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 10 adits now exist in the mine, varying in length up to 2,000 feet; they run with the strike of the country formation and are really drives along the " reefs."

Diagrammatic Section across the Westerberg Valley.

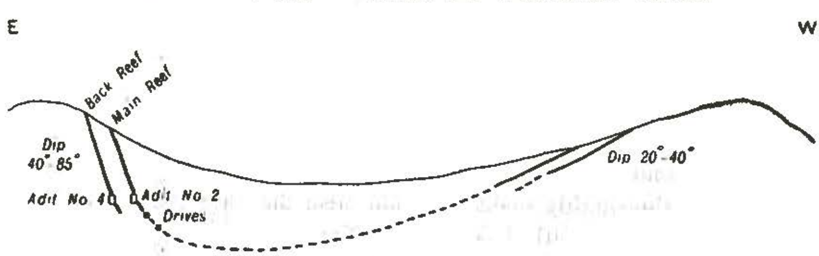


Fig. 2.

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 " is applied to the lower set of seams, situated more to the east and exposed along No. 4 adit. About 60 feet of country rock (measured along the true thickness) separates this set from the upper or *Main Reef*, which lies more to the west and is seen along No. 2 adit—over this part of the mine (see Fig. 2 and Plate IV). 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. From the latter 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 for a distance of approximately 420 feet measured from the original outcrop in the direction of the dip.

Development further down in this direction has ceased, because fibre was not found to persist under economic conditions below a certain depth. (See Chapter IX.)

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

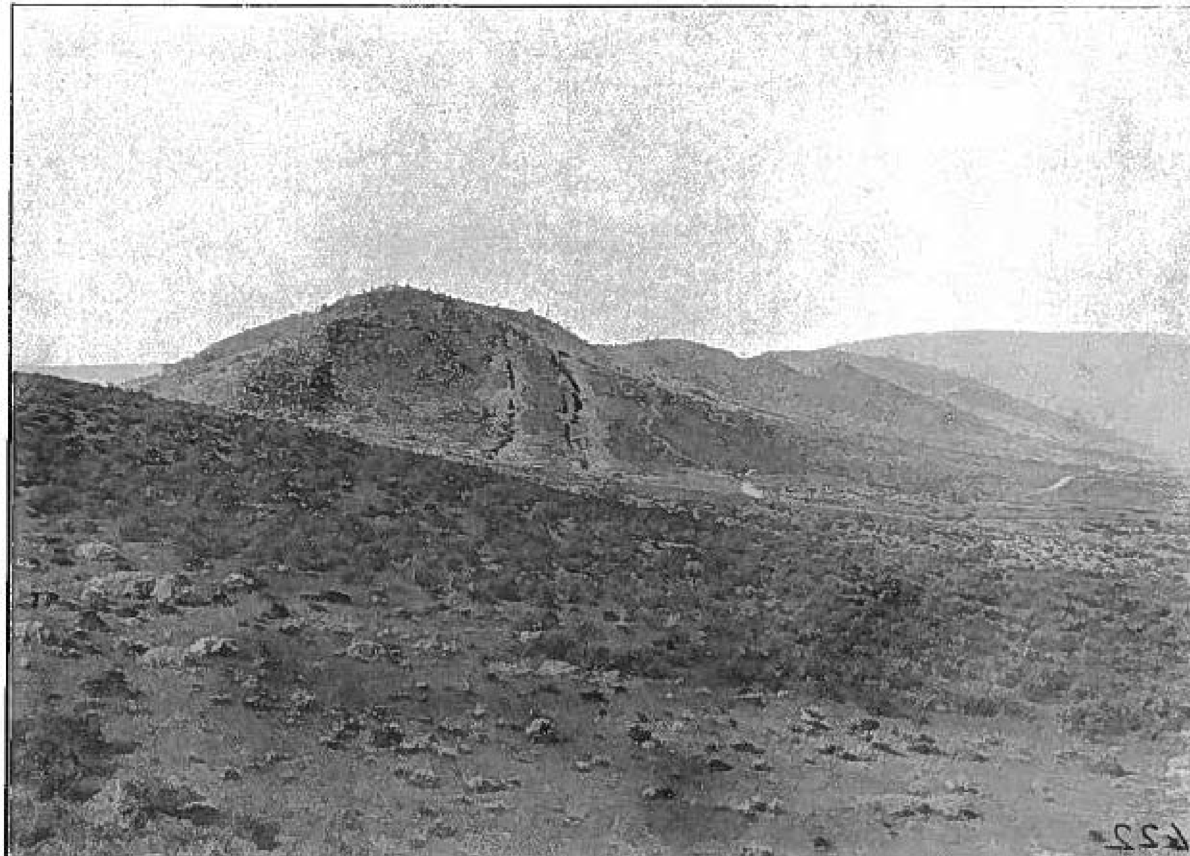


PLATE IV.—*General View along the Eastern Flank of the Westerberg Valley*, showing the main groups of crocidolite workings—the Main "Reef" (more towards the right) and the Back "Reef" (more towards the left).

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 V.

On the western side of the valley water level was 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 has been struck. Under these conditions the country formation becomes softer and more clayey, but no marked deterioration in fibre quality was noticed, beyond slight discolouration.

In other parts of the workings, however, one can observe that the country rock close to the fibre seams is sometimes distinctly softer in the deeper levels than it is at the surface. This is also the case sometimes in the lower workings of the Penge amosite deposits in the Lydenburg District.

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, and at one time worked by the Cape Asbestos Company, the banded ironstones dip for 45 to to 65 degrees, but 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 to a large extent of hard yellowish jaspery rocks, and little of the bluish softer types is found. The workings of the Cape Asbestos Company are near the common boundary of Stilverlaats and Leelykstaat near a short nek, whence the main level extended for some 200 feet into the slope at right angles to the strike. A little way in, a drive branched off laterally along the strike, but led back to the main level, owing to the folding. Further development was by means of several inclined shafts on the dip, so as to allow the fibre rock to be exploited in regular blocks, 60 feet long in the direction of strike. In this way seam continuity was proved over a distance of over 120 feet on the dip.

Though the production was much smaller compared with Westerberg, there was a much higher proportion in the neighbourhood of an inch in length.

The farm *Leelykstaat,* adjoining Stilverlaats, was also formerly worked by the Cape Asbestos Company; during 1928 production was carried on by the Leelykstaat Asbestos Syndicate. Here the formation is inclined from 40 to 90 degrees and also exhibits sharp local folds. Along the main level, which under the earlier regime extended for some 200 feet into the hill, the Lower Griqua Town Series showed a much smaller proportion of a 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 tiger-eye—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.

Among other occurrences worked by the Cape Asbestos Company may be mentioned the deposits on *Buisvley* and *Klein Naauwte* (lying some 15 miles north-west of Prieska, the former on the left and the latter on the right bank of the Orange River), *Kliphuis* (some six miles north of Prieska close to the right bank of the same river), *Keikams Poort* (south of Prieska) and *Blackridge* (about 50 miles north of Koegas).

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 contast to the Westerberg, while closely resembling the Stilverlaats and Keikams Poort variety of country rock. The development includes 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. One fibre horizon is composed of from two to five seams, of which only one is generally payable.

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.

Some 20 miles south of Prieska, in the Doornbergen, crocidolite has been recovered for a good many years on *Keikamspoort,* also known as Carn Brea, since this locality belonged to the Carn Brea Syndicate, before it came under the control of the Cape Asbestos Company. 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 several hundred feet long 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.

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 sharply round to the east and north-east, so as to cause curved dip slopes in places (see Fig. 3). The development includes a series of adits, through which the fibre horizon persists for several hundred feet on a dip of about 45 degrees. 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, though, as a rule, only a small number are payable; they are found in the common type of interbedded cross fibre seams of blue crocidolite.

On Keikamspoort conditions exist, similar to those on Westerberg, showing that crocidolite does not persist under economic conditions indefinitely in depth. (See Chapter IX.)

The asbestos occurrences on Breckenridge ("*Blackridge*") illustrate that fact, that now and then crocidolite is found well away from dolomite outcrops: such a situation is much less common, compared with the distinctly more numerous cases, where the fibre horizon is only a little above the top of the underlying dolomite. (See Chapter IX.) The workings have been in existence for some years and though the locality is referred to as "Blackridge," it is actually not on the farm bearing that name, but on the one adjoining it on the east, called Breckenridge, about 50 miles by road east-north-east of Koegas. Development has now reached a depth of 320 feet on an average dip of 45 degrees: in places

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

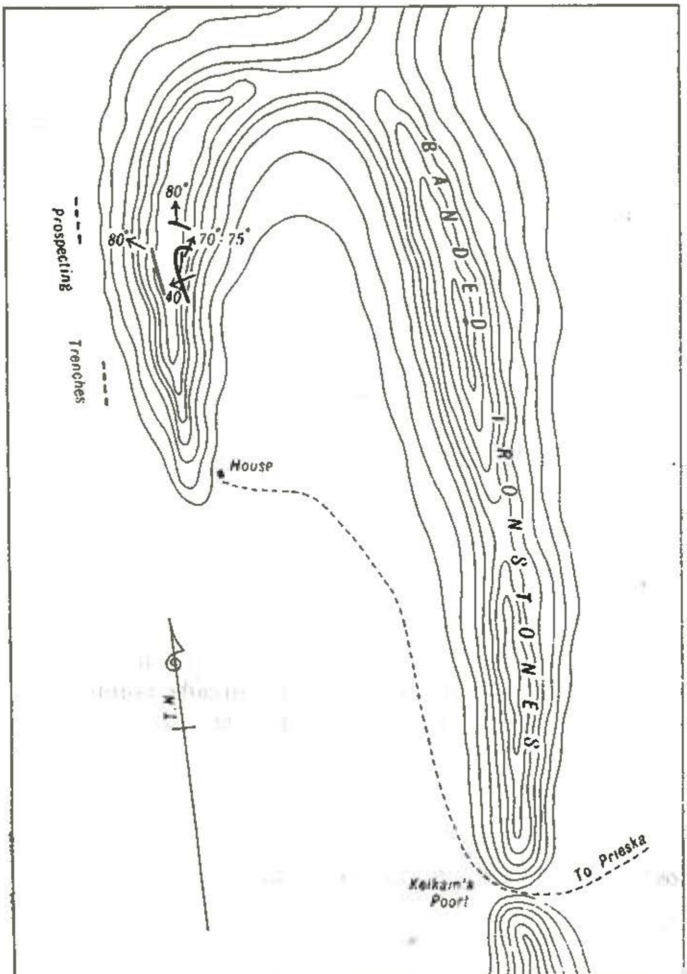


Fig. 3.

the ironstones are more steeply inclined, up to about 60 degrees. There are three parallel fibre horizons or "reefs" designated C, D, and E. Some 4 to 12 feet of country formation separate C from D, while about 200 feet intervene between D and E, each fibre channel consisting of a number of separate interbedded seams, up to about 8 in number; there is an underground connection between the C and D channels, that of E being separate.

Here again there are indications that the persistence of economical fibre is limited in depth. (See Chapter IX.)

One of the more recently established producers is the *Nauga Asbestos Company,* which are developing several fibre horizons on *The Willows,* made up from portions of the farms *Nauga* and *Kalkfontein,* situated on the left side of the Orange River some 22 miles north-west of Prieska. The workings lie on the upper slope of a low hill or ridge built of steeply but more or less regularly inclined banded ironstones and are developing seams that have been traced along the strike for about one mile. In these workings the fibre had been followed (February, 1930) for a distance of some 150 feet in depth on an average dip of 70 degrees. There are three principal ore channels, from three to seven feet in width, distinguishable as "North Reef," "Main Reef," and "South Reef"; between these there are subsidiary interbedded seams, the principal of which are referred to as "Intermediate South Reef" and "Intermediate North Reef." These deposits are opened up by means of an Upper Level, supported, at a distance of 70 feet below, by the Lower Level. The Main Reef Ore channel shows up to some six distinct seams and furnishes the main production. Of this, roughly one-half is A grade, i.e. ½ to ¾ inch fibre.

Another interesting more recent development is that of the *Griqua Town Exploration and Finance Company* on the farm *Elandsfontein;* this company also controls the following properties, on all of which crocidolite is stated to occur: Spion Kop, Kameel Rand, Klipnek, Kafirkrans, and Grootdoorn. Elandsfontein lies some 17 miles south of Griqua Town and well illustrates the tendency of many of the asbestos farms in the Cape fibre belt—as already pointed out above—to occupy a position not far above the top of the underlying Campbell Rand dolomite.

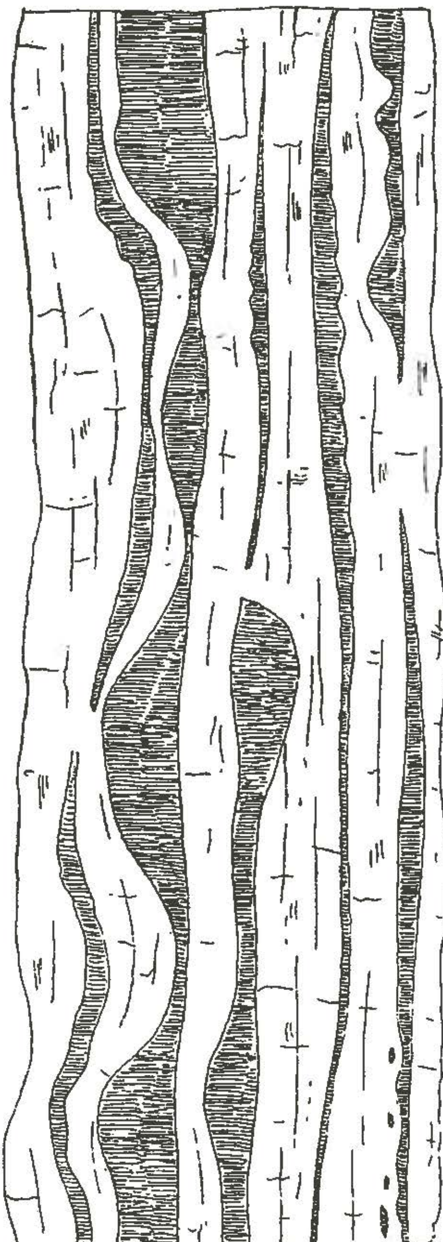
Since the main eastern contact between the latter and the overlying Lower Griqua Town Series runs along the escarpment side of the Asbestos Mountains (facing east) their edge (most easterly strip of this feature) is characterized by a large number of asbestos deposits, including most of those referred to above as belonging to this company.

Elandsfontein itself, previously exploited for some years under a different control, lies in the eastern or marginal zone of the Asbestos Mountain within somewhat dissected country; the works are spread out over the lower slopes of a prominent krantz built up of sensibly horizontally bedded banded ironstone, which extends from the floor of the valley up to the plateau-like summit of the Asbestos Mountains. The inclination, where not quite horizontal, does not exceed 4 degrees and there are practically no folds. The mine shows some 9 separate seams of asbestos, the fibre having been traced through about one and a quarter miles of strike. Practically only one seam is worked in the " main " workings and has been followed for some 700 feet on the dip. A soft clayey layer, known as the " soft seam," and from one to three inches lies usually directly on or in places up to 12 inches above the seam: this favourable condition enables the fibre to be more cheaply gouged out rather than stoped out by the usual method. The proportion of longer fibre is unusually high, since from 50 to 60 per cent. belong to the grade of 1–1½ fibre length.

Where the mode of occurrence shows more regular and extended persistence along the strike, the *method of exploiting the deposits* in some of the larger mines such as those of the Cape Asbestos Company 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 measured 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 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 lb. 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 ton 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



CORRUGATED STRUCTURE IN CROCIDOLITE, WARRENDALE, NEAR DANIELS KUIL.

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

Fig. 4. (Natural Scale.)

are repeated with essentially the same characters in the Northern Section (e.g. Klipvley, Wonderwerk, Warrendale, Cubbie, etc.), while they have also been noted in the Lydenburg–Pietersburg fibre area, both in crocidolite and amosite seams. (See Figs. 4, 5, and 6.)

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 latter corresponding to long and the former to shorter fibre. In length and amplitude such waves vary between fairly wide limits; at the same time the ridges may slope symmetrically towards

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

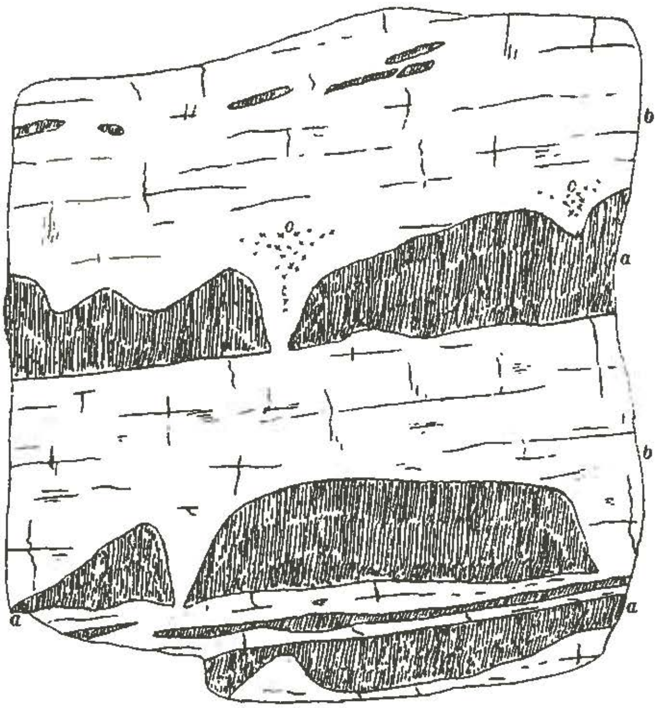


Fig. 5. (Natural scale.)

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

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. (Fig. 7 and Plate XVII.)

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

CONE STRUCTURE IN AMOSITE. PIETERSBURG DISTRICT.
(No. 4197, S.A. MUSEUM.)

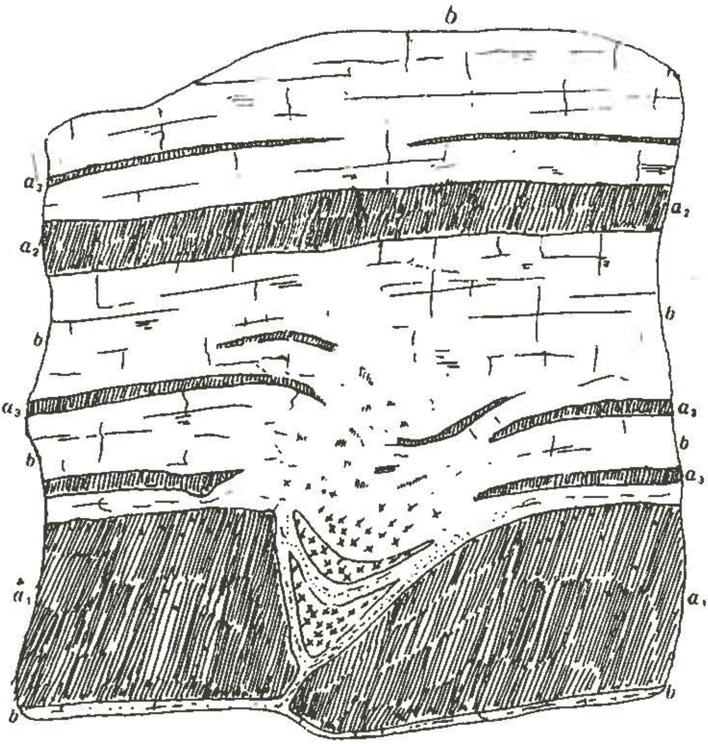


Fig. 6. (Natural scale.)

a_1. Pale greenish amosite with small scattered crystals of iron ore.
b. Dark ironstone. Inlenticular areas in the centre of a are brown carbonate of ron.
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.
In lenticular areas in the centre of a_1 are brown carbonate of iron.

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 IX 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 probably exerted on the country rock, as evidenced by the disturbed extension of bedding planes in a festoon-like manner across 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.

It is worth noticing specially, that the conical projections from the country wall rock into the seam consist in many cases of banded iron-stone, blue shale, etc., similar to the material that lies outside (above or below) the seam, and without fibrous structure, yet in some cases the "cones" are built of fibrous iron oxide (hematite), in which the orientation of the fibres conforms to that of the asbestos structure; this is a point of interest in the genetic conditions. (See Chapter IX.)

Individual crocidolite seams consist of 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, but 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 darked 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 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

MOULD OF BANDED IRONSTONE, AFTER THE NEARLY COMPLETE REMOVAL OF A CROCIDOLITE SEAM SHOWING "CONE AND CORRUGATED STRUCTURE." (KLIPVLEY, NORTH OF DANIELS KUIL. MUS. COLL. No. 3000$_{g}$.)

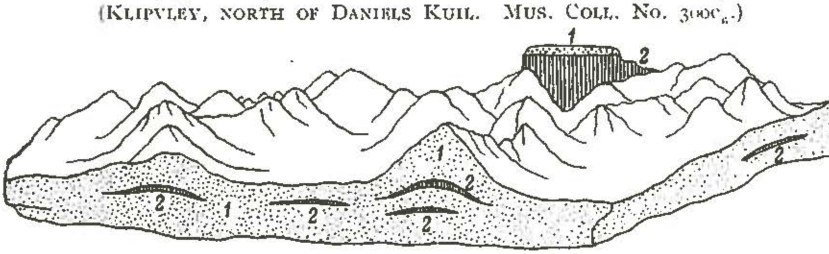


Fig. 7.
1. Banded Ironstone. 2. Crocidolite; nearly natural scale.

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 was used in the first edition, and covering the year 1917. The company were at that time working eight separate mines and contributed (as they still do) the largest share of the whole output within the Southern Section; hence the average obtained from their figures should approximate closely to that of all the workings in that portion of the fibre belt. The writer is greatly indebted to Mr. Rundle Olds for the detailed information required for these rather laborious calculations, which gave ·62 inches as the average over the mines together, individual mines showing average lengths ranging from the minimum of ·508 inches on Naauwpoort through ·75 inches on Leelykstaat, to 1·027 inches on Stilverlaats as the maximum.* In

* In arriving at these figures, grade E (length 2 in.) which only formed 0·138 per cent of the total output of the company during 1917, is ignored.

April, 1918, according to Mr. Neil McLeod, when the Carn Brea Syndicate had been working Keikamspoort (now belonging to the Cape Asbestos Company) for 20 months, the proportion of longer fibre (1 inch and over) for the preceding 6 months averaged about 50 per cent. of the output, while that of grade E (over 2⅛ inches) only amounted to about two tons. More recent data are given in Table 15.

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.

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 V). 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. Westerberg, Elandsfontein, etc., the hand-cobbed material is graded by machinery.

The sieving process serves to separate the mixed fibre into the required grades, and is usually carried out by an inclined cylindrical sieve (grading trommel) of wire netting or perforated sheet iron, open at the ends and commonly worked by hand. The whole sieve may consist of uniform mesh or may be built up of a series of different mesh, or is otherwise varied to suit particular grading schemes.

In the case of the Cape Asbestos Co., all fibre is hand cobbed, and then goes to the grading screens at Westerberg, which delivers all fibre ½ of an inch and over ready for shipment and classified into appropriate grades. All fibre less than ½ of an inch goes to Koegas to undergo further treatment by roll crusher and classifiers. The mixed fibre is passed between two short cylindrical rollers (see Plate VI) made of cast-steel, 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 these rolls the material is discharged into the innermost cylinder of the classifier.

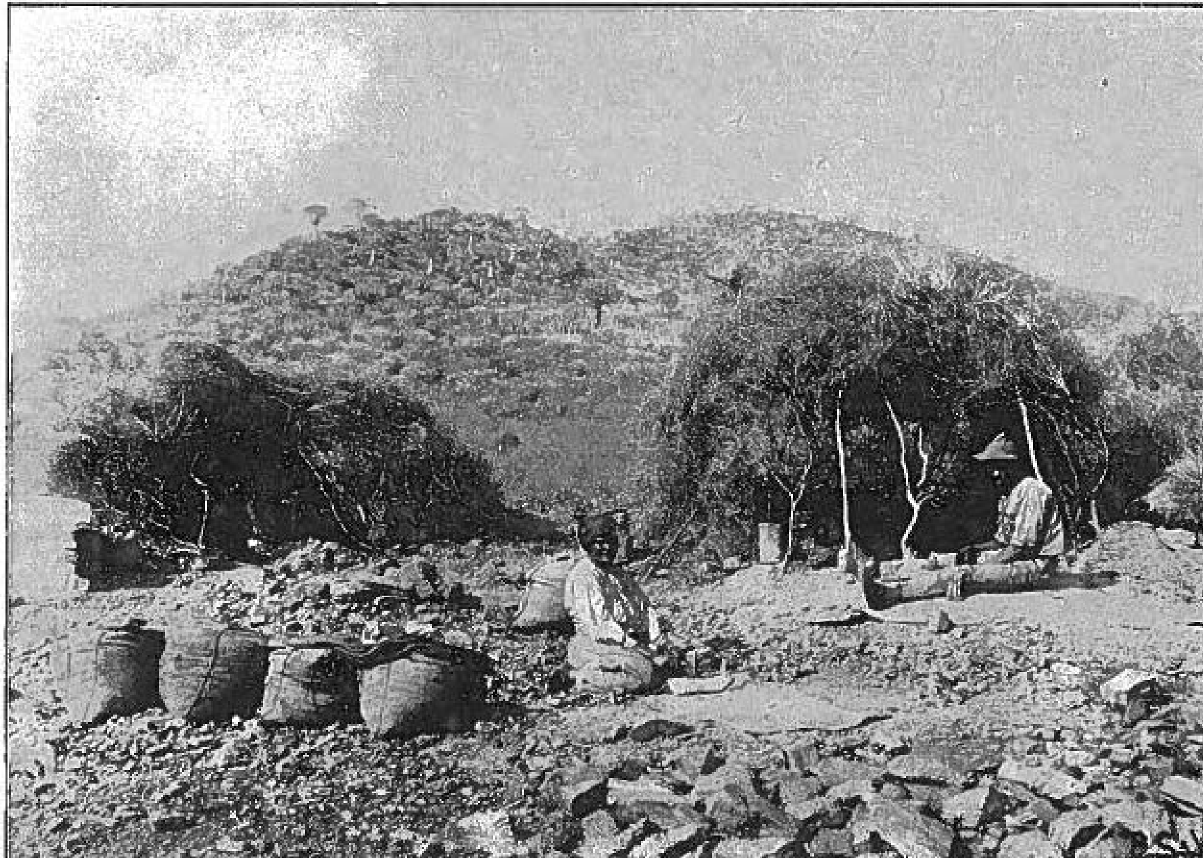


PLATE V.—*Cobbing Operations, Westerberg Mine*, Cape Asbestos Company.

This ingenious device (see Plate VII) consists of two slightly inclined coaxial cylinders of perforated sheet-iron, the perforations of the inner cylinder being $\frac{1}{4}$ of an inch and those of the outer $\frac{1}{8}$ of an inch in diameter. At the roller end the cylinders are conterminous, but overlap towards the lower end. What passes through the outer cylinder (the shorter) is rejected as sand or siftings, while the oversize from this outer cylinder forms SS grade. The oversize from the inner cylinder issues from its lower end as S grade. (See Plate VII.)

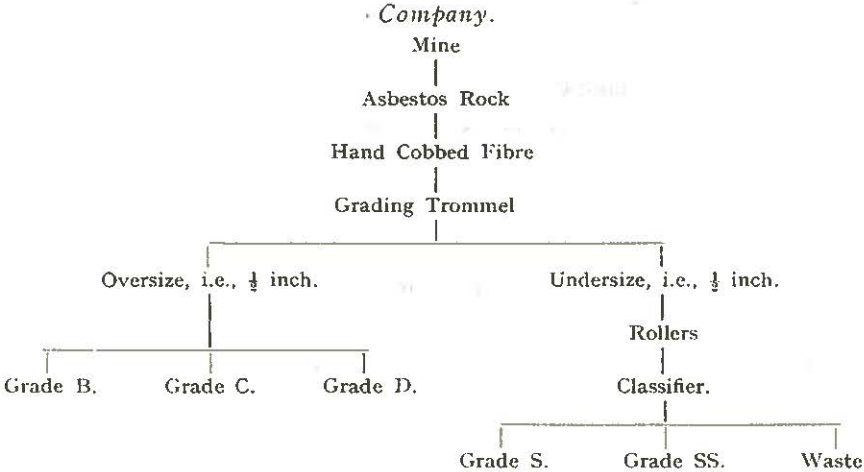
Grading is invariably based on fibre length, but in some mines discoloured fibre forms an additional grade; a variety of schemes are in use. The present schedule of the Cape Asbestos Company is shown in Table No. 9, and since this company has the largest output of all, and also buys much fibre from smaller producers, their schedule holds good for a large number of producing centres:—

TABLE No. 9.—*Grading Scheme of the Cape Asbestos Company.*

Designation.	*Description.*
SS (Shorts)	Less than $\frac{1}{8}$ inch.
S	$\frac{1}{4}$ inch to $\frac{1}{2}$ inch.
A	$\frac{1}{2}$ inch to $\frac{7}{8}$ inch.
B	$\frac{7}{8}$ inch to $1\frac{1}{4}$ inch.
C	$1\frac{1}{4}$ inches to $1\frac{3}{4}$ inches.
D	Over $1\frac{3}{4}$ inches.

The simplified schedule of operations thus assumes the form given in Table No. 10.

TABLE No. 10.—*Schedule of Grading Operations, Cape Asbestos Company.*



At Elandsfontein (Griqualand Exploration and Finance Company) all asbestos rock is also cobbed, after which it is sieved and graded by means of an inclined hand-worked grading trommel having five sizes of mesh. The classification is according to the scheme shown in Table No. 11.

TABLE No. 11.—*Grading Scheme at Elandsfontein.*

Designation.	*Description.*
SS.	Up to ¼ inch.
S.	¼ inch to ½ inch.
A.	½ inch to 1 inch.
B.	1 inch to 1½ inches.
C.	Over 1½ inches.

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 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 workings actually producing were to be extended and carried down to the maximum depth to which the seams persist under economic conditions. The relatively small output—compared e.g. with that of the great Canadian chrysotile deposits—is partly due to the difficulties of competing with white asbestos and its much larger and more regulated supplies, difficulties which led the Cape Asbestos Company to establish their own factories. Nevertheless, crocidolite has now firmly established itself on the market, so that a steady and increasing output may be anticipated with confidence, given continued favourable market conditions.

The method, sometimes applied, of working out the fibre resources of a mine, by measuring the precentage of fibre exposed in the workings on the basis of the ratio between total fibre length and stoping width, and then applying this result to a certain length of strike and assumed persistence on the dip, though tempting, is not as sound in the case of crocidolite (and other varieties of asbestos) as it may be for other mineral deposits. Even if a large number of percentages are measured at short lateral intervals, the seams are lenticular in shape and often die out in a comparatively short distance. In practise, also, it is often found that the actual amount of fibre produced does not correspond to the theoretical yield, and this discrepancy is not one that can be allowed for with any degree of certainty. Furthermore, in dealing with asbestos, one has to reckon with genetic conditions essentially different from those associated with other forms of mineral deposits, so that persistence in depth is a most difficult and uncertain factor.

The total output for the whole of the Cape fibre belt is given in Chapter XI, but figures for the Southern and Northern Section separately are not available for publication. The average monthly production from the mines of the Cape Asbestos Company amounted during 1929 to about 150 long tons (in which Westerberg leads with a steady output of 30 to 40 long tons per month), while an approximately similar

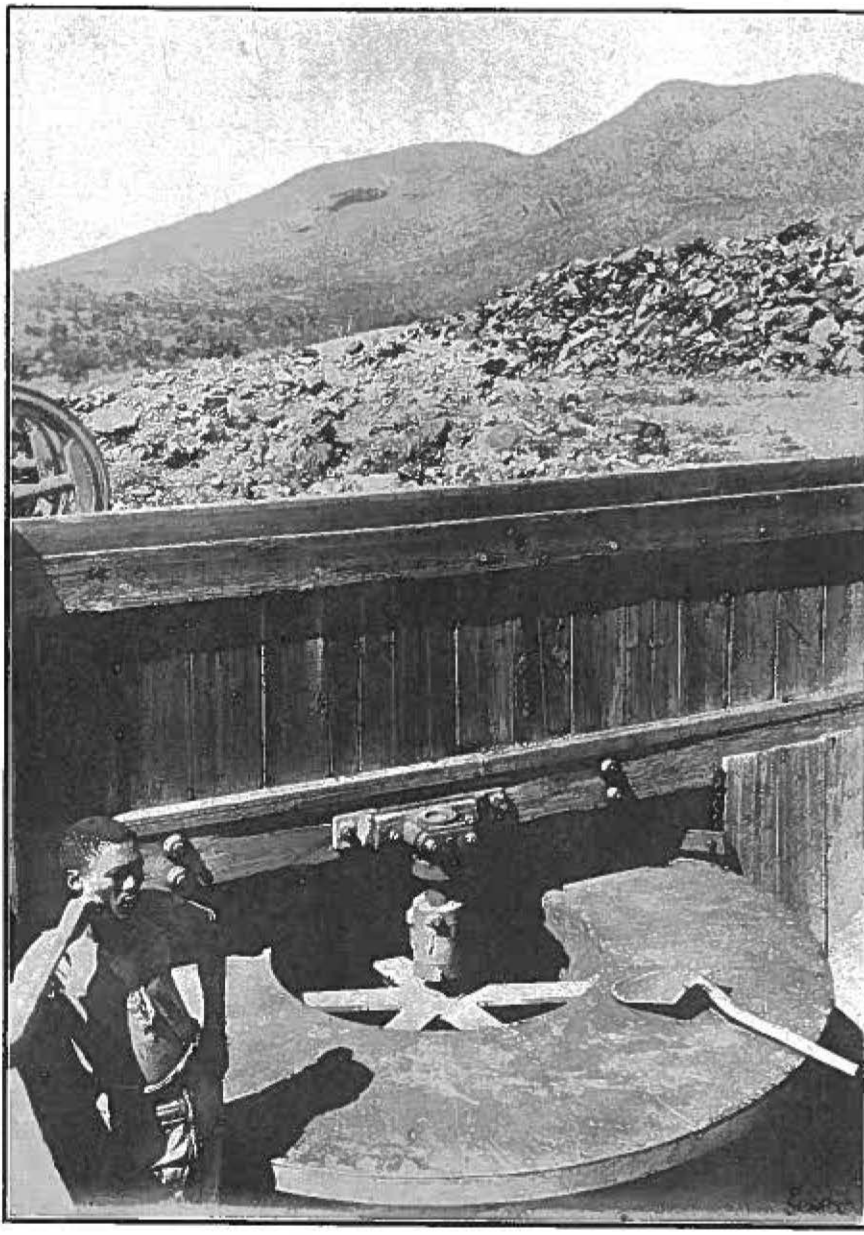


PLATE VI.—*Preparation of Shorter Grades of Crocidolite for the Market;* the upper end of the Classifier, where mixed fibre enters the rollers. Koegas, Cape Asbestos Co.

amount was purchased from other producers. Since this company are the principal manufacturers of blue asbestos goods, the supply goes to feed their factories at Turin, Laval in Northern France, Barking near London, and Bergedorf near Hamburg.

The output of each grade throws some interesting light on the relative proportions of the yield; the results during 1917 (when the grading scheme was a little different were those shown in Table No. 12).

TABLE No. 12.—*Output of the Various Grades of the Cape Asbestos Company during* 1917.

Grade.	Description.	Long Tons.	Percentage.	Remarks.
X........	0 in. to ¼ in.......	69·55	5·729	
S........	¼ in. to ½ in.......	363·60	29·949	
A........	½ in. to ¾ in.......	538·00	44·314	
B........	¾ in. to 1¼ ins.	192·60	15·864	Spinnable, 20·008 per cent.
C........	1¼ ins. to 1¾ ins...	37·25	3·068	
D........	1¾ ins. to 2 ins....	11·40	·938	
E........	Over 2 ins.........	1·65	·138	
		1,214·05	100·000	

To the output given by Table No. 12 the various mines contributed as shown in Table No. 13.

TABLE No. 13.—*Output from the Mines of the Cape Asbestos Company during* 1917.

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

The corresponding information for the year 1929 will be found in Tables Nos. 14 and 15.

Table No. 14.—*Output from the Mines of the Cape Asbestos Company during* 1929.

Mine.	*Long Tons.*	*Percentage.*
Westerberg } Keogas } Nauga East }	497·70	27·07
Buisvley	116·60	6·34
Kliphuis	92·40	5·02
Blockridge	158·65	8·63
Carn Brea	205·00	11·15
Klein Naauwte	304·90	16·58
Glen Allen	133·05	7·23
Klipfontein	13·05	·71
Kameelpoort	35·55	1·94
Botallack	154·15	8·33
Pomfret	128·50	7·00
	1,839·55	100·00

Table No. 15.—*Output of the Various Grades of the Cape Asbestos Company during* 1929.

Grade.	Description.	Long Tons.	Percentages.	Spinnable. Per cent.
SS	Under ⅛ in.	37·50	2·04	
S	⅛ in. to ½ in.	1019·90	55·44	
A	½ in. to ¾ in.	521·85	28·37	
B	¾ in. to 1¼ in.	139·60	7·59	14·15 per cent.
C	1¼ in. to 1¾ in.	66·40	3·61	
D	Over 1¾ in.	21·65	1·18	
Discoloured	Not sorted	32·65	1·77	
		1839·55	100·00	

The combined output of Westerberg, Nauga East, and Koegas, separate returns not being available, during 1929 is given in Table No.

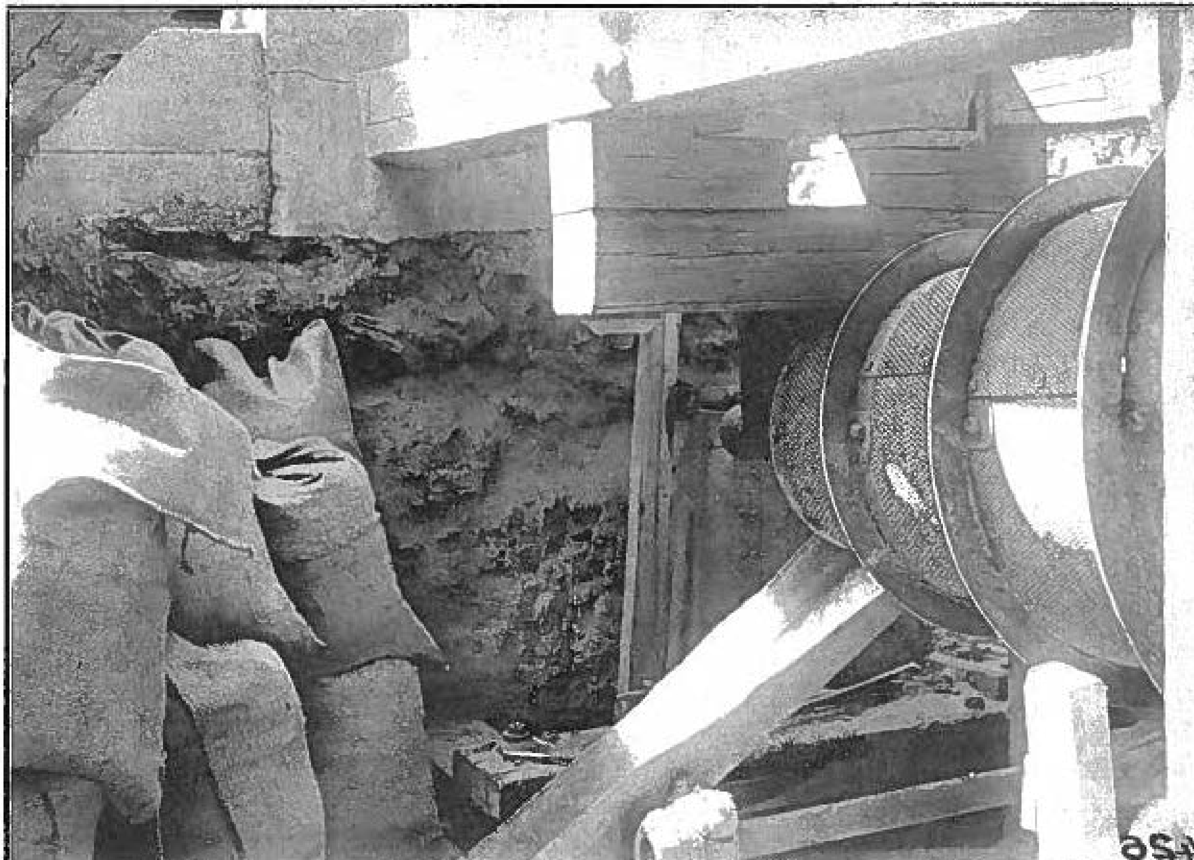


PLATE VII.—*Preparation of Shorter Grades of Crocidolite for the Market*

16 in terms of each grade; in this production, the contributions from Koegas and Nauga East are very small compared with that from Westerberg :—

TABLE No. 16.—*Output of each Grade from Westerberg, Koegas, and Nauga East during 1929.*

Grade.	Description.	Long Tons.	Percentage.	Spinnable. Per cent.
SS.......	Under 1/8 in............	28·50	5·73	
S........	1/4 in. to 1/2 in..........	100·75	20·24	
A........	1/2 in. to 3/4 in..........	269·85	54·22	
B........	7/8 in to 1 1/4 in..........	54·50	10·95	19·81 per cent.
C........	1 1/4 in. to 1 3/4 in.........	31·20	6·26	
D........	Over 1 3/4 in............	12·90	2·60	
		497·70	100·00	

It will be seen from the above tables that the proportion of fibre with medium length (Grade A) is high. According to information received from Mr. Stott, the monthly output from Elandsfontein is round 25 long tons, of which no less than 50 to 60 per cent. is represented by Grade B, which in their scheme designates fibre from 1 to 1½ inches long.

The limit of *spinnability* is variously given 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 ¾ inch, over 20 per cent. of the main company's output for 1917 was spinnable; for the 1929 output this factor is represented by 14·15 per cent. In this respect the Cape fibre area is superior to the Canadian chrysolite fields.

The *prices* realized may be illustrated by Table No. 17, which shows the value (February, 1930) of the various grades at railhead.

TABLE No. 17.—*Prices of Crocidolite, f.o.r. Draghoender.*

Grade.	*Description.*	*Price per Long Ton.*
SS (Shorts)..............	Under 1/8 in..............	£7 10 0
S......................	1/4 in. to 1/2 in............	21 10 0
A......................	1/2 in. to 3/4 in............	35 0 0
B......................	7/8 in. to 1 1/4 in...........	70 0 0
C......................	1 1/4 in. to 1 3/4 in..........	80 0 0
D......................	Over 1 3/4 in..............	85 0 0

* Provided A grade is good, a small quantity of it can be added to the longer grades for spinning purposes.

For *market disposal* the separate grades are usually put up in bags of 112 lb. each, this size being convenient to handle and bearing a simple proportion to the long ton. Kimberley, Draghoender, Prieska, and Douglas are the common railheads; the deposits round Daniels Kuil should be materially assisted by the Koopmansfontein–Postmasburg branch now nearing completion. The Cape Asbestos Company deliver mostly to Draghoenders Station, Prieska, and Vryburg.

Distinctive Characters in the Southern Section.

The mode of occurrence of the crocidolite as interbedded cross fibre seams as well as the mode of origin being the same throughout the whole fibre belt, and associated with banded ironstone showing, on the whole, essentially similar features over the entire field, there is not much that is specially characteristic of the Southern Section. In this there is probably a larger proportion of the deep blue stringy fibre variety—with its tendency to predominate in the bluish more shaly type of ironstone—that appears to be rather more common in the Southern as compared with the Northern Section, though it is sometimes very striginly seen in the latter (e.g. Hurley). The so-called " stringy " fibre is said to be specially desired by the manufacturers for spinning purposes and preferred to the extremely delicately fibrous " fleecy " variety, more common in the Northern Section.

In former years it was correct to say that in the Southern Section there was a greater proportion of more systematic underground mining development going on: this was partly because some of the mines had at that time already been under exploitation for a longer period, but partly also on account of the more limited use of the contract system of labour. The effects of this system were at one time more noticeable in the Northern Section, where prospecting and development was more usually left to the native, while in the southerly parts the selection of mine ground and its methods of development remained more generally under the direct control of the management. During the last 10 or 12 years this difference has become less noticeable, specially since the establishment in the Northern Section of the Dominion Blue Asbestos Mines (Pty), Ltd. (a subsidiary company of Turner and Newall, Ltd.), that have acquired control of a series of deposits, formerly held by less powerful concerns. In several respects the activities of this important company stand in a relation to the Northern Section similar to that of the Cape Asbestos Company to the Southern Section.

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

In this section a number of small companies, syndicates and individual producers have been developing the fibre occurrences for a considerable number of years. Some of these activities have been intermittent and some of the crocidolite working companies no longer exist, while their farms have passed under new control. The most important producer to-day is the *Dominion Blue Asbestos Mines (Pty.), Ltd.*, which has acquired (or taken over from pre-existing concerns) a series of fibre-bearing properties: it is a subsidiary company to Messrs. Turner and Newall, Ltd., and stands to some of the smaller producers within this section in the same relation as does the Cape Asbestos Company in the Southern Section.

Not uncommonly a given farm is worked at a fairly large number of points, and while the output from any one point is somewhat small, the production in the aggregate is substantial. Among the fibre-bearing farms may be mentioned :—Hurley, Klipvley, Brettby, Cubbie, Crawley, Khosis, Warrendale, Oudeplaats, Skietfontein, Mansfield, etc., though this list * is not exhaustive. (See List of Crocidolite Localities given above.) These localities are situated on private land, or on Crown Lands or sometimes fall into Native Reserves.

Where the workings are not on private ground, but fall on Government ground (Crown Lease land) 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 thorough tests.

From Owendale, nine miles south-west of Daniels Kuil, the workings extend across the Barkly West District into the Kuruman and Vryburg Districts 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;

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

this question is touched upon in Chapter IX. 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.

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. In many cases this principle does not admit of more systematic underground mining, such as, e.g. a well-defined regularly bedded gold reef calls for elsewhere. In this respect, specially so during the earlier period of development, the majority of the workings in the Northern Section afford some contrast, when compared with the more typical mining operations possible in the Southern Section, e.g. at Westerberg, and are in strong contrast to the regular manner in which the very thick amosite seams of the Egnep and Amosa Mines north of Lydenburg, can be exploited along levels, drives, and stopes. (See Chapter V.) At present the Northern Section has made substantial advance in this respect, so that several deposits are now being developed along more systematic lines; the advent of the Dominion Blue Asbestos Mines (Pty), Ltd., has greatly stimulated such development (Klip Vley, Hurley, etc.).

The special features of the contract system of labour, favoured in the Cape Belt, has also, not infrequently, an important bearing on the economic conditions. Native labour is paid according to the grades per standard amount of cobbed fibre, 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.

Where this system of labour is in force, the countless occurrences of fibre on many farms (or at numerous points within one farm) provide abundant opportunities of shifting development to some other place as soon as the work ceases to be remunerative, so that extensive underground workings are comparatively few; many of the workings were, and a good deal of them still are, small scattered quarries, in places leading into short stopes, along which more promising seams are followed up on the dip, but rarely for more than a few yards. On Warrendale, for example, there were a few years ago, some twenty of this type of working, and most properties under development show several, specially in the case of smaller producers. 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 mining is seen on Wonderwerk, Klipvley, Hurley, etc.

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 sort-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. 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.

No. 4 Workings, Warrendale, showing seam density.

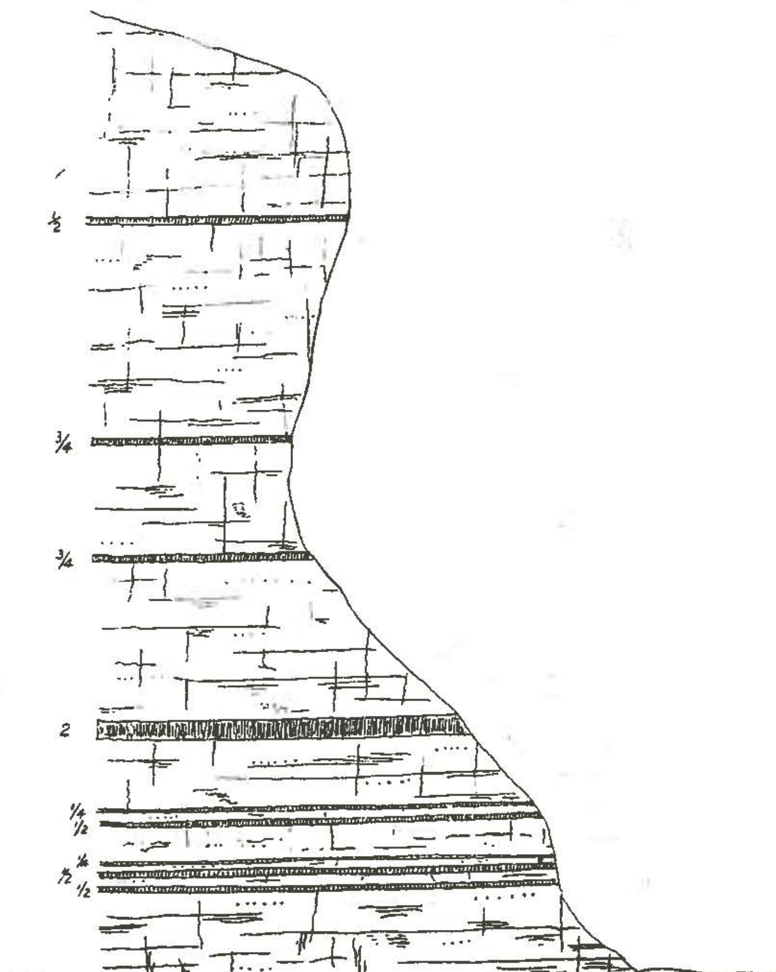


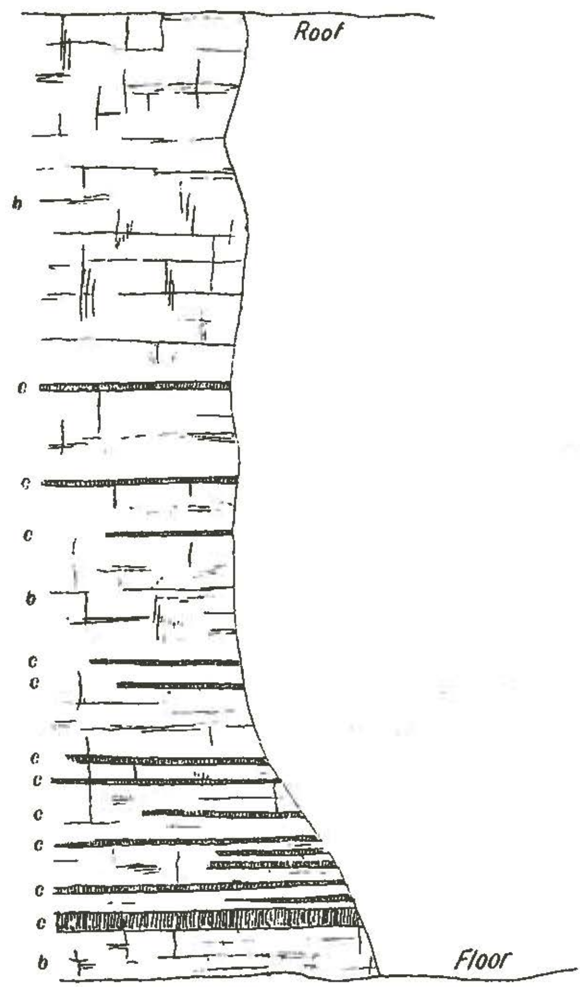
Fig. 8.

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

Examples, typical of such associations observable in many workings, are illustrated by Figures 8 and 9, but much minor variation in

" seam density " (i.e. number of seams per linear foot of succession) occurs. Commonly 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 Daniels Kuil.



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

Fig. 9.

On *Warrendale*, at No. 4 workings, the seam density may be gathered from Fig. 8, showing 9 seams, ranging from 2 inches down to ¼ inch in thickness and all of pale to darker lavender blue fibre.

In No. 3 workings on *Brettby*, where a large open cast working leads into a stope extending some distance into the hillside on the dip (from 0 to 25 degrees), one point showed the succession represented by Fig. 9. Over some 8 feet of thickness from the roof of the stope to the floor some 12 to 15 seams are seen, the majority of which being less than one inch thick.

On *Cubbie* a face 18 feet high showed a large number of seams, many under 1 inch across, but with occasional values exceeding 2 inches. The more extensive underground development on *Wonderwerk* includes longer irregular stopes supported by pillars; here the combined fibre width measured 5 to 6 inches, but made up largely of seams under ¾ inch in thickness. During the earlier period of developments on *Klipvley*, near Daniels Kuil, from 12 to 14 seams were found over a 7-foot face; this led to more regular mining, continued to this day. (See below.)

Also situated on the edge of the Asbestos Mountains lie the fibre deposits of *Oudeplaats*, four miles south-west of Daniels Kuil, not much above the floor of a long valley cutting into these mountains. The country formation is distinctly folded at the mouth of the main drive (see Plates VIII, Fig. 2, and IX), which continues for some 300 feet into the hill, and exposes up to about 30 seams over 8 feet of succession. Folding is locally well marked, and increased fibre length is noticeable, specially in the synclines. Oudeplaats is typical of many minor fibre occurrences in this section.

The localities worked* by the *Dominion Blue Asbestos, Limited*, are as follows:—

(*a*) South of Kuruman: Klipvley, Hurley, and Mansfield; and
(*b*) North of Kuruman: Gamohaan, Sardinia, Mauratanche, Eldoret, and Maipin.

Among the best developed workings Klipvley and Hurley are specially important and instructive.

The farm *Klipvley* (formerly controlled by the Gillanders and Campbell Syndicate) lies some 9 miles north of Daniels Kuil and 52 miles south of Kuruman, close to the western edge of the Kaap Plateau, i.e. within the Asbestos Mountains and near their eastern face in somewhat highly dissected country; the main workings fall into the upper parts of a fairly narrow valley 200 feet deep, bounded by steep slopes built of krantzes of banded ironstone (see Plate VIII, Fig. 1), a little below the plateau-like summit of the Asbestos Mountains. The country formation shows a very regular sensibly horizontal dip, in places very slightly undulating. The general succession and the relative position of the fibre horizons are showns in Fig. 10.

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* February, 1930.

PLATE VIII. *Fig. 1.—General view of the crocidolite workings of Klip Vley,* north of Daniels Kuil. Photo by A. K. Parrott.

PLATE VIII. *Fig. 2.—Crocidolite Workings on Oudeplaats,* near Daniels Kuil. Photo by A. K. Parrott.

DIAGRAMMATIC SECTION ACROSS THE CROCIDOLITE HORIZONS ON KLIP VLEY, NORTH OF DANIELS KUIL.

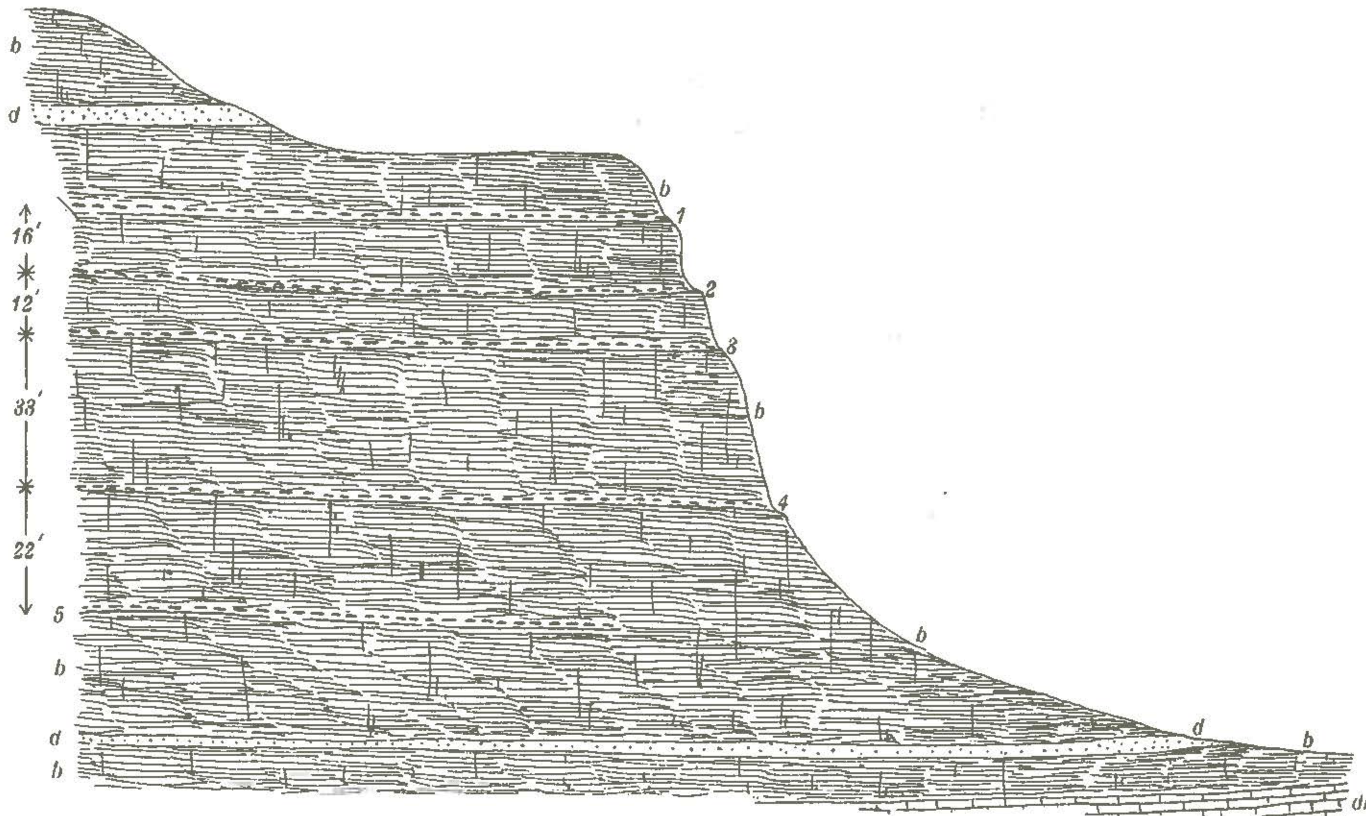


Fig. 10.

d. Dolerite Sill. *b*. Banded Ironstone. 1 to 5 Asbestos horizons. dm. Dolomite.

Diagrammatic Section across the Crocidolite Horizon on Hurley, North of Daniels Kuil.

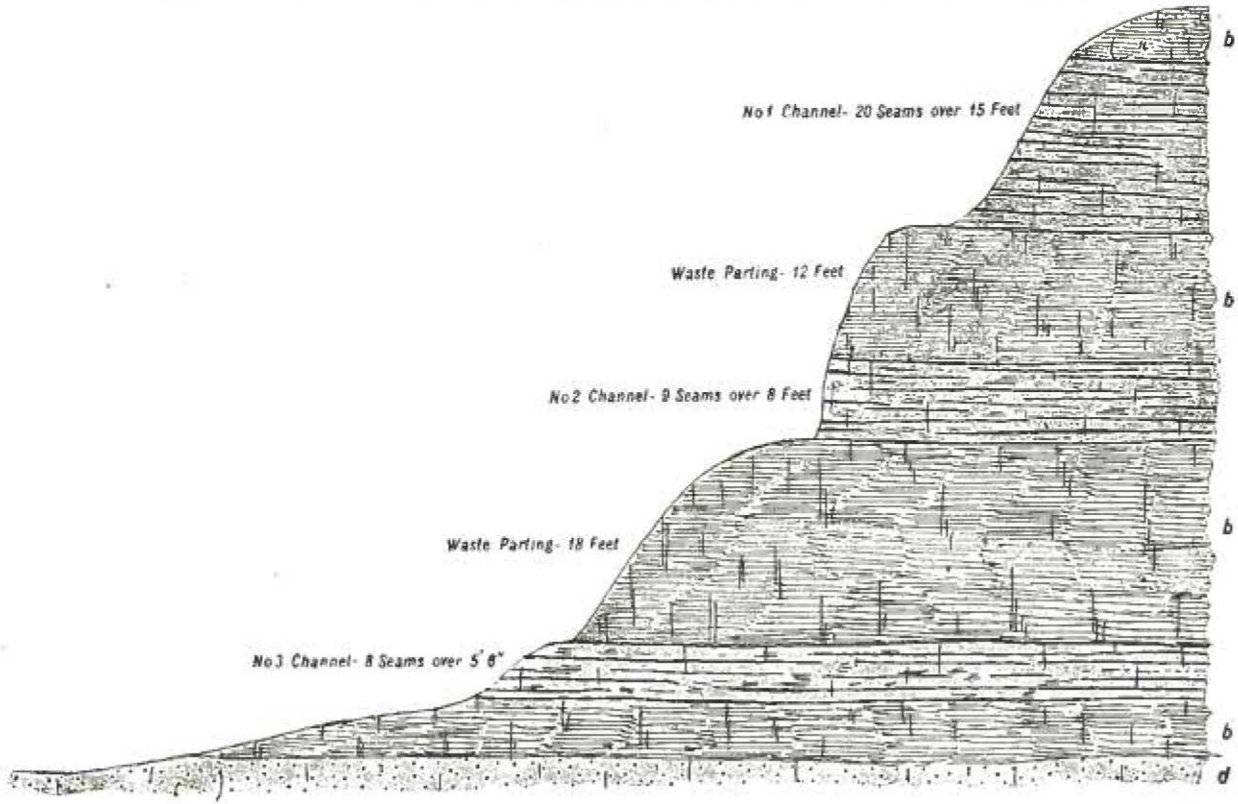


Fig. 11.

d. Dolerite Sheet. *b*. Banded ironstone.

PLATE IX.—*Typical Folds in Banded Ironstone;* Oudeplaats crocidolite workings near Daniels Kuil.

Near the top of the succession lies a thin doleritic sheet a few feet thick, while a second similar formation is exposed almost in the floor of the valley. Within the banded ironstones defined by these igneous sheets there are five distinct fibre channels, disposed parallel to one another and conforming to the dip of the associated banded ironstones (Fig. 10). The highest of these, No. 1, is undeveloped, while No. 2 is partially developed, No. 3 being worked out. The main underground workings are concerned with No. 4 channel and No. 5 channel. The former has a width of 12 to 15 feet and shows from 15 to 30 interbedded cross fibre seams, giving approximately 8 per cent. of economic fibre over a variable stoping width of up to 12 feet; No. 5 ore channel is in the neighbourhood of 10 feet wide and carries some 16 seams. It is interesting to note that No. 4 fibre channel is the result of prospecting from No. 3 vertically on the theory that an area of enrichment has further economic fibre underlying it; the discovery of No. 5 channel was similarly due to sinking from No. 4 on the same theory.

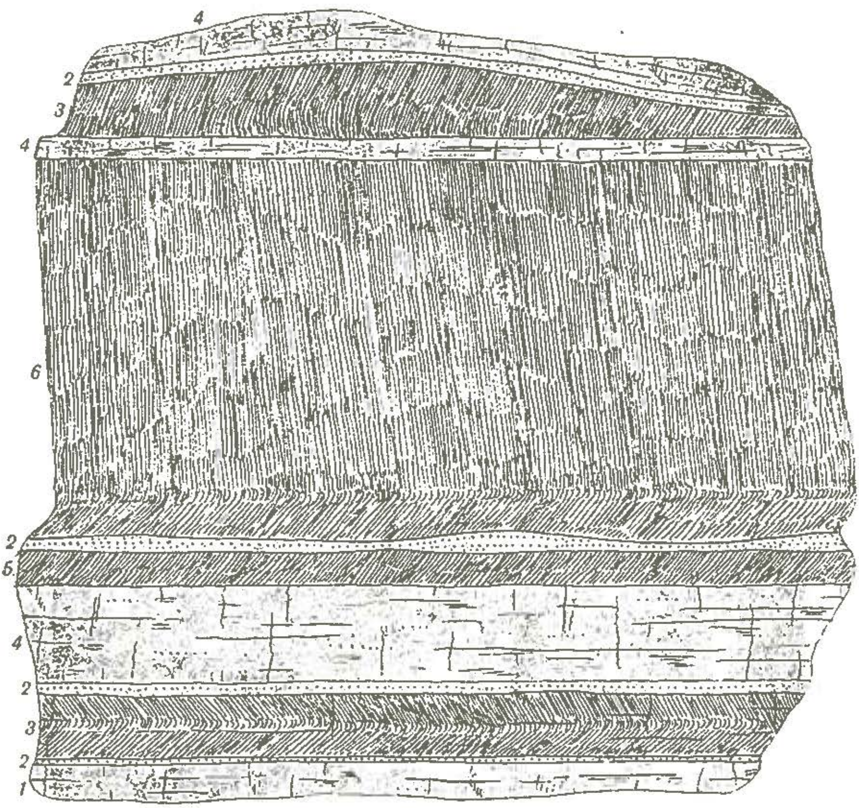
Some 35 miles south of Kuruman lies the important crocidolite deposits on *Hurley*, where development has proceeded for a number of years (also under the former control of the Gillanders and Campbell Syndicate). The workings are again near the eastern edge of the Asbestos Mountain not far above the base of the underlying Campbell Rand dolomites, and are distributed over the lower slopes of a long narrow valley that cuts for some distance from the western edge of the Kaap Plateau westwards into the Asbestos Mountains.

Over some 60 feet of the succession of banded ironstone (see Fig. 11) there are three separate ore channels, each composed of a series of interbedded cross fibre seams, No. 1 channel being the highest; these fibre horizons are spaced relatively to one another as shown in Fig. 11, which also gives the number of seams in each; the adit by which No. 2 is approached is now 350 feet long. The proportion of economic fibre on Hurley is approximately 5 per cent. The country rock consists not only of the more common yellowish brown ironstone, but in some of the workings includes hard vivid blue "shale," some of which is identical with the so-called crocidolite potential of Westerberg and elsewhere (locally referred to as "Hurley Blue"). "Cone" and "corrugated" structure is well seen, e.g. in No. 2 Level, showing cases where the conical projections of the country rock point definitely downwards into the fibre layer.

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

LUMP OF CROCIDOLITE ROCK, SKIETFONTEIN, NEAR DANIELS 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. 12. (Natural scale.)

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. 12).

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 some chrysotile deposits elsewhere 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. 12.)

The example shown in Fig. 12 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 symetrically 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 show much variation in the length over which they persist; this is sometimes to be measured in inches, but more often in feet or yards, though a continuity over tens of yards is exceptional. As a rule they do not end abruptly but 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 commonly many times as much as the thickness; on Wonderwerk larger slabs of drifted material were found due to ovoid sheets of very dark blue, almost black crocidolite.

A single seam may preserve a nearly uniform width for some distance before gradually dying out, but in almost every working one observes some kind of 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 V. 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, Hurley, Klipvley and elsewhere (compare Figs. 4 to 7, and Plate XVII).

Potential crocidolite is occasionally met with, as on Hurley, 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.

Some years ago, during the regime of the Northern Asbestos Company—at that time the largest producer in the Northern Section—fibre from ⅜ inch to ¾ inch was represented in 6 months' ouput in 1917 by 70.2 per cent., and that from ¾ inch upwards by 10.9 per cent. In the production of the former Harris' Syndicate, the proportion of fibre 1 inch and over in length, was estimated as forming 18 per cent., and that under 1 inch as 72 per cent.

The relative proportions of the various fibre lengths found over a larger section of different mines, under economic conditions, afford more trustworthy data as reflected in the percentages of grades recovered. This is shown in Table No. 18 below, which points to a proportion of spinnable fibre comparable to that found in case of the Cape Asbestos Company (compare Table No. 15), so that the favourable condition in this respect—in comparison with the Canadian chrysotile deposits—holds good for the Northern Section also.

Output and 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 there are a large number of farms under development, and not infrequently several workings within a single farm, so that in the aggregate the production reaches a substantial figure. Separate returns for the various producers in the northern section are not available for publication, though it is permissible to state that the Dominion Blue Asbestos Mines are maintaining a steady output which in February, 1930, was at the approximate rate of 170 short tons per month, exclusive of what this company buys from smaller producers. Since the Dominion Blue Asbestos Mines is easily the largest producer in the Northern Section and conducts its development on systematic lines at a series of localities, the above figure probably forms the lion's share in the total yield from the Northern Section.

To attempt to estimate the amount of fibre still obtainable under economic conditions is for many obvious reasons very difficult and unsatisfactory. Some of the difficulties have been touched upon above. On the other hand, the steady output already maintained for many years, without any substantial and continuous decline, as well as the numerous centres at which further economic deposits can be observed, leave no reasonable doubt that this section is capable of maintaining its present rate of production for a long time, so long as the present steady demand for crocidolite continues.

Preparation for the Market, Grading, Disposal, Prices, etc.

The asbestos rock is hand-cobbed by native labour, and the shorter fibre, mixed with chips of rock, etc., is sieved by simple mechanical devices, e.g. swinging sieves, inclined rotary trommels and provided with screening material graded, as to meshes, according to the particular grading scheme adopted. The latter, in former years, varied a good deal among the different producers, and the resulting lack of uniformity in the specification of the final products led at one time to some difficulty in disposal on the world's market. The same complication resulted from the variety of methods in vogue for market preparation, sometimes not very carefully carried out. The method at one time used on Wonderwerk may be mentioned as one typical during the earlier period of crocidolite developments. Here the grading was carried out by means of an inclined rotary trommel, the upper half of which was provided with a wire screen of smaller mesh, so that the grade known as SX or short siftings accumulated under this part of the trommel; the oversize descended to the lower end, carrying coarser mesh, which allowed Grade S, up to and including ⅜-inch fibre, to be collected under it. The finest fluffy very short fibre was known as "droppings" (e.g. on Brettby). Discoloured is still sometimes kept separate, as it finds a certain use in the industry, in spite of its impaired colour.

At the present time substantial progress has been made in reducing the variety of grading schemes and standardizing, as far as possible, the methods of market preparation. The influence of the Dominion Blue Asbestos Mines, in establishing a central mill at Kuruman and laying down a definite grading scheme, tends to a larger measure of co-ordination in the methods of market preparation, etc., than has been previously possible, since similar producers, who wish to take the advantage of the local market, offered by the Dominion Blue Asbestos Mines, will naturally conform as far as possible to the requirements laid down.

In the preparation adopted by the Company referred to, a certain proportion of the asbestos rock is hand-cobbed, while that carrying shorter fibre goes to the central mill in the form known as "cobs," i.e. small lumps about the size of an egg or walnut, but with country rock still adhering. The mill is at Kuruman and delivers the Grades No. 2 and No. 3, specified in Table 18 below. The principle of this mill rests on the use of crushers, sorting tables, heavy rolls, and disintegrator, the two grades being finally delivered each into its appropriate cyclone.

The grading scheme is shown in Table No. 18, in which the designation " Dis " means " discoloured " :—

TABLE No. 18.—*Grading Scheme of the Dominion Blue Asbestos Mines (Pty.), Ltd.*

Grade.	*Description.*	*Approx. per cent. of Total Output.*	
ES	Over 1¼ ins.	1·5 (hand cobbed)	8·5 per cent.
No. 1	¾ in. to 1¼ ins.	7·0 (hand cobbed)	
No. 2	⅜ in. to ¾ in.	40·0 (milled)	
No. 3	⅜ in. and under	47·0 (milled)	
Dis. No. 1	+ ¾ in.	5·0 (hand cobbed)	
Dis.	Any length		

The *approximate proportions of the various fibre lengths* obtained are also given in Table No. 18; the limit of spinnable length depends upon certain technical aspects, beyond the scope of these pages, and is variously estimated as from ⅜ to ¾ inch. If the limit is taken as ¾ inch, the *spinnable proportion* would be in the neighbourhood of 9 per cent., i.e. of the same order of magnitude as in the Southern Section.

The grades are put up in bags of 100 lb. each, this size being easy to handle and bearing a simple ratio to the short ton. *Disposal* of the output from the Northern Section has for many years involved great distances by road (Taungs on the Cape Main Line), but the completion of the Koopmansfontein–Postmasburg extension should ease the transport situation.

The fibre produced by the Dominion Blue Asbestos Mines is primarily absorbed in their own (Turner & Newall's) factories, and thus does not come into the open market, but some indication of the value of the fibre, obtained in this section, can be gathered from the *prices* at which independent producers are able to dispose of their output to the company referred to; this information is shown in Table No. 19.

TABLE No. 19.—*Prices at which Fibre is Bought by the Dominion Blue Asbestos Mine (Pty.), Ltd. (delivered at Kuruman).*

Grade.	*Description.*	*Price per Short Ton.*
ES	Over ¼ in.	£84
No. 1	¾ in. to 1¼ ins.	64
No. 2	⅜ in. to ¾ in.	28
No. 3	⅜ in. and under	16
Dis. No. 1	+ ¾ in.	31
Dis.	Any length	16

Summary of the Principal Features of the Cape Asbestos Belt.

The following is a short summary of the main geological and economic features which characterize this asbestos field:—

(*a*) The enormous extent of the fibre belt through some 250 miles, which is a record among asbestos areas.

(*b*) The restriction of the fibre to the crocidolite variety and its strict limitation to banded ironstones as the country rock—in the form of interbedded cross fibre seams.

(*c*) The occurrence of seams, usually in a series, at a very large number of points, spread out more or less along the entire belt, but tending to cling to near the contact of the banded ironstones with the underlying dolomite.

(*d*) The large amount of fibre available in the aggregate, notwithstanding the relatively small amount obtainable from most individual workings.

(*e*) The usually favourable mining conditions, and the prevalence of development near, or at comparatively shallow depths from, the surface.

(*f*) The commercial grade of many of the occurrences, and their secure position in the international markets.

(*g*) On the whole, simple methods of market preparation.

Chapter III.

PRINCIPAL DEPOSITS OF ASBESTOS IN THE TRANSVAAL.

I. Chrysotile or White Asbestos.
II. Amosite.
III. Crocidolite.

Varieties and General Distribution.—The varieties of asbestos found in the Transvaal have been summarized above in Table No. 7, which shows that *chrysotile, amosite* and *crocidolite* occur under economic conditions in the North-Eastern and Eastern Transvaal, while the less important variety *anthophyllite* occurs north of the Zoutpansberg in considerable quantities, where it was exploited at one time. *Tremolite* has not so far been discovered as an economic fibre deposit in this province.

The most important *chrysotile* deposits lie in the Barberton District near the village of Kaapsche Hoop in the Eastern Transvaal (New Amianthus and Munnik-Myburgh Mines) and their steady production for a number of years continues a main factor in the Union's increased output of asbestos. Here also belong the deposits of the Kalkkloof Mine east of Carolina. Minor deposits of chrysotile have also been found in the Komati River Valley (Sterkspruit, etc.) near Krugersdorp and elsewhere. (See Chapter VII.) In all these localities the mode of occurrence is typically associated with serpentinous rocks.

Chrysotile has also been discovered in a series of localities in the Eastern and Northern Transvaal in the Dolomite Series, where this has been altered by intrusive sills; exploitation has been intermittent, and so far their contribution to the Union's output has remained almost negligible.

During recent years the asbestos resources of the Transvaal have been very materially enriched through the discovery of *amosite*, first in the Lydenburg District (Penge Mine), but later on found to extend without any geological break across the Olifants River into the Pietersburg District, so as to form the so-called Pietersburg Asbestos Fields. These new resources thus constitute a belt extending through some 60 miles from the Steelpoort River in the Eastern to Chuniespoort in the Northern Transvaal; very large quantities of this fibre are beyond doubt available here.

Within the limits of the Lydenburg and Pietersburg Fields, *crocidolite* is found at intervals along certain horizons in the same formation that carries amosite, though the quantities available of the "Blue" fibre is very much less than in the case of the amosite, while—in general—the quality is on the whole, not so good as in the Cape Crocidolite belt.

Anthophyllite has up to the present been found—as an economic deposit—only in the Zoutpansberg District west of Waterpoort Siding, but the fibre does not come up to textile standard.

IA. Chrysotile Deposits Associated with Serpentine (Barberton-Carolina Asbestos Fields).

General Remarks.

Within the area here referred to as the *Barberton-Carolina Asbestos Fields, chrysotile* is the only fibre variety so far exploited, though tremolite has been recorded but is not up to the present found under economic conditions. The chrysolite workings are associated with two quite distinct formations; in one case the fibre occurs in more or less typical serpentine, comparable to that of the well-known Canadian and Rhodesian asbestos deposits. In the other case chrysotile is found in the much younger dolomite formation of the Transvaal system. (See Chapter IV.)

Within that section which falls into the Barberton District, the most important deposits are those of the *New Amianthus* and *Munnik-Myburgh* mines, which, notably the former, contribute a substantial share of the Union's output: there are also a series of minor occurrences, that are referred to in Chapter VII.

The most important chrysotile deposit in serpentine within the Carolina District is that worked in Kalkkloof (African Asbestos Trust) on the south side of the Komati River, but here also there are a series of minor occurrences of chrysotile in serpentine; they lie on the north side of the Komati River in the extreme eastern portion of the Carolina District. (See Chapter VII.)

Chrysotile Deposits in the Barberton District Near Kaapsche Hoop (New Amianthus and Munnik-Myburgh Mines).

1. *Situation.*—The New Amianthus and Munnik-Myburgh mines are respectively 14 and 17 miles by road from Godwan River Station (Delagoa Bay Line); the nearest centre is the little village of Kaapsche Hoop, distant 2½ miles from the first and 5½ miles from the second mine. Both lie in the same broad belt of serpentine, and though chrysotile was first noted from this locality as long ago as 1905, systematic prospecting was not carried out until about 1915; soon after this the

great potentialities of these deposits were fully appreciated, with which development the late A. T. Judge was prominently associated; active exploitation of asbestos has now been carried on at these mines for over 10 years.

The serpentine belt together with the area surrounding the workings are associated with very striking scenery, falling for the most part into the so-called "Mist Belt"; a region of exceptionally high rainfall, due to the fact that the area belongs to the eastern slopes of the Transvaal Drakensberg. Very deeply dissected country with consequent high and striking relief is characteristic of this section of the Eastern Transvaal. The Drakensberg here builds the Great Eastern Escarpment, capped by a plateau-like feature due to nearly horizontal and resistant quartzites (Black Reef Series), underlain by relatively easily eroded softer formations—Older Granite, serpentine, small masses of basic schists, etc. On its east side the Drakensberg presents a steep escarpment which leads from the plateau down into the De Kaap Valley (filled for the most part with granite) situated some 2,000 feet below the edge of the escarpment. Over these "Eastern Slopes" the softer formations referred to are more or less decomposed, sometimes to a depth of as much as 50 feet. The New Amianthus Mine (see Plate X) lies on the lower portion of the "Eastern Slopes," under the Escarpment, while the Munnik-Myburgh Mine lies some 3 miles to the east, but in the same serpentine belt.

2. *Geological Features.* (See Plate XXXV at end.) In passing from the plateau at the top of the Drakensberg down the eastern slopes into the De Kaap Valley, the following succession is traversed:—

(*a*) Quartzites and conglomerates—belonging to the Black Reef Series.
(*b*) Basic Amydaloidal Lavas.
(*c*) Brown, somewhat ferruginous slates, underlain by a thin impure quartzite.
(*d*) Serpentine.
(*e*) Older Granite.

(*a*) *The Black Reef Series* (lowermost division of the Transvaal System) consists of a group of thickly bedded gray quartzite, often showing scattered rounded pebbles, and generally having conglomerate bands at or near the base. This formation has a approximate thickness of about 60 feet and dips a few degrees to the west; it is highly resistant to weathering and thus forms a plateau-like capping above the underlying rocks. Being much younger than the serpentine belt, it is not directly concerned in the geology of the chrysotile deposits.

(*b*) Directly underlying these quartzites comes a considerable development of greenish *amygdaloidal lavas*—several hundred feet thick, and well exposed above the New Amianthus workings; these lavas in general appearance recall the Klipriversberg Amygdaloid of the Ventersdorp System. Their strike is approximately north and south, and their distribution in plan is in the form of a very narrow strip, widest around the New Amianthus Mine, but rapidly tapering away towards the north as well as towards the south.

(*c*) Below these lavas is a thin group of soft thinly bedded brownish *ferruginous slate,* underlain by a thin impure *quartzite.* The strike of these beds is again roughly north and south, while they dip approximately to the west at from 10 to 40 degrees; the total thickness is not very clearly seen, but probably in the neighbourhood of 20 to 60 feet.

The stratigraphical position of formations (*b*) and (*c*) is doubtful; they certainly do not belong to the Black Reef or to the Jamestown Series, which includes the serpentine belt, and may be provisionally assigned to the Ventersdorp System. In the deep valleys west of the escarpment, where the Black Reef Series has also been cut through (e.g. top end of Barretts Berlyn Creek), there are indications of similar lavas.

The shales and quartzites form a useful marker when tracing the theoretical position of the " Ribbon Line "—the chrysotile horizon worked at the New Amianthus Mine—along the strike, since that line is characteristic of the immediate contact between the slate-quartzite group and the underlying serpentine formation.

Towards the north the rocks of group (*c*) can be traced almost to the edge of the escarpment (i.e. to the Black Reef quartzites), and towards the south they persist from Northern Joubertsdal (in which the New Amianthus Mine lies) into southern Joubertsdal, but their presence has not been demonstrated further south nearer to Kaapsche Hoop Village. The limited distribution of the lavas and their underlying sediments suggests the possibility that one is dealing with a small development of Ventersdorp beds formed in a local hollow due to the erosion of the pre-existing Jamestown Series.

Right at the base of these sediments, between them and the underlying serpentine, one finds not infrequently a doleritic sheet, well seen as the hanging wall in some of the underground workings of the New Amianthus Mine; in places it is so highly altered as to form a soft brown clayey band.

(*d*) *The Serpentine Belt.*—This forms a long narrow band of predominantly basic rocks, included in the Jamestown Series, which separates the abnormal " granite " of the De Kaap Valley from the normal granite of the Nelspruit area and embraces serpentine and allied basic igneous rocks, soft talcose, together with other basic schists, as well as a quite subordinate development of sediments such as slaty

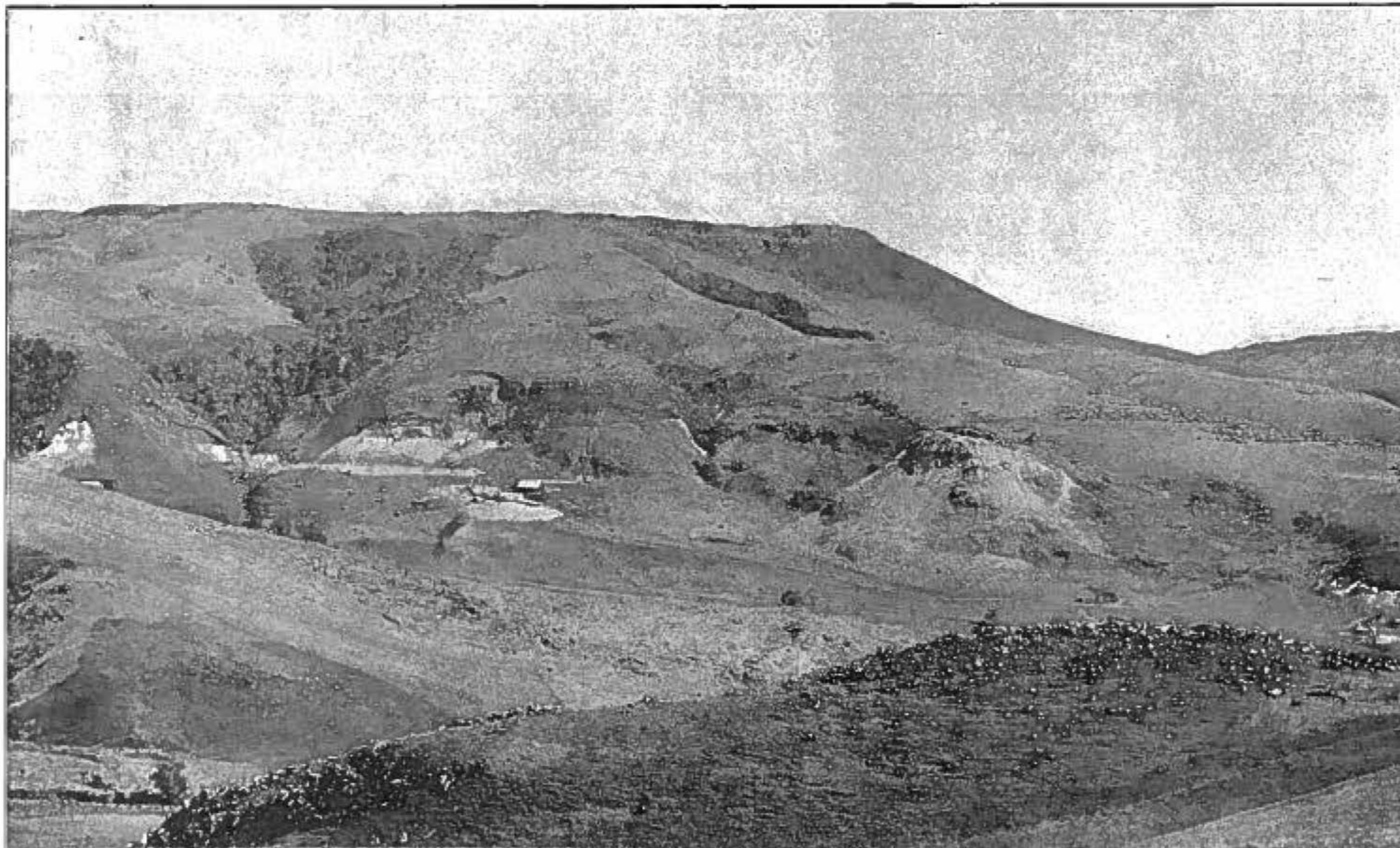


PLATE X.—*General View of the Amianthus Mine* near Kaapsche Hoop (Barberton District); in the background is the edge of the Transvaal Drakensberg (Black Reef quartzites); a little to the right of the centre the old workings of the Griffin Line. To the left of the centre are seen the outcrop workings of the Ribbon Line. Photo by Alan Yates.

quartzites, quartzitic slates, etc. This belt extends* for some 50 miles continuously from near Hectorspruit in the east westwards through Sheba siding, until it passes under the Transvaal Drakensberg a little north of Kaapsche Hoop.

The asbestos occurrences are in this serpentine band; from Sheba Siding westwards towards the edge of the Great Eastern Escarpment, the dominant schistose character—as seen e.g. along the Worcester Mine Section—gradually gives place to thoroughly massive basic rocks, in which various serpentines of great thickness predominate. From the Drakensberg eastwards for some 3 or 4 miles the serpentine formation on Joubertsdal (New Amianthus Mine) and on the adjoining Government Ground (Lots Nos. 165, 161, etc., Munnik–Myburgh Mines) is from 2 to 2½ miles wide, and is made almost wholly of serpentines with closely allied basic or ultrabasic rocks, showing the structure represented in Fig. 13; for the most part the basic belt gives rise to long serrated and conspicuous rugged ridges, strewn with large pitted blocks of serpentine often having a characteristic black surface of weathering.

GENERALIZED SECTIONS ACROSS THE EASTERN PART OF THE SERPENTINE BELT NEAR KAAPSCHE HOOP, TO ILLUSTRATE THE PROBABLE TYPE OF FOLDING.

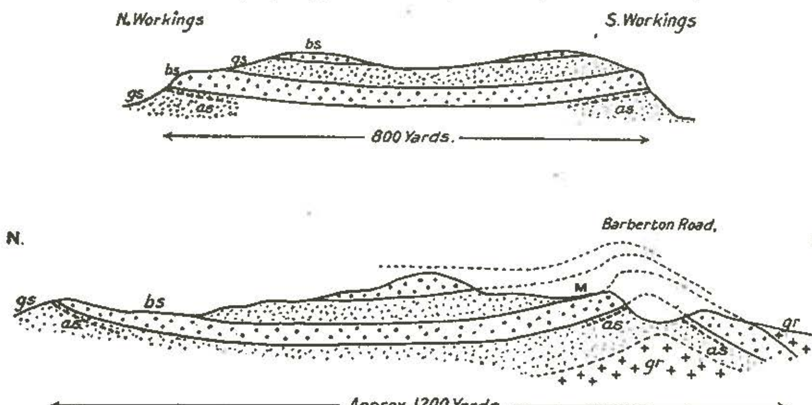


Fig. 13.

gr. = granite; as = cross fibre chrysotile; gs = green or fibre serpentine; bs = dark bluish black or "barren" serpentine.

In the neighbourhood of the chrysotile occurrences (specially at the Munnik–Myburgh Mine and near the abandoned Griffin Line workings of the New Amianthus Mine) the serpentine belt is made up of a number of separate, but petrographically closely related sheets of basic rocks, that have been thrown into a gently folded structure. Fig. 13 is taken from north to south across the nearly east and west

* Its general distribution is shown on the map accompanying Geological Survey Memoir No. 9.

strike and shows a synclinal arrangement followed near the southern edge of the belt by an anticlinal structure (*as* in Fig. 13). The anticlinal axis more or less coincides for some distance with the floor of a short narrow side valley, up which runs the Barberton main road, each side of this valley being defined by steep rugged slopes due to successive sheets (marked *gs* and *bs* in Fig. 13); a definite measurement of the thickness of each sheet is very difficult to obtain, but probably it is not less than 100 feet. In the field the differences between the sheets is clearly traceable in the scenery; along the little valley referred to, for example, the lower sheets *gs* of Fig. 13 (lower section) developes almost black surfaces of weathering, whereas over the highest slopes the upper sheet *bs* gives rise to short conspicuous krantzes of large rugged blocks with characteristic gray weather surfaces. Similar scenic contrasts can be traced over the south-western portion of Joubertsdal—where the earliest workings of the New Amianthus lie (abandoned Griffin Line)—and further east towards the Munnik-Myburgh area; in the latter direction an exactly similar contrast is repeated at the upper contact between *bs* and its overlying sheet (point M in Fig. 13, lower diagram).

From the point of view of the asbestos deposits there are *two distinct varieties of serpentine.* One of these is a dull green serpentine, denoted by *gs* in Fig. 13; it forms the lowermost (and also a second one higher up): another, marked *bs* in the same figure, rests above the lowermost green variety and is a dull black or bluish black rock, when freshly broken. These distinct bands thus form an alternating series of green and black serpentines.

The Green or Fibre Serpentine.—It is this variety that carries the asbestos, and occupies the lower slopes of the hills and ridges; though distinctly green on a fresh fracture, it has a characteristic black surface of weathering. In some workings, the rock is very fine grained, with a smooth texture resembling that of jet (so-called talcose serpentine); elsewhere it has a granular appearance as e.g. in the "bush gully" workings.

Apart from cross fibre seams of chrysotile, the green serpentine shows thin veins of ilmenite and stichtite in delicate irregular brilliantly lilac-coloured veinlets or more often in similarly coloured very thin films on joint faces. Under the microscope the rock is almost entirely made up of very pale green serpentine with characteristic fibrous structure and dusted with granular iron ore. There are also a few scattered grains of pale pink stichtite with good crystal outlines, which appear like a replacement aggregate of a cubic mineral, most probably chromite, since chromium is an essential constituent of stichtite; this mineral is also found in very slender veins traversing the serpentine. The derivation of the latter is doubtful, as no residual parent mineral can be definitely recognized, but though typical mesh structure is not always well marked, there is little doubt that the rock must be classed as an olivine rather than as an amphibole serpentine, a conclusion borne out by the Bulk Analyses I and II in Table No. 20, and also by the intimate association with chromium-bearing stichtite, chromite being highly characteristic of intrusions rich in olivine.

TABLE No. 20.—*Analyses of Serpentines and Stichtite.*

	Serpentines.				Stichtite.
	I.	II.	III.	IV.	V.
SiO_2	40·15	41·15	37·15	50·75	4·50
TiO_2	—	—	—	—	—
Al_2O_3	2·35	1·95	3·20	3·40	·90
Cr_2O_3	—	—	1·40	—	8·90
Fe_2O_3	3·85	2·35	7·70*	1·25	10·60
FeO	·45	·25	—	7·40	·85
NiO	·30	·30	—	—	·10
CoO	Nil	·40	—	—	—
CaO	·40	·05	—	·75	—
MgO	38·40	38·05	36·20	28·80	36·70
K_2O	·10	·10	—	·15	tr.
Na_2O	·25	·25	—	·50	·05
CO_2	—	—	—	—	6·90
H_2O (100° C.)	—	—	—	—	3·65
H_2O (Ignition)	—	—	—	—	26·80
Ignition	14·35	16·05	15·10	6·75	—
	100·60	100·90	100·75	99·75	99·95

* Total iron calculated as Fe_2O_3.

I. Green Serpentine, Northern Joubertsdal; analysis by Dr. McCrae, Government Chemical Laboratories, Johannesburg.
II. Green Serpentine, adhering to chrysotile, Northern Joubertsdal; analysis by Dr. McCrae, Government Chemical Laboratories, Johannesburg.
III. Stichtite bearing green serpentine, Northern Joubertsdal; analysis by Dr. McCrae, Government Chemical Laboratories, Johannesburg.
IV. Blue-Black Serpentine; Northern Joubertsdal; analysis by Dr. McCrae, Government Chemical Laboratories, Johannesburg.
V. Stichtite from the New Amianthus Mine, Northern Joubertsdal; analysis by Dr. McCrae and H. G. Weall, F.I.C., Government Chemical Laboratories, Johannesburg.

Note on Stichtite.—This mineral is a chrome-bearing hydroxy-carbonate of magnesia, with a very beautiful delicately lilac colour; it is named after Sticht, the general manager of the Mount Lyell Mining and Railway Company in Tasmania, where it was known since 1891, though its first discovery is due to Dunn in 1883, where the old wagon-track to Barberton used to intersect the serpentine north of the New Amianthus Mine. The mineral occurs essentially as a surface phenomenon and is found plentifully in the old workings and the dumps of the new abandoned Griffin Line of the New Amianthus Company. The usual occurrences is in thin veneers or irregular small pockets in the green serpentine; at depth stichtite becomes distinctly scarce, and its general distribution and composition as a hydrated magnesium carbonate are characteristic of a mineral found within the zone of weathering; this aspect is of special interest, in view of the intimate association with chrysotile and the restriction of both minerals to the green variety of serpentine. In No. V of Table No. 20 an analysis of stichtite is given; for further details see Bibl. No. 30.

The *Blue or Barren Serpentine* overlies, or comes between two sheets of, the green serpentine (Fig. 13, lower section), often forming the higher slopes of the ridges, and is also a massive fine-grained rock, but has a uniformly dull dark grayish blue or dark bluish gray (almost black in places) colour, when freshly broken; it then shows a rough surface. In strong contrast to the green variety, its weathered outcrops tend to develop grey surfaces, often deply pitted as in the other variety. No asbestos, ilmenite, or stichtite are found in it, and it is also distinctly harder than the green serpentine. The thin section shows a very small amount of iron ore, but otherwise consists of large pale gray to nearly colourless crystals, more or less completely replaced by irregular aggregates of finely fibrous talcose or serpentinous material. In hand specimens the general appearance is that of serpentine, but the microscopic characters of the blue are different from those of the green variety, though both are highly serpentinized. It is difficult to define the difference precisely, but it is reflected in the analyses, given under IV in Table No. 20, which shows the rock to be less basic through having a markedly higher silica percentage and being poorer in magnesia in comparison with the green variety tabled under I and II. There is also a notable increase in the amount of ferrous iron, and a much smaller percentage of water of constitution. The green serpentine originated almost certainly as a basic rock rich in olivine, but the blue serpentine is probably derived from an amphibole or pyroxene—rich rock—both now more or less wholly serpentinized; this view also has some support from the absence of chromium in the blue variety, since rocks essentially amphibole- or pryoxene-bearing are not the characteristic home of chrome iron, in the sense that olivine often is; the differences are not essential, and may be regarded as cognate rather than accidental—i.e. consistent with a series of intrusions derived successively from a common basic or ultrabasic stock, a genetic history almost certainly applicable to the serpentine belt as a whole.

(*e*) *Granite.*—This formation is intrusive in the Jamestown Series (serpentine included) the resultant metamorphic effects being very powerful both mineralogically and structurally, as more fully set out in Geological Survey Memoir No. 9. On the south side of the serpentine belt the granite is that described elsewhere (Bibl. No. 28A) as the De Kaap valley type, that on the north side forming the Nelspruit type of Older Granite. It is interesting to note that the distribution of the chrysotile deposits within the serpentine does not show any definite relation to the margins of the granite, such as one might expect to find on the supposition that chrysotile is the result of metamorphism due to an intrusive granite.

THE CHRYSOTILE DEPOSITS OF THE NEW AMIANTHUS MINE.

1. *Situation and Horizon.*—The asbestos deposits owned by the New Amianthus Mines, Ltd. (subsidiary to Turner and Newall, Ltd.) lie in the south-western portion of the farm Joubertsdal No. 99 and west of the powerful perennial stream, known as Gladde Spruit which crosses the farm from south to north. The area controlled by the above company forms the major portion of Joubertsdal, known as Northern Joubertsdal; the remainder forms a narrow strip, known as Southern Joubertsdal, the northern boundary of which coincides with the southern limit of Northern Joubertsdal. A block of 60 claims—formerly worked by the Kaapsche Hoop Chrysotile, Ltd.—and situated on Southern Joubertsdal—has also passed into the control of the New Amianthus Limes, Ltd., but is no longer worked.

It is now well established that there are two distinct fibre horizons on Joubertsdal; they are known as the *Griffin Line* and the *Ribbon Line,* both lying in the serpentine belt referred to, but whereas the former is associated with the contact between the green or fibre serpentine and the blue or barren serpentine, thus striking east and west, the Ribbon Line strikes approximately north and south, and is restricted to the contact zone between the base of the shale-quartzite group (series *c* described above) and the underlying serpentine.

2. *Distribution. Mode of Occurrence and Development of the Griffin Line.*—This deposit was the first to be discovered and continued to be exploited by the original Amianthus Co. until about 1921, when the location of a very much richer horizon, known as the Ribbon Line, led to the abandonment of the first discovery.

The Griffin Line was found to persist continuously over some 800 yards from the left bank of Gladde Spruit westwards towards the Drakensberg along an east and west strike. In conformity with the synclinal arrangement (see Fig. 13 upper section), a fourth occurrence was located and opened up at the northern end of the sheet of green serpentine. The seams keep to the contact between the two kinds of serpentine so as to extend up to about 15 feet from that horizon downwards into the green or fibre serpentine (*gs* in Fig. 13, upper section). No chrysotile was found in the overlying blue or barren serpentine. On Northern Joubertsdal the asbestos horizon coincides with the *lower contact—as* in Fig. 13 above referred to—between the two basic sheets, and this position is so definite and persistent that it can hardly be accidental, but points strongly to some genetic condition depending upon the constant association of the two varieties of serpentine. This conclusion is much strengthened by the experience that further along the serpentine east of Gladde Spruit at the Munnik–Myburgh Mine the fibre horizon is similarly placed at the junction between the green and blue types of country rock, but now it is along the *upper contact* of the same sheet; the letter M in Fig. 13 Lower Section indicates the Munnik Myburgh asbestos horizon.

Under the regime of the former Amianthus Company, the Griffin Line was opened up by a large number of prospecting pits, irregular small quarries and other opencast workings, but including two major adits, aligned north and south, each some 120 feet long. At a point some 50 feet below the surface, each adit led into drives along the fibre line, the latter being followed for a total distance of over 360 feet; the developments along the southern edge of the syncline were grouped as the "Southern Workings," those situated at the other end of the syncline being known as the "Northern Workings." The principal source of production was the southern line.

The fibre is all in the form of cross fibre chrysotile seams made up of very delicate silky fibre of superior quality and without foreign admixtures. The most striking features * about these seams is their remarkably regular disposition and great number (e.g. 20 to 40 per linear foot of face). In almost all faces the seams are often nearly parallel—in some cases strictly parallel—to one another and to the contact plane between the green and blue serpentine, in strong contrast to the behaviour of chrysotile seams in other parts of the world, where an irregular network is the rule. In conformity with the structure, the dip of the contact plane and seams is to the north in the southern and to the south in the northern workings—varying from 10 to 25 degrees.†

The frequent occurrence of stichtite in brilliant lilac coloured coatings on the green serpentine or in very slender veinlets has been referred to and is a very characteristic feature in the workings of the Griffin Line.

3. *Mode of Occurrence of the Ribbon Line.*—The later discovery of the second fibre horizon on Northern Joubertsdal was made about

* Similar features can be observed at the Kalkkloof Mine in the Carolina District and were noted in 1905 on the farm Honing Krantz, south-west of Pretoria.

† Later work carried out by the New Amianthus Co. showed this value to become locally as high as 50 to 60 degrees.

1921 at the spot now known as "Bush Gully" and the great significance of the extraordinary richness of the new deposit was soon realized; since the date referred to production has been restricted to the Ribbon Line, both by the original Amianthus Co. as well as by the New Amianthus Mines, Ltd. Plate XI was taken in 1921 and shows a typical outcrop (now destroyed) of the fibre channel not far from its first point of discovery.

As already remarked, the Ribbon Line strikes approximately north and south, i.e. almost at right angles to the Griffin Line and is restricted to the contact plane between the base of the shale-quartzite series (Ventersdorp System?) and the underlying green serpentine. The hanging wall is formed in some places of the bottom of the quartzite band, but elsewhere it is due to a thin doleritic sheet, seen in the roof as a well-defined fine-grained dark greenish rock, not infrequently separated from the underlying serpentine by a thin clayey parting only a few inches thick, probably igneous material.

Fig. 14 represents a typical mode of occurrence of the Ribbon Line nearer the surface, the seams dipping at this point some 10 degrees to the north, while the fibre channel measures 15 feet in width.

Over some 7 feet the serpentine is densely packed with a very large number of parallel seams—increasing from 15 per linear foot in the uppermost to 30 per linear foot in the central portion of the face—the fibre length ranging from half an inch downwards. The marked regularity of this alternation recalls the appearance of the "calico" or "bacon" rock common in the banded ironstone of Moodies and the Lower Griqua Town Series. Examples are abundant, in which the alternation of seams and serpentine is as regular as ruled paper, while the fibre disposition is at the same time so uniform, that on holding out such a lump to the sun at suitable angles, there is a kind of "optical continuity" that may be likened to an excessively coarse poikilitic structure. In the figured face the upper 7 feet consist roughly of 40 per cent. of chrysotile and 60 per cent. of rock. It is underlain by more green serpentine in which the seam "density" (i.e. number of seams per linear foot) decreases markedly, but individual seams become much thicker—up to three inches and over. (See Plates XI and XII.) This characteristic progressive decrease in seam density with corresponding increase in fibre length, when pasing downwards from the hanging wall is a constant feature more or less throughout the workings, notably in the upper levels and nearer the surface. (See Plate XII.) The section illustrated in Fig. 14 is therefore not an exceptional occurrence, but recurs again and again over several hundred feet of strike, with only minor variations in seam density and fibre length.

Along one drive the banded serpentine was 7 feet wide and crowded with parallel seams, none of which under one quarter of an inch thick, while 10 seams consisted of fibre about ¾ of an inch long; at one point occurred a short seam 8⅝ inches thick, but interrupted by a plane of discontinuity.

SECTION EXPOSED NEAR THE WEST END OF THE AMIANTHUS MINE ON JOUBERTSDAL.

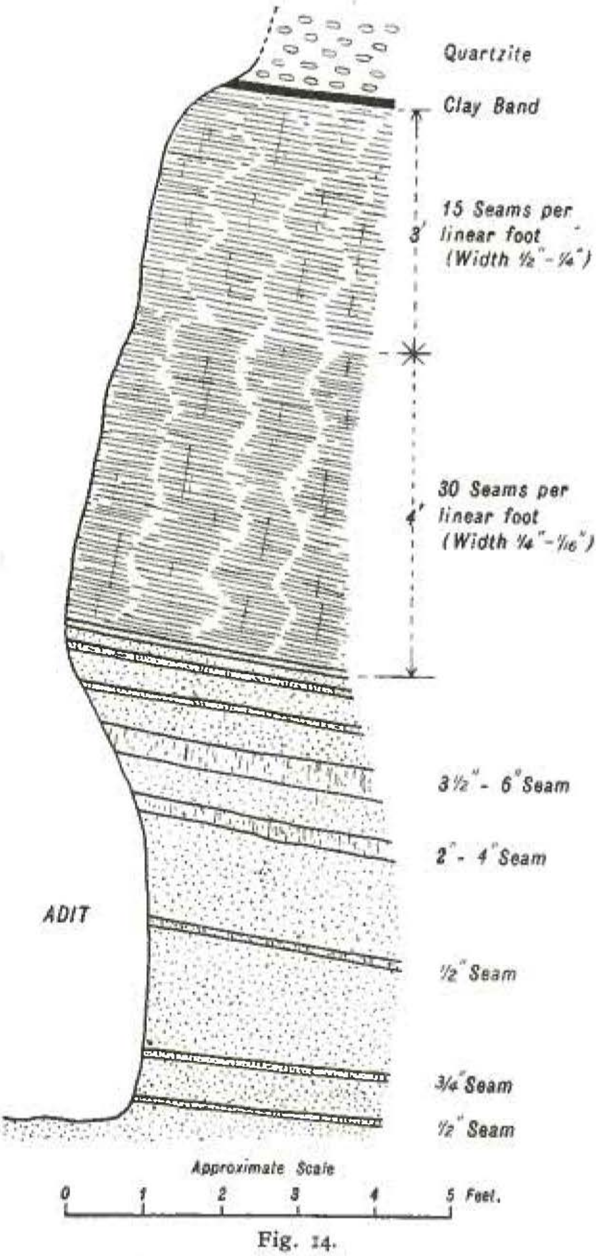


Fig. 14.
Chrysotile in green serpentine.

PLATE XI.—*New Amianthus Mines,* near Kaapsche Hoop (Barberton District) showing the characteristic association of countless parallel chrysotile seams.

In what was then known as the "Ribbon Adit" the regularly banded character of the fibre was very strikingly displayed over about 100 feet from the surface along the dip; the asbestos zone kept up a width between 5 and 7 feet, the entire face of 7 by 7 feet being ribbon rock. Over 150 parallel seams were counted, ranging from more or less ¼ up to 1½ inches, the great majority being close to the lower limit.

It is not surprising, therefore, that the underground appearances of the mine—specially in the upper levels nearer to the outcrop—presented a spectacle of striking beauty, the sides and faces of the drives being scored by countless seams of glittering white or faintly golden coloured chrysotile. Since the country rock is for the most part fairly soft, it can be readily understood that in a deposit of such richness, it was possible to maintain a steady production of marketable fibre almost entirely from development alone.

The extent to which the experience along the outcrop of the fibre horizon (or nearer the surface) was found to persist, as the development proceeded further on the dip, is hown by the instructive Table No. 21.

TABLE No. 21.—*Number and Thickness of Seams at Various Depths Below Surface. (Amianthus Mine.)*

Position.	Below Surface.	On Dip.	Width of Fibre Line.	Seam No.	Details.
First Level	10 ft. Vertical	15 ft. from Surface	12 ft.	165	2 over 1 in. 5 ½ – 1 in. 158 ½ – 1/16 in.
First Level	250 ft. Vertical	250 ft. from Surface	7½ ft.	100	1 1 in. 5 ½ in. 94 ½ – 1/16 in.
No. 4 Adit, Second Level	300 ft. Vertical	325 ft. from Surface	10–12 ft.	100	5 1 in. and over. 5 ½ in. 90 ½ – 1/16 in.

This table shows that the width of the Fibre Belt, number of seams, and their thicknesses are maintained with the same orders of magnitude from the surface down to the maximum depth reached at the time the above results were obtained (March, 1923).

4. *Development.*—Since the present company acquired control, a large amount of development has been done, a detailed account of which lies outside the scope of these pages. In principle the lay-out of the

mine is by means of six levels, numbered from above downwards. Of these No. V and No. VII do not exist, while Level No. VIII is only reached from Level No. VI. The following Table No. 22 will give some idea of the underground extent of the mine :—

TABLE No. 22.—*Some Factors in the Development of the New Amianthus Mine.*

Levels.	Vertical Intervals.	Level from Surface. Length of Adit.	Approx. Length of Drives.	Remarks.
I..........	0	—	—	—
II.........	62	—	—	—
III........	65	—	—	Reached from IV.
IV........	35	1,180 feet	3,200 feet	—
V.........	—	—	—	Non-existing.
VI.........	120	2,570 feet	3,000 feet	—
VII........	—	—	—	Non-existing.
VIII.......	106	—	1,100 feet	—

The dip varies from 10° to 22° directed to the north-west, while the proved continuity of the fibre channel along the strike is not less than 3,500 feet. The farthest point reached underground, in following the asbestos zone on the dip, is approximately 1,650 feet from its outcrop, which figure corresponds to an approximate vertical depth of some 800 feet below the surface. The essential geological features in the mode of occurrence of the fibre, as described above, hold good in this development, but as a general rule, the width of the fibre belt lies between 5 and 7 feet, with many closely spaced parallel seams in the upper, and a few more widely-spaced but thicker seams in the lower portion; this is typically seen in the fourth level, at he upper end of the incline shaft leading to the sixth level.

From the sixth level an incline shaft leads down to the eighth level, and in the hanging wall of the fibre channel at several points along this incline some very sharp contacts are seen between the serpentine and the overlying country. Directly at the contact the hanging wall is a light-coloured fine-grained rock (altered serpentine?) occupying the position which in other levels marks the extreme lower selvedge of the doleritic sill. Close to the point where the incline opens into the eighth level the fibre zone shows a synclinal structure and a cross-cut some 110 feet long, aligned along the horizontal component of the direction of dip, intersects the asbestos channel at the far end of the cross-cut, the seams now dipping in the reverse direction. From this point a subsidiary parallel level known as No. VIIIA follows the fibre zone both east and west for several hundred feet, though the ore channel

PLATE XII.—*Typical Section across the Ribbon Line* of the New Amianthus Mine near Kaapsche Hoop (Barberton District) to show the characteristic upper portion with many parallel chrysotile seams, and the lower portion with a few, more widely spaced, thick seams.

is not continuous all the way. Its width and display is sometimes comparable to what is typical of higher levels, and several seams occur up to 2 inches thick and of very fine quality. More often, however, the width of the fibre channel is round 30 to 36 inches, as compared with 5 feet in the upper levels.

The writer's general impression of the deep levels, as they appeared in June, 1930, is that on the whole the display—specially as regards ore channel width and proportion of textile fibre to "shorts"—is not as favourable as it is in the upper levels, i.e. not comparable to the fibre development reflected in Table No. 21 above. This naturally does not imply that large tonnages of fibre are not still available from the deepest point reached.

5. *Proportion of Fibre to Rock.*—Attention has been called above to the danger of basing the fibre percentage on the simple method of measuring sections across the faces at regular intervals, and the best and really reliable data can only be obtained from a comparison between the tonnage of fibre rock cobbed and milled and the total market production. Detailed information is not, however, always available for publication. At one period in the history of the Amianthus Mine three short tons of fibre rock from the Ribbon Line produced one short ton of graded asbestos (equivalent roughly to 30 per cent. recovery), made up as follows:—

10 per cent. of grade ½ inch to ¾ inch.
40 per cent. of grade ¼ inch to ½ inch.
50 per cent. of grade 1/5 inch to ¼ inch.

Over the upper section of the fibre body the recovery* remained consistently near 30 per cent., while over the lower section in the best portions of the mine it repreesnted 10 per cent. through distances up to 300 feet along the strike. The zone of closely spaced seams was found to maintain more or less uniform features, while the lower zone of more widely spaced and thicker seams showed more variation, the most payable sections roughly corresponding to extended lenticular "chutes."

In respect of this high proportion of fibre to rock later developments of the New Amianthus do not present any experience fundamentally different, though the present underground evidence suggests that this aspect is not so favourable as that indicated above.

The treatment plant has a capacity of 6,000 short tons per month, so that the normal monthly output of about 1,000 tons of fibre points to a recovery of between 15 and 17 per cent.

The *fibre length* varies between wide limits, but individual seams often maintain the same thickness for feet or even a few yards. The

* A certain proportion of fibre is also recovered from the furrows draining the workings.

variation in fibre length is usually much more apparent with reference to the distance at which a seam lies from the contact plane above. What is probably a record length from this fibre channel amounts to 7 inches—naturally a very exceptional occurrence; fibre measuring 3 to 4 inches is not uncommon, though constituting a very small fraction of the total production. Values between one inch and a quarter inch are the common rule, apart from those sections in the upper portion of the fibre belt, where there is a greater development of densely crowded very narrow seams. It is very difficult to arrive at an " average " fibre length, and a more satisfactory economic picture is furnished by the relative proportions of the various lengths recovered during a normal working period; such information affords the only satisfactory index of what the potentialities are regarding fibre length of textile proportion.

Table No. 23 shows how the total production was divided among the different grades during an earlier stage in the development, covering two distinct periods. In the first period—4 months—the output was classified into five grades, with the result that 27.21 per cent. of the total output was fibre over one inch long. In the second period (fifth month), after it has been shown that it was possible to recover fibre from the more finely banded section of the asbestos zone, a new factor was introduced into the grading scheme, so that the fibre percentage over one inch in length dropped to 8.24. This result is not due to a decrease in the number of thick seams encountered in the mine, but to a more thorough fibre recovery from the thinner seams.

TABLE No. 23.—*Proportions of Fibre Length in the Output of the Amianthus Mine.*

Description.	Preparation.	Percentage of First Period.	Total Output. Second Period.
		Per Cent.	Per Cent.
Over 2½ inches............	Hand Cobbed	3·87	1·80
1½ to 2½ inches...........	Hand Cobbed	9·25	3·04
1⅛ to 1½ inches...........	Hand Cobbed	14·09	3·40
Over ⅝ inch..............	Screened	39·89	24·30
¼ to ⅝ inch...............	Screened	32·98	42·20
⅛ to ¼ inch..............	Machine Milled	—	27·50

The present position* at the New Amianthus Mine (July, 1930) with regard to spinnable and non-spinnable proportion is shown in Table No. 23A.

* Information kindly supplied by Mr. R. Starkey, General Manager, Rhodesian and General Asbestos Corporation, Ltd.

TABLE No. 23A.—*Textile Proportion in the New Amianthus Mine* (1930).

	Per Cent.	
Crude (Hand Cobbed)	0·9	8·0 per cent.
Spinning Fibre	7·1	
Shingle Stocks	92·0	
TOTAL	100·0	

The above proportion correspond to 8.0 per cent. of the output being spinnable, which compares very favourably with that of the Canadian deposits, where the textile proportion is 6·65 per cent.

6. *Fibre Quality, Plastic Fibre, Cone Structures, Nickel Sulphide.*—Fresh fibre lumps show the delicate pale olive green or greenish yellow tints characteristic of the best varieties of chrysotile and are sometimes translucent, even when three-eighths of an inch thick measured across the direction of fibrous structure. They are readily fiberized by hand, when a snow-white or almost snow-white fleecy material is obtained made up of extremely slender strands of great tensile strength; other properties of chrysotile—to which the New Amianthus fibre also corresponds—are given in Chapter I. Seams are also occasionally met in which the fibre has a lower tensile strength and a tendency to become talcose. Table No. 1 above includes an analysis of typical fresh longer fibre, and shows the composition to agree very closely with the mean of 11 analyses from the Canadian chrysotile deposits.

Plastic Fibre.—At many points in the drives of the higher levels, specially in the wetter portions of the workings, where the seams have been exposed for a longer time, long thin pale yellow strands of thoroughly damp matted fibre, sometimes as much as five feet long, were observed hanging from the edges of seams. The term "plastic fibre" has been used to denote this material from the fact that it can be readily moulded into all manner of shapes; when taken out of the mine and left exposed to the sun, such fibre loses most of its moisture, shrivels up and hardens, until the appearance of the material is best described as resembling biltong or deteriorated leather.

Abundance of water in the mine, combined with the soft character of the country rock, and the weight of super-incumbent rock tend to accentuate the effects of mountain pressure. Under this some of the seams yield laterally and are slowly squeezed out, a result probably assisted by the lubricating action of ground water. A very slight lateral movement of chrysotile with its perfect fibrous structure and high tensile strength would suffice to produce a short strand lengthening out under gravity as soon as the seam has lost the support of its footwall, until eventually a long mass of pendant fibre is produced. Kupferbürger has shown (Bibl. No. 46) that no marked difference exists in chemical composition between the normal and plastic varieties of chrysotile and has concluded that the plasticity is due to the colloidal state of some of the constituents.

Cone Structures.—At the New Amianthus Mine is a unique occurrence of cone structure in fibre rock, first described by the writer in 1923 (Bibl. No. 31), of which no previous record in the literature appears to exist.

The most interesting display of these structures was met with in October, 1922, when at a point some 20 feet vertically below the surface in the Ribbon Line the face of the adit presented the appearance reproduced—slightly simplified, in Fig. 15.

This face is now destroyed: it was 7 feet high and about 5 feet wide and consisted of massive dark greenish serpentine, showing chrysotile seams and cone-shaped masses of fibre rock. From the floor upward through a width of about 3-4½ feet the face showed the normal appearance characteristic of the lower portion of the Ribbon Line, i.e. a few more widely spaced thick parallel seams of chrysotile. From the hanging wall downwards over a vertical width of 2 to 3 feet the upper part of the face showed a feeble development of ribbon fibre in the form of a few closely spaced short and narrow somewhat shadowy seams of chrysotile, associated with several striking cone-shaped bodies each made up of an alternating series of thin seams and serpentine. Some cones start at the roof of the face, others begin in the serpentine a little below the hanging wall (see Fig. 15); some end in a blunt apex while others taper off delicately to a fine point, whence an almost invisible thread of fibre rock passes down to merge with a seam below. Neither in the country rock between the seams nor round the cones was there any fibre.

The same structures were later on found in other parts of the mine, but on the whole the cones are rare. In a few instances a cone was also found right in the upper portion of the ribbon line, with the horizontal seams on either side continuous right up to the mantle of the cone. Some 17 cones had been recovered—most of these in perfect condition—before a fall of rock destroyed the face shown in Fig. 15.

The form of these peculiar bodies is usually more or less conical, and they build either a single or a compound cone, the latter double or even triple. In size they vary much, from structures 18 inches high on a roughly circular or oval base 7 inches across, down to others only 2 inches high on a base of 1 inch across. The outline may be that of an almost perfect right cone, or the axis may be inclined, while elsewhere the cross section is oval or markedly elliptical.

The *mantle* has a glistening and slickensided appearance and is coated with a veneer of asbestiform matter; round the mantle one sees a series of more or less parallel seams separated by soft serpentine free from fibre. On an *axial section* the internal structure shows many

SECTION FORMERLY EXPOSED IN THE FACE OF AN ADIT OF THE RIBBON LINE AT THE AMIANTHUS MINE, JOUBERTSDAL NO. 99, SHOWING CONICAL MASSES OF ASBESTOS ROCK.

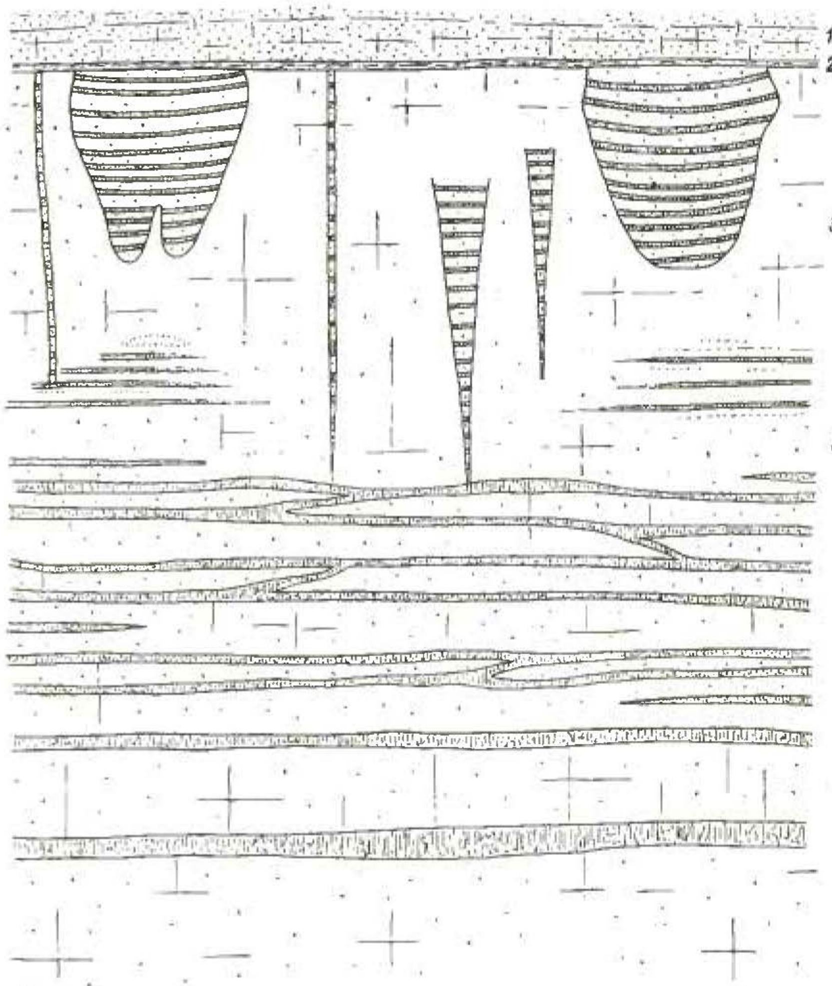


Fig. 15.
1. Hanging Wall. 2. Clayey Parting. 3. Serpentine. Approximate scale: 1 inch = 1.5 feet.

rudely parallel cross-fibre seams extending right across, but rapidly thinning down towards the axis: this coincides with a delicate fibre thread connecting the seams with one another and resembling similar threads seen in the figured face. The *compound cones* are of two kinds. In what may be termed the " lateral " variety two or three originally distinct cones have become partially fused over the basal end, though still showing their axes in parallel position. In the " co-axial " variety there are two conical growths nested in one another, but with a single axis in common.

It is clear that these bodies do not correspond to what is generally known as " cone in cone " structure, since it is only the outline that is conical, while internally there is no such arrangement. The distribution and mode of occurrence of these cone-shaped bodies, specially the structure of the " lateral " variety of compound cones, suggests that the upper part of the Ribbon Line with its many closely-spaced seams is the final result of the fusion through lateral growth of a large number of many single cones. (For further details see Bibl. No. 31.)

Another unique feature in this mine are the *nickel sulphide lumps.* They were described for the first time by the writer in 1924, and no previous record appears to exist in the literature. Some 330 feet horizontally from, and some 300 feet vertically below, the surface in the Second Level, fourth adit, west, the section reproduced in Fig. 16 was met with; it seems that this is the only point where these sulphide masses have up to the present been observed.

Extending for some 5 feet from the dolerite hanging wall runs a steeply inclined narrow irregular band of slip fibre chrysotile, swelling out here and there into lenticular masses up to 3 inches wide. Embedded in this fibre are vivid green heavy oval or elongated lenticular bodies of ore, consisting of approximately 70.5 per cent. of NiS and 24.5 per cent. of NiO with 5 per cent. of impurities, some of the nickel being replaced by cobalt.

Isolated from their fibrous matrix, the oval lumps are seen to owe their striking colouration to a veneer of bright green serpentinous matter, the fresh fracture revealing the interior as made up of a thoroughly irregular association of vivid green country rock and pale green or slightly yellow heavy particles of metallic sulphides. Polished surfaces are very striking and have an appearance not unlike that of turquoise matrix. The largest lump weighed 108 grams and is 7 cm. long, with a roughly triangular cross section; the smallest lump weighed 1.27 grams and is almost circular in outline and about half a centimetre thick. The mode of origin is probably due to slight momevement along a joint plane. Particles of metallic sulphide (nickel being an accessory by no means rare in olivine-bearing basic rocks) originally concentrated in more or less detached aggregates along this plane, suffered the same differential movement, so as to become rolled out into oval lumps. (See Bibl. No. 33.)

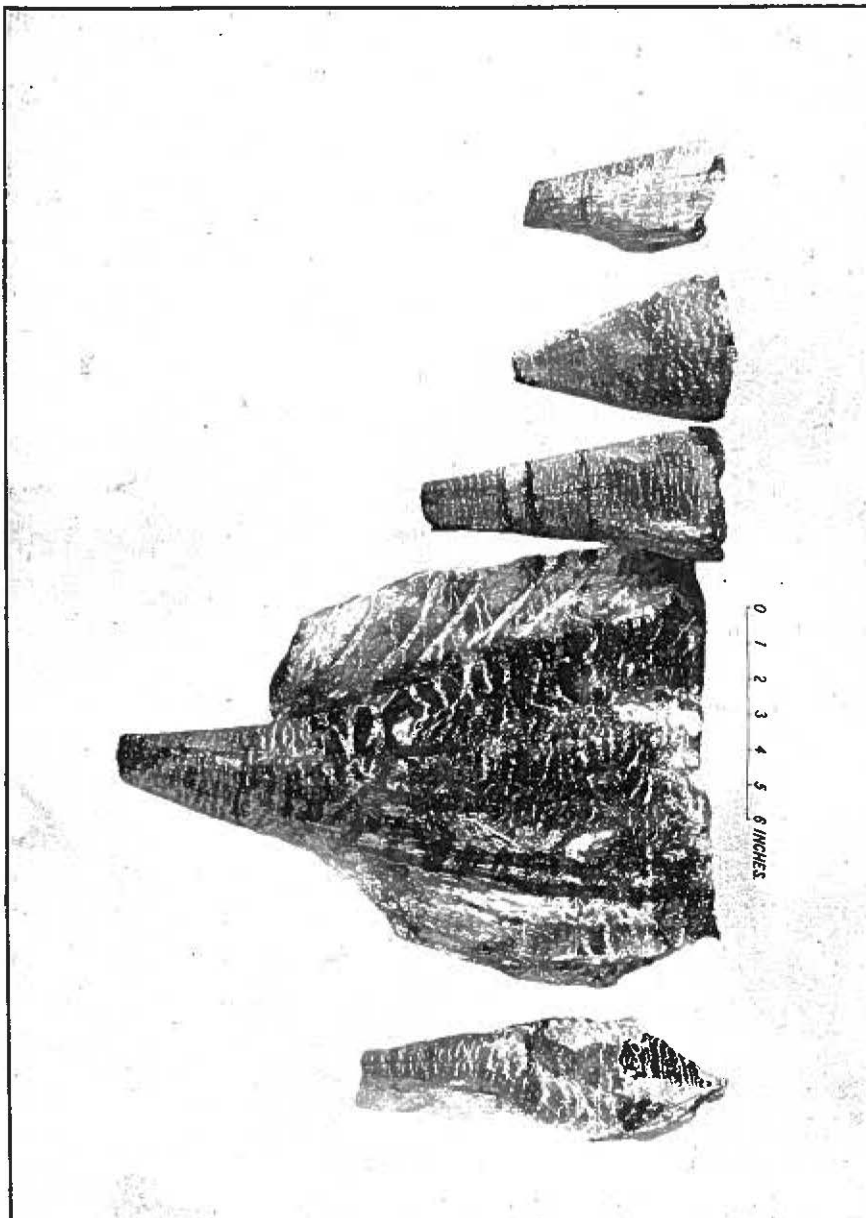


Plate XIII.—*Cone Structures* in Chrysotile-bearing serpentine; Amianthus Mine, near Kaapsche Hoop.

7. *Grades, Market Preparation, Disposal, etc.*—The present grading scheme is shown in Table No. 24, which also gives the specifications laid down by the method of testing the fibre by King Test Box, well established in the industry. This consists of a special set of sieves

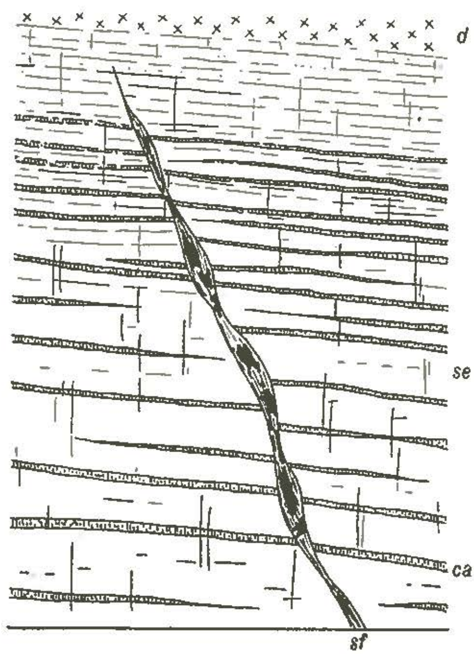


Fig. 16.

Slip fibre band (*sf*) of chrysotile carrying nickeliferous lumps; (*ca*) bearing serpentine (*se*); the roof is altered dolerite (*d*). New Amianthus Mine, near Kaapsche Hoop, Barberton District. Approximate scale: 1 :20.

arranged in a standard box, into which 16 ounces of the sample are introduced and the box agitated to enable the different length of fibre to remain sorted in the appropriate compartments.

TABLE No. 24.—*Grades and Test Box Specifications at the New Amianthus Mine.*

Grade.	Specification.				Remarks.
	+ ½ in.	+ ¼ in.	+ $\frac{1}{16}$ in.	− $\frac{1}{16}$ in.	
Crude............	Over ¾ in.	long.	—	—	Hand Cobbed.
1................	8 ozs.	6 ozs.	1¾ ozs.	¼ oz.	Milled.
2................	—	10 ozs.	5 ozs.	1 oz.	Milled.
3 (Shingle)........	—	—	13 ozs.	3 ozs.	Milled.
H (Shingle)........	—	—	7 ozs.	9 ozs.	Milled.
T................	—	—	3¾ ozs.	12¼ ozs.	Milled.
AA. (Shingle)	1 part of 3 + 1 part of H.		10 ozs.	6 ozs.	Milled.
BB. (Shingle)	1 part of 3 + 2 parts of H		9 ozs.	7 ozs.	Milled.
PS. (Paper Stock)	1 part of H + 3 parts of T		4½ ozs.	11½ ozs.	Milled.

The upper sieve has 2 meshes per linear inch and on it remains all fibre longer than half an inch; the undersize passes downwards to the middle sieve (with 4 meshes per linear inch) and on this remains all fibre between ½ and ¼ inch; the undersize then passes on to the lower sieve (10 meshes per linear inch). Since allowance must now be made for the wire thickness, the fibre remaining on the lower sieve is between the limits ¼ inch and $^1/_{16}$ inch. Finally the undersize from this sieve reaches the bottom of the box as fibre less than $^1/_{16}$ inch in length. Taking, for example, Grade No. 2, this will be so constituted that out of every one pound there will be 10 ounces of fibre over ¼ inch long, 5 ounces between ¼ and $^1/_{16}$ inch and 1 ounce of fibre under $^1/_{16}$ inch in length.

The *market preparation* is based on two main principles: Hand Cobbing, and Machine Milling. The output from the mine is first separated into material with longer fibre, which is treated by hand cobbing, furnishing the grade: Crude. The remainder is treated in the mill, which embraces a rather elaborate series of successive stages, i.e. drying, sorting, crushing, fiberising, disintegrating, grading on shaking tables, wind blast treatment, etc., a detailed consideration of which involves many technical aspects that lie outside the scope of this volume.

For *disposal* the finished product is bagged in units of 150 lb. each and conveyed by aerial railway (Bleichert Monocable) through a distance of about 6 miles from the mill up over the edge of the Drakensberg and down to Elandshoek Station; by means of this transport a long train of buckets, with a capacity of 300 lb., leave the loading station at the normal rate of 1 bucket per minute and travel to railhead with an approximate speed of 4 miles per hour. This recent improvement has very materially reduced the heavy transport item, when the disposal involved road transport by mule wagons from the mill (4,200 feet above sea level) through a rise of some 1,200 feet to the village of Kaapsche Hoop, followed by a drop of about 2,200 feet to Godwan River Station.

A steady output has been maintained and is now in the neighbourhood of 1,000 short tons per month.

8. From the preceding remarks the following *Summary of Outstanding Geological and Economic Features* is added for convenient reference :—

(*a*) The *New Amianthus Mine* lies on Northern Joubertsdal in a belt of basic rocks, now altered in a series of alternating bands of green (olivine) or fibre *serpentine* and dark bluish black or barren serpentine, chrysotile being confined to the former variety. This belt is up to about 2½ miles wide and extends from the Transvaal Drakensberg eastwards for some 50 miles through Kaapmuiden to beyond Malelane.

(*b*) *Two distinct fibre channels* exist in the serpentine. The first discovery—now abandoned—is the *Griffin Line*, confined to the contact zone between the two varieties of serpentine and extending from this contact through some 10-15 feet into the green variety. It shows a very large number of nearly parallel, very closely spaced thin seams of chrysotile (disposed conformably to the contact), and persists for some 800 yards along an east-west strike.

(*c*) The *Ribbon Line* (to which the production is now confined) was discovered later and is very much richer than the Griffin Line. It lies directly at the contact between the serpentine and the overlying shale—quartzite group of the Ventersdorp (?) System, striking nearly north and south, but having a dip of from 10 to 20 degrees to the west. This fibre channel is now developed over distances up to 1,650 feet from the outcrop in the direction of the dip, corresponding to a maximum depth of some 800 feet vertically below the surface. The normal width of the ore channel falls between 5 and 7 feet in the upper levels, but drops commonly to between 2 and 3 feet in the lowest level; the upper portion shows a very large number of closely spaced thin seams, disposed conformably to the dip of the overlying sediments, and often almost strictly parallel to one another, while the lower portion has fewer more widely spaced and wider seams. In many places the roof is formed by a thin doleritic sill emplaced along the base of the overlying quartzite. Along the strike the proved continuity is not less than 5,000 feet.

(*d*) *Stichtite*—a lilac-coloured hydroxy-carbonate of magnesia—is a characteristic accessory mineral in both fibre channels, but distinctly more noticeable in the upper as compared with the deeper levels.

(*e*) The *economic importance* of the Ribbon Line lies in the large quantities of fibre rock available, in the high flexibility, high tensile strength, and general superior quality of the fibre, in the ease with which the asbestos comes off the country rock—not only in milling but already in the course of development—in the large amount of asbestos provided by the latter alone (apart from stoping), in proximity to railhead, while the remarkably *high proportion of fibre to rock* (15 to 25, locally as much as 30) is unique among chrysotile mines.

9. *Extension of the Ribbon Line.*—The richness of the New Amianthus Mine and its successful economic development naturally stimulated the search for a possible extension, of the Ribbon Line beyond Northern Joubertsdal, and a considerable amount of prospecting has been done and is (to some extent) still going on. Since the fibre channel is restricted to the contact between the serpentine and the overlying group of sediments, which dip generally to the west, an eastward extension across the Gladde Spruit is obviously out of the question. As previously remarked, the base of the sediments forms very definite outcrops, e.g. directly above the main workings of the New Amianthus Mine, and this serves as an indicator for the possible extension of the Ribbon Line along its north-south strike.

Towards the *north* the lower edge of the shale-quartzite group can be traced at intervals, and its theoretical continuity in that direction should bring it ultimately to the western boundary of Joubertsdal, which is contiguous with the eastern boundary of the Government ground Barretts Berlyn No. 119. On the latter—close to the edge of the Drakensberg escarpment—there are good outcrops of the brown shales and below them lies serpentine in which chrysotile deposits have been found and to some extent opened up; this area forms the claims of Payne's Syndicate, as part of the farm Berlyn. The seams dip at a much steeper angle—40 to 50 degrees towards the west, but in several respects their situation and associations recall some of the features of the Ribbon Line, though, as far as present developments go, the amount of fibre is very disappointing compared with that seen at the New Amianthus Mine; overlying the sediments above this fibre horizon there are again the basic amygdaloidal lavas, extending up to the Black Reef quartzites of the plateau, so that the geological succession is here essentially similar to that observable at the New Amianthus Mine.

Towards the *south* the Ribbon Line persists across Northern Joubertsdal into Southern Joubertsdal, where it was at one time opened up by Kaapsche Hoop Chrysotile, Ltd., whose ground now belongs to the New Amianthus Mines, Ltd., but is not worked. Theoretically one would expect the Ribbon Line to extend still further south into Southern Joubertsdal; over the extreme south-western corner of this portion the succession from the Black Reef quartzite plateau corresponds generally to that of the opposite side of the valley, where the workings of the New Amianthus Mine lie, and includes an outcrop of the shaly sediments.

A borehole was consequently put down in the south-western corner of Southern Joubertsdal, and carried down to a depth of approximately 1,000 feet, but no fibre was struck. After passing through a considerable thickness of amygdaloidal lavas, a band of fine-grained doleritic rock was intersected, below which followed a dark medium-grained rock—composed essentially of hornblende and quartz—with gneissic affinities and almost certainly associated with the Older Granite rather than with the Serpentine Belt, into which it is probably intrusive, so as to cut off the serpentine; at least 500 feet of this gneissic rock were pierced down to the bottom of the borehole.

The volcanic and sedimentary rocks provisionally assigned to the Ventersdorp System certainly have a very limited distribution, such as to suggest their occupying a small valley or depression formed by the denudation of the Jamestown Series. This depression and the sediments subsequently deposited on it no doubt originally extended further to the east, but have since been removed by denudation. On this view, one now has only the portion nearer the centre of the hollow, so that a borehole placed well away from the outcrop of the sediments might fail to intersect them, because the formation had thinned out altogether. The failure of the Southern Joubertsdal borehole to strike the serpentine is most likely explained by the probable intrusive origin of the gneissic rock, met in the borehole, cutting off the serpentine belt.

The possible persistence of the proved Ribbon Line on the dip has also directed attention to what may be termed the " Deep Level Extension." It might be argued that the general westerly dip of the principal fibre channel should eventually bring it into the farm Berlyn, adjoining Northern Joubertsdal on the west, but at a very great depth, so that boring operations ought to intersect the Ribbon Line within the former area. The chances of success in such an obviously very costly undertaking must, however, be considered in the light of the following aspects :—

(*a*) The deepest workings of the New Amianthus are still at least some 1,000 feet distant from the eastern boundary of Berlyn.

(*b*) In dealing with chrysotile deposits, one cannot ignore the more or less uncertain mode of origin of asbestos; it would be dangerous to assume that such a mineral must show a degrees of persistence in depth comparable with that e.g. of the Main Reef horizon on the Witwatersrand.

(*c*) The impression was already referred to that in the deeper levels of the New Amianthus Mine the fibre display is not as striking as it is at or nearer the surface.

The Chrysotile Deposits of the Munnik–Myburgh Mine.

1. *Situation.*—As pointed out above, the serpentine belt extends from the New Amianthus unbroken eastwards across Gladde Spruit under essentially similar geological conditions, with a maximum width of about 2 miles, so as to give rise to hilly country, marked by high conspicuous ridges which run from east to west or from east-north-east to west-south-west in close agreement with the strike of the fibre horizons. The serpentine builds rudely stratified masses with steep slopes towards the south—not unlike escarpments—and gentler slopes towards the north. The same alternating succession of soft green or fibre serpentine and relatively hard dark bluish gray or barren serpentine recurs here just as west of Gladde Spruit (see Fig. 13, lower section). No rocks answering to the shale-quartzite group above the Ribbon Line have been met with, no doubt for the reason given above.

The most important developments in this eastern section are those of the Munnik-Myburgh Mine, which controls a large area belonging to the Government Grounds Uitkyk and Sunnyside, adjoining Joubertsdal on the south, and is maintaining a steady output.

2. *Distribution and Mode of Occurrence of the Asbestos.*—At least four approximately parallel fibre zones have been located striking with the major ridges nearly east and west, up to some 7 feet wide and separated by horizontal distances up to 200 or 300 feet.

Beginning on the south, the first ore channel—*Jones'* or *No. 1 Line*—is traceable in a series of outcrops from east to west, and keeps fairly closely to the Barberton main road a little north of the granite-serpentine contact; the fibre channel shows a number of rudely parallel rather closely spaced seams inclined about 55° to the north.

Extending for a long distance across the area under the control of the Munnik-Myburgh Company is the *Griffin* or *No. 2 Line,* maintained westwards to the Gladde Spruit, and almost certainly continuous with the Griffin Line seen in the old workings of the Amianthus Company. The earlier developments at the Munnik-Myburgh Mine include an adit in the extreme east, forming a short drive on this line. The seams here dip 60° to the north, and from this eastern adit the fibre zone is exposed in several prospecting pits right up to the western end of the company's claims, normally forming a single band of fibre rock, but locally formed as a double band, both of which dip to the north and are some 30 to 40 feet apart. In this way, the total proved continuity of the Griffin Line is near 3 miles, of which about half falls within the company's ground.

A little further north is *No. 3 Line* or *Smithy Lode;* it is less extensive, while the seams are normally vertical or steeply inclined to the north.

No. 4 or *Main Line* forms the most northerly fibre belt, found a little south of the southern boundary of Joubertsdal and showing the seams dipping northwards on the whole. This is the horizon that is being systematically developed and from which a regular output is being obtained. The extension is over 3,300 feet; possibly this particular line corresponds with the horizon on which the northern group of workings of the Griffin Line lie on Joubertsdal.

A close general similarity exists between the mode of occurrence and character of the chrysotile in the four belts described above, and in general the main features described from the Griffin Line west of the Gladde Spruit hold good for the eastern section also. The fibre location in the main workings is also characteristic of the contact between the green or fibre and the bluish or barren serpentine. Almost invariably one finds a large number of more or less *parallel seams,* spaced closely together when thin—analogous to the "ribbon" rock further west—or placed wider apart, when they tend to be thicker. Seams over an inch wide are less common. The position of the four fibre belts and the continuity between No. 2 Line in the east with the Griffin Line on the west, when considered with reference to the folded arrangement at the Gladde Spruit end of the serpentien belt, admit of the possibility that the four horizons are not distinct, but may be repetitions of one or two fibre channels only.

The total length of fibre-bearing zones included in the Munnik-Myburgh ground probably exceeds 2 miles and may be even more.

As in the western section, *stichtite* is often associated with the chrysotile-bearing rock, but is again distinctly in greater evidence at or near the surface, while scarce or altogether missing in the deepest workings.

3. *Development* is practically confined to the Main Line, where the workings are along the floor of a shallow depression rising gently from east to west, and consist of some 6 adits, each facing east; they are numbered from east to west and spaced at varying vertical intervals up to about 120 feet. Adits No. 3 and No. 4 are at the same elevation, since here the fibre belt is locally duplicated and separated by a thin band of hard dark grayish serpentine. Each adit is in reality a drive on the reef which shows the seams inclined almost consistenly to the north at angles varying from 35° to 80°. The total extent of underground development is now over 3,300 feet, exclusive of an adit some 800-900 feet long, in course of construction and designed to cut across the fibre channel from the north side of the slope. The persistence from the outcrop of the asbestos horizon in the direction of dip now amounts to some 500 feet. Near the centre of the workings is a basic dyke, about 40 feet wide, cutting across the serpentine formation. The soft green or fibre serpentine is again the characteristic chrysotile carrier, as it is in the western section.

4. *Quality and Length of Fibre; Grading Scheme and Market Preparation.*—The chrysotile of the Munnik-Myburgh Mine has a delicate olive green tint in lumps of crude, which are translucent and is not too thick; the teased fibre shows the striking pure white fleecy appearance and high tensile strength characteristic of high-grade chrysotile, and is indistinguishable from that of the western section. Table No. 1 gives an analysis of fibre from No. 4 Main Workings (Grade Extra IXL) which shows a very close agreement with the composition of the Amianthus fibre.

The *length* of the fibre varies in the usual manner; occasionally one meets a few seams approaching two inches in thickness, but the great majority of economic seams range from half-an-inch to one-sixteenth in width. During the early stages of development, before the present mill was installed, one month's total output showed the proportions of various lengths given in Table No. 25. This revealed an exceptionally

TABLE No. 25.—*Proportions of Grades in One Month's Output of the Munnik-Myburgh Mine.*

Grade.	*Description.*	*Amount.*	*Percentage.*
Extra IXL.....	Over 2 in....	·5 short tons	5
IXL.....	Over ¾ in....	·5 ,, ,,	5
XL.....	½ in. to ¾ in.	1·8 ,, ,,	18
X.......	¼ in. to ½ in.	2·5 ,, ,,	25
XX.....	⅛ in. to ¼ in.	3·0 ,, ,,	30
Milling.........	Under ⅛ in..	1·7 ,, ,,	17
		10 ,, ,,	100

high proportion of over ¾ inch in length, and cannot fairly be taken as reflecting the permanent fibre length conditions, which naturally have to include the mill products, that constitute the mainstay of production in all chrysotile mines and consequently raise very materially the proportion of shorter fibre.

The *grading scheme* now in use, as well as the relative amounts produced over a period are shown in Table No. 26.

TABLE *No. 26.—Grading Scheme and Proportional Output per Grade, Munnik-Myburg Mine, for the Seventeen Months ending May,* 1930.

Grade.	*Specification.*	*Percentage.*	*Treatment.*
IXL.............	Over ¾ in......	·14	Hand Cobbed.
XL.............	½ in. to ¾ in...	·53	Hand Cobbed.
X.............	¼ in. to ½ in...	2·14	Hand Cobbed.
XX............	Under ¼ in.....	1·77	Hand Cobbed.

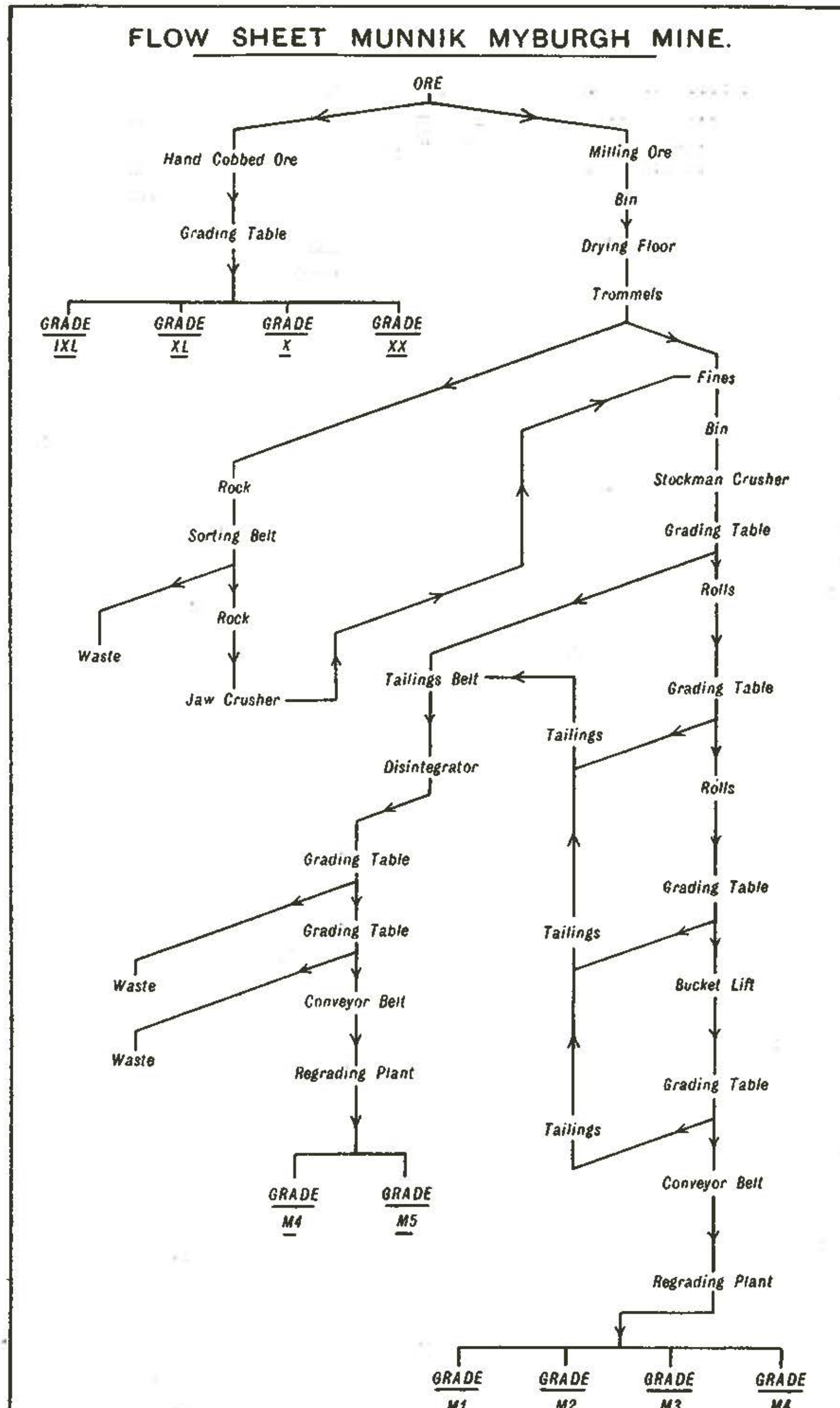

FLOW SHEET MUNNIK MYBURGH MINE.
ORE
Hand Cobbed Ore
Grading Table
GRADE IXL
GRADE XL
GRADE X
GRADE XX
Milling Ore
Bin
Drying Floor
Trommels
Fines
Bin
Stockman Crusher
Grading Table
Rolls
Rock
Sorting Belt
Waste
Rock
Jaw Crusher
Tailings Belt
Disintegrator
Grading Table
Tailings
Rolls
Grading Table
Grading Table
Waste
Conveyor Belt
Waste
Regrading Plant
GRADE M4
GRADE M5
Tailings
Bucket Lift
Grading Table
Tailings
Conveyor Belt
Regrading Plant
GRADE M1
GRADE M2
GRADE M3
GRADE M4

Fig. 17.

Test-box Formula (Ounces).

Grade.	*Specificaeion.*	*Percentage.*	*Treatment.*
M. 1............	2 – 11 – 2 – 1	3·49	Milled.
2............	0 – 8½ – 6 – 1½	·84*	Milled.
3............	0 – 3 – 10 – 3	63·91	Milled.
4............	0 – 0 – 8½ – 7½	22·61	Milled.
5............	0 – 0 – 4½ – 11½	4·57†	Milled.
		100·00	

* 7 months. † 14 months.

In the *market preparation,* lumps with longer fibre are first sorted out, hand-cobbed, and differentiated over shaking tables into the four first grades shown in Table No. 26. The balance passes over drying-floors to an inclined trommel, whence the oversize is delivered over a sorting-belt to a rock crusher, thence passing to a Stockman crusher, in which it joins the undersize from the trommed referred to. The joint product goes to a shaking table, from which the oversize passes through rolls and shaking tables until M1, M2, and M3 are recovered, while the undersize goes to a tailings recovery plant, from which grade M4 is obtained; all M grades are then regraded. The above is merely a statement of essential principles in market preparation, the detailed discussion of the milling operations being too technical for these pages; they are embodied in a treatment plant of a capacity of some 14 short tons per day (see Fig. 17).

The Munnik-Myburgh Mine has now been producing for some 10 years and records a steady output, which is at present over 200 short tons per month.

The value of the fibre ranges from £5 to £200 per short ton, f.o.r. Nelspruit, but the bulk of the output lies between £18 and £22 per ton.

Chrysotile Deposits in the Carolina District East of Carolina: the Kalkkloof Mine.

1. *Situation.*—It was pointed out at the beginning of this chapter that the deposits of the Kalkkloof Mine form the principal chrysotile occurrence in serpentine that falls within the Carolina District, which also has several minor ones on the north side of the Komati River, referred to in Chapter VII.

The Kalkkloof Mine lies east of Carolina on the farm Kalkkloof No. 250, about 3 miles south of the Komati River; it is usually approached via Carolina, from which it is distant 47 miles by the Barberton main road via Rooihoogte, down the Thee Spruit valley, and past the Warmbaths (Badplaats); just before reaching the Komati

River at Hlom-Hlom, a minor road branches off towards the north-west to the mine; by the direct route (more difficult in wet weather) from Carolina along the top of the high plateau via Verdrukking No. 210, Suikerboschfontein No. 139, the distance is 35 miles.

The workings are distributed over the floor and slopes of a long narrow valley (see Plate XIV) running approximately north and south —known as Assegai Loop—and flankd by rather steep slopes, capped by gently inclined resistant beds of the dolomite and Black Reef Series.

Sketch Plan of the area round the Kalkkloof Asbestos Mine, east of Carolina.

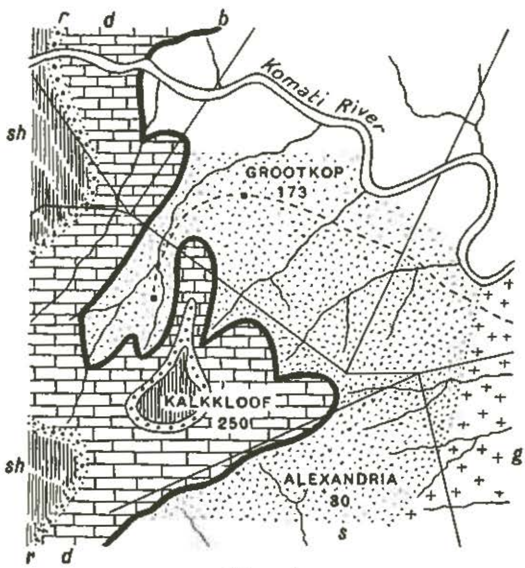


Fig. 18.

g = granite; *s* = serpentine; *b* = Black Reef quartzites, etc.; *d* = Dolomite; *r* = Rooihoogte quartzite; *sh* = Shales. Scale: 2.35 miles to the inch.

2. *Geology.*—This is associated with deeply dissected country, belonging to the southern end of the Transvaal Drakensberg and determined by the differential rate of erosion between certain hard bands in the overlying Transvaal System (Black Reef quartzite, chert of the Dolomite Series, and the Rooihoogte quartzite of the Pretoria Series) and the underlying soft serpentines. The complex topography is thus the result of prolonged denudation, which has cut through (see Fig. 18) the high plateau formed by these resistant sediments deep down into the underlying older formation (serpentine, quartz schists, quartzitic phyllites, etc.); this simple arrangement is, however, complicated by faulting (see below). The highest portion of the plateau regions are in the neighbourhood of over 5,000 feet above sea-level, while the floor of Assegai Loop at the Mill is at least 1,200 feet lower.

The following formations are found at or near the Kalkkloof Mine:—

(c) Quartzites—Black Reef Series. }
(a) Rooihoogte Quartzite. } Transvaal System.
(b) Dolomite and Chert. }
(d) Serpentines, with subordinate hard schists.

The beds (a) to (c) are inclined conformably to one another and dip at low angles (from 5 to 10 degrees) to the north-west or west-north-west; they rest unconformably upon the formation (d).

(a) *The Rooihoogte Quartzite* forms a band up to 20 feet thick (often less) marking the base of the Pretoria Series and composed of quartzite, but often conglomeratic in certain layers and cherty near the bottom, so as to form a transition to the underlying Dolomite Series. It is characteristic of the highest portions of the plateau overlooking Assegai Loop from the east and is an important element in the linear features over this portion of the Transvaal Drakensberg.

(b) The *Dolomite and Chert* Series presents the usual features of the Transvaal Dolomite, including at the top a thick band of chert—corresponding to the so-called " Giant Chert " of the type section near Pretoria. This is very well seen near the summit of the high hill, in the lower parts of which lies the eastern section of the Kalkkloof Mine.

(c) The *Black Reef quartzites* are up to 20 feet thick and form conspicuous krantzes, showing rusty brown weathered surfaces, along both sides of Assegai Kloof, but their distribution within this valley is very clearly affected by vertical movements due to faulting (see below).

(d) The *Serpentine-schist* group is the most important formation, since it carries the chrysotile deposits. It occupies * the whole of Assegai Loop from the floor up to the base of the Black Reef quartzite and also extends some distance to the north into the Komati River valley, including (in a southerly direction) the slopes of the Drakensberg on Grootkop No. 173 and Alexandria No. 30. (See Fig. 18.)

The serpentines consist of two varieties, which form an alternating series of thick masses of a soft green or fibre serpentine; in thickness these bands vary up to 200 or 300 feet, while they are disposed with a steep westerly dip in approximate conformity with that of the chrysotile seams. The lithological contrast between the two varieties is not uncommonly very clearly seen in the scenery, since the green serpentine tends to give rise to belts of smooth bare surfaces—almost free from boulders—while the hard dark serpentine forms more broken ground, freely strewn with irregular blocks showing more or less deeply pitted weathered surfaces. In appearance, and even in their minor petrographical characters, these serpentines show a very close resemblance

* On the map accompanying Geological Survey Memoir No. 9 (Barberton) the serpentine group is not separately indicated.

PLATE XIV.—*Looking up the valley of the Assegai Spruit on Kalkkloof;* showing in the background the Southern chrysotile workings in serpentine; east of Carolina.

to the successive bands associated with the Griffin Line of the Amianthus and Munnik-Myburgh Mines, the green type most probably again representing an originally olivine-bearing formation, and the barren dark type a rock rich in pyroxene.

The chrysotile seams are confined * to the soft green serpentines, which is an evenly massive rather fine-grained rock, sometimes having delicate veins of rudely fibrous lead gray ilmenite, occasionally a little magnetite, and frequently the brilliantly lilac-coloured stichtite in thin films on joint faces; in these respects, there is a strong resemblance to the corresponding formation within the Kaapsche Hoop asbestos mines.

A thin development of highly inclined hard thinly bedded quartzitic *schists*, quartz *phyllites*, fine-grained arenaceous slate, etc., are seen in places in the serpentine, e.g. near the manager's house, where they determine the precipitous eastern side of a little knoll, or at the junction of Assegai Loop with Segoia's Kloof close to the drift north of the house referred to.

The *geological structure*—particularly in so far as the position and distribution of the Black Reef Quartzite is concerned—has been markedly affected by the *faulting*. Along the northern portion of Assegai Loop (north of the point where it is joined by Segoias Kloof from the west) the Black Reef quartzite krantzes on opposite sides of this valley agree with the steady dip of that formation, but further to the south the outcrops are vertically displaced relatively to one another [see Fig. 19, section (*b*)], and also limited in their extent; this effect is due to a powerful fault which runs almost true north and south, so as to coincide more or less with the course of the stream.

Near the summit of the steep hill rising from the right bank of the stream at the mill, and carrying the developments of the Eastern Section of the mine, is a tiny platform—some 900 feet above the valley floor. At this point [marked W in section (*a*) of Fig. 19] are two shallow prospecting shafts in serpentine, but only a few yards to the east, this formation is in direct contact with the Giant Chert of the Dolomite Series, thus marking a point on the line of the fault, which must have caused a vertical shift amounting to some 200 feet. Looking to the south, the Rooihoogte quartzite is seen in the sky line cut off at a tiny outlier, the serpentines end a little east of the southern group of workings, while the Black Reef krantzes are also cut off in two places. Looking to the north, it is clear that on the east side of the valley the Black Reef quartzites lie much too low to fit in with their outcrops above the southern and northern sections (on the west side) while detached strips of these quartzites remain on the same side of Assegai Loop; further north beyond the junction with Segoias Kloof,

* Quite exceptionally chrysotile has also been observed inside the dark or barren serpentine up to within about 5 feet from the contact with the green serpentine.

SECTIONS TO ILLUSTRATE THE FAULTING AND PRINCIPAL FIBRE BELT AT THE KALKKLOOF MINE, EAST OF CAROLINA.

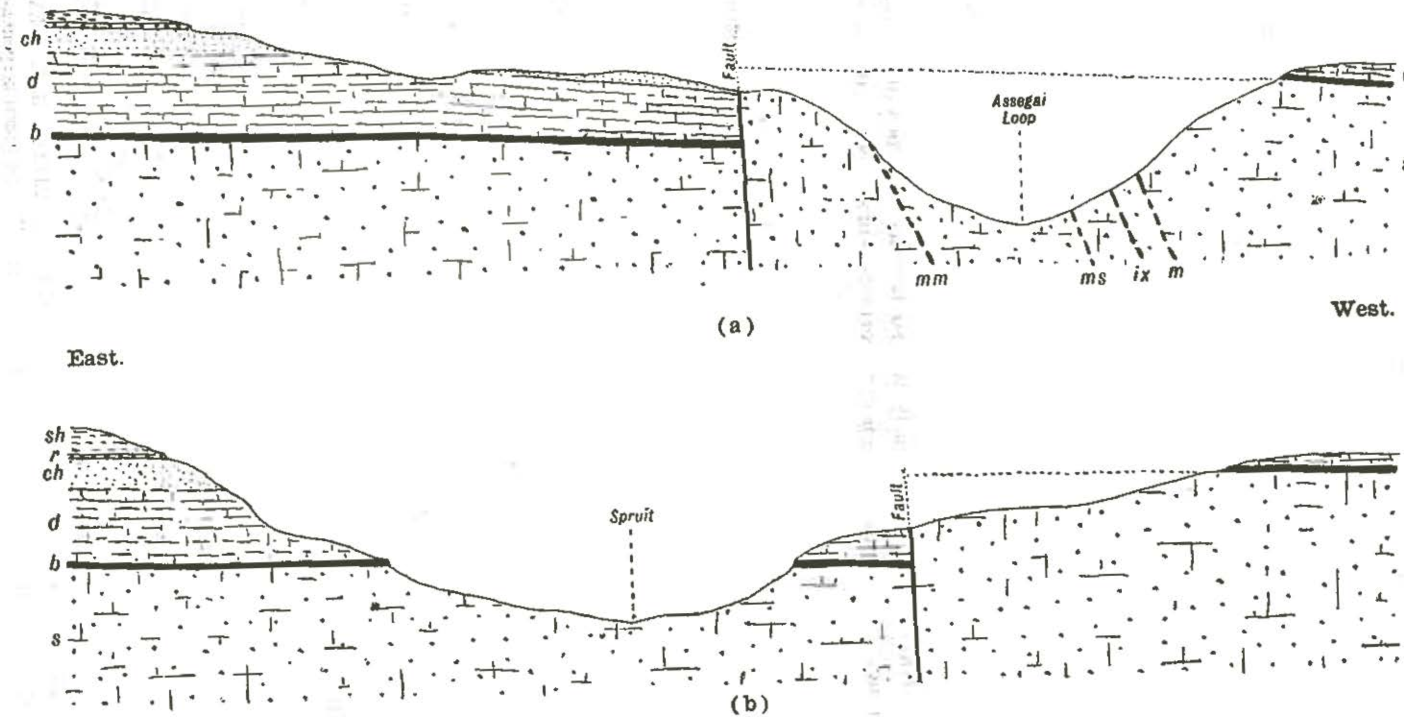


Fig. 19 (*a*) and (*b*).

there is a short remnant of the quartzite (on the west side) agreeing in position with the Black Reef krantz on the east side of the valley. The effect of the fault is also seen far away on the N. side of the Komati River, where the clear cut feature due to the Black Reef quartzite is sharply broken and displaced.

The main fault thus passes from south to north and in doing so it cuts across the floor of the valley. (See the two sections of Fig. 19.) A short steep gully enters Assegai Loop from the west a little south of the manager's house and the sudden ending of the schists in the floor of this gully probably indicates the position of a short cross fault connecting the fault with its western (and northern) extension. Along the latter the steep and prominent slope east of the house as well as the wall-like body of schists at the drift to the north are strongly suggestive of fault scarps.

3. *Mode of Occurrence and Distribution of the Fibre Channels.*—There are at least four major distinct asbestos-bearing zones, all inclined to the west, running approximately parallel to one another, and striking roughly north and south; in addition, there are a series of minor fibre deposits. The major as well as most of the minor ones fall into the valley of Assegai Loop, where they outcrop sometimes near the floor, but elsewhere high up on its slopes; chrysotile has also been located well to the west within the basin of Segoias Kloof.

The total length of strike through which fibre has been traced at intervals should not be less than 5,000 feet, from the junction of Segoias Kloof and Assegai Loop southwards.

The different sets of workings are distinguished as follows:—

(*a*) The *Southern Section*—situated in the extreme southern end of Assegai Loop and on its west side several hundred feet above the valley floor.

(*b*) The *Central Section*—also called No. 1 Mine; here most of the development has been done, while it also furnished the main source of fibre. The workings lie low down almost in the floor of the valley (west side).

(*c*) The *Eastern Section* lies opposite to (*b*), but on right (east) side of Assegai Loop.

(*d*) The *Northern Section* occupies the low slopes rising from the left bank of Segoias Spruit at its junction with Assegai Loop. Here the fibre deposits were promising near the surface, but poor below, so that further prospecting has ceased in this part of the mine.

(*e*) The *Western Section* lies high above the floor of Segoias Kloof, its workings being known as No. 2 or No. 3 Mines, but development has ceased here.

In the *Central Section,* there are the following three distinct fibre zones (see Fig. 19, Section 1), enumerated from west to east:—Main Lode, No. 1-X Lode, and Millsite Lode, the first two being separated by a horizontal distance of about 200 feet, while from No. 1-X Lode to the Millsite Lode is 300 feet. The three ore channels are inclined from 45° to 60° to the west, the actual dip of the Main Lode in this section amounting to 58°; they are approximately parallel to one another and strike more or less north and south. In thickness the fibre channels range up to 5 feet, but they are usually between 3 and 5 feet wide. Almost invariably the asbestos horizons lie in the green serpentine, their

SECTION ACROSS THE MAIN LODE AT THE KALKKLOOF MINE, EAST OF CAROLINA.

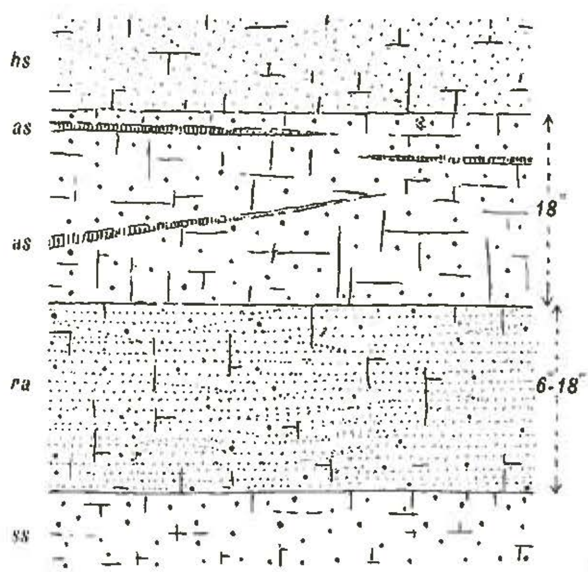


Fig. 20.

hs = hard dark serpentine-hanging wall; *as* = Chrysotile asbestos seam; *ss* = soft green serpentine; *ra* = ribbon rock—many thin parallel seams in soft green serpentine (6 inches to 18 inches wide).

hanging wall (or footwall) marking the contacts between that variety and the dark grayish black hard barren serpentine—in which respect one notices a close analogy with the Griffin Line near Kaapsche Hoop, while a similar association is also characteristic of the chrysotile occurrences, e.g. on Sterkspruit on the north side of the Komati River. (Chapter VII.)

Well within a band of the green serpentine (away from the contact referred to) one may find a little slip fibre, but no cross fibre seams. Stichtite is common and irregularly scattered—often forming delicate lilac films on joints, etc.—or else rather more common towards the footwall end of the fibre channel. The presence of stichtite is described as an infallible indicator of the green serpentine—a most valuable help in underground development. It is obvious that where a band of the green is sandwiched in between two bands of the barren dark serpentine, the latter forms the footwall of one, and the hanging wall of the next fibre channel. In the course of underground development the Main Lode has now been followed for some 3,000 feet along the strike.

As a general rule the chrysotile deposits are in the form of very many thin and nearly (or sometimes truly) parallel cross fibre seams spaced closely together, just as in the Griffin and Ribbon Lines near Kaapsche Hoop. Thicker seams occur sparingly, and are usually spaced wider apart. Fig. 20 represents an association and distribution of such different seam varieties, that is not uncommon.

The *eastern section* lies over the lower slopes of a high ground which rises directly from the right bank (eastern) of Assegai Loop opposite the Mill. It includes the so-called Munnik Myburgh Lode, the horizontal distance from the latter to the Millsite Lode being approximately 1,000 feet.

The *Southern or Top Section* is still in the prospecting stage, and includes the " Amianthus Lode " together with at least three further lodes (top, middle and bottom). In one working the seams are more promising in number and thickness, but on the whole the fibre display over this section is patchy, and the continuity disappointing at greater depths.

4. *Fibre Quality, Length, Market Preparation, etc.*—The quality of the Kalkkloof fibre is high and compares favourably with that of the chrysotile mines in the Barberton District. Production has not yet reached the stage of steady continuity, which enables one to arrive at the proportion of fibre to rock based on records covering a more extended period; a carefully conducted test yielded 43.75 short tons (including hand cobbed as well as milling fibre) from 582 short tons of milled fibre taken from the main Lode, which corresponds to a recovery of 7.5 per cent. Of the fibre produced in this test, 4 per cent. represents hand cobbed grades. Probably the percentage of fibre to rock *in* the mine is somewhat less than this result suggests. Full details are not available to show the relative percentages of the various grades that make up the output, and the mill, moreover, has been in full running order for a short period only; there is little doubt, however, that there is a large preponderance of shorter seams. A fully equipped recovery plant was in full swing towards the end of 1929, but the activities have been restricted since then.

The grading scheme is shown in Table No. 27.

TABLE No. 27.—*Grades of the Kalkkloof Mine.*

Designation.	*Specification.*	*Treatment.*
Special 1............	+ ¾ inch..........	Hand Cobbed.
No. 1...............	+ ½ – ¾ inch......	Hand Cobbed.
No. 2...............	+ ¼ – ½ inch......	Hand Cobbed.
R.O.M. No. 2.......	⅛ – ¼ inch.........	Milled.
R.O.M. No. 3.......	Less than ⅛ inch...	Milled.

5. *Outstanding Geological Features of the Kalkkloof Mine.*—These may be summarized as follows :—

(*a*) Almost complete restriction of the fibre to the soft green serpentine, at its contact with hard dark barren serpentine.

(*b*) Development of a series of steeply inclined parallel fibre channels, persisting over some 5,000 feet of strike, and furnishing asbestos of high grade quality.

(*c*) Preponderance of many closely spaced and parallel thin seams over thicker seams, and a consequent high proportion of short length mill product.

(*d*) Close general resemblance to the Griffin Line type of deposit, i.e., similar associations of country serpentines, stichtite, etc., etc.

CHAPTER IV.

PRINCIPAL ASBESTOS DEPOSITS IN THE TRANSVAAL (CONTINUED).

IB.—CHRYSOTILE ASSOCIATED WITH ALTERED DOLOMITE (CAROLINA, PILGRIMS REST, PIETERSBURG DISTRICT, ETC.).

1. *General Remarks.*—This chapter deals with those exceptional modes of occurrence of chrysotile that depend upon the metamorphic effects of intrusive dolerite sills on carbonate rocks, belonging to the Dolomite Series of the Transvaal. The earliest attempts to recover chrysotile within the Union are associated with this type of deposit, and although mining activities have been carried on at intervals since 1905—and at several localities—they have not so far furnished any substantial and continuous contribution to the output of chrysotile, comparable to that which has been and is being supplied from the more common occurrences of this fibre in serpentine, derived from basic rocks. Though the yield, therefore, has been intermittent and never an important factor in the market, the geology of these occurrences is of great interest in forming a close parallel to the deposits of the Grand Cañon of Arizona, described by L. F. Noble (Bibl. No. 55).

2. *Situation and Geology.**—The principal workings of chrysotile in altered dolomite lie east of Carolina on the farms Diepgezet, Goedverwacht, Rietfontein, and Silverkop in bare, highly dissected and well-watered country belonging to the extreme southern end of the Transvaal Drakensberg and its slopes; the areas concerned belong to the upper portion of the Zeekoe Spruit valley, the deposits being situated from 20 to 25 miles due east of Carolina as railhead, very favourably placed for mining operations, and some 4,500 to 5,000 feet above sea-level.

Prospecting began about 1905 on Rietfontein by the Anglo-Swiss Company, though no development was done; about this time the same deposits were opened up along their easterly extension on Diepgezet and work continued to about 1909 in connection with the Transvaal Asbestos Syndicate and the Carolina Asbestos Company. Several years after this mining period, the same workings were continued by another syndicate,

*The general geology of this area is shown on Plate VII of the Annual Report of the Geological Survey of the Union of S. Africa for 1913 (Bibl. No. 26).

who carried on from about December, 1913, to the outbreak of the Great War. On Rietfontein the Andes Prospecting Syndicate acquired the interests of the previous concerns in 1914, but later transferred to Goedverwacht, where a small but steady output of high-grade chrysotile was kept up for some 18 months.

Later on, a series of similar occurrences were found elsewhere, but always in the same dolomite of the Transvaal and at widely separated localities (e.g. Graskop near Pilgrims Rest, Chuniespoort, Kaspers Nek, etc.). These show geological conditions practically identical with those east of Carolina, so that a similar mode of origin for this type of deposit is clearly indicated and holds good for all their occurrences.

East of Carolina, the Dolomite Series is defined above by the Rooihoogte quartzite (base of Pretoria Series) and below by the Black Reef quartzites, and within these limits the dolomite shows a series of from five to seven intrusive dolerite sills, having a variable thickness up to some 30 feet. The chrysotile has been found close to the *upper* contact of several of these sills, the relative positions of which are shown on Fig. 21, which also indicates the particular intrusion belonging to each of the principal developments. Invariably the dolomite within a few feet of the contact referred to has become serpentinized, and it is in this altered calcareous rock that one meets interbedded cross-fibre seams of chrysotile, always disposed in conformity with the dip (and with the inclination of the contact plane). It is obvious that another development of fibre should lie at the *lower* contact of the sills, since the serpentinization (though not necessarily the fibre itself) is due to the metamorphic influence of the igneous sheet—a result depending just as much on the lower as on the upper contact. Since prospecting is actually confined only to the latter, it is quite possible that additional horizons—not yet proved—may be located *below* the sills close to their base.

3. *Diepgezet No.* 33.—This farm occupies a large deep valley facing more or less east and cut up by numerous lesser spruits and gullies descending down to a tributary of the Buffels Spruit 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 basic sill,* with doleritic affinities below.

THE PRINCIPAL FILM HORIZONS IN THE DOLOMITE EAST OF CAROLINA.

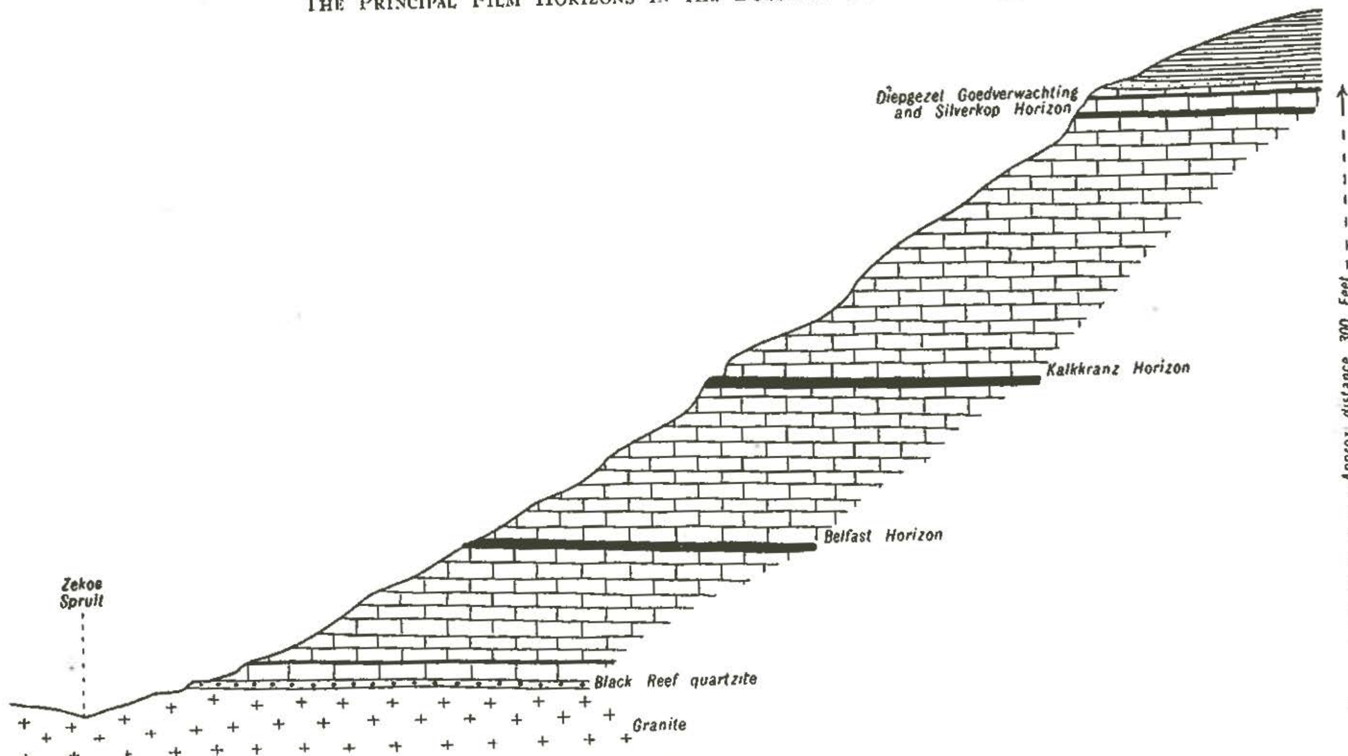


Fig. 21.

The *Rooihoogte Quartzite* is named* after the locality east of Carolina, where the Barberton main road drops from the plateau region into the granitic Komati River valley; it is up to some 30 feet thick and forms a convenient line at which to draw the base of the Pretoria Series. On Diepgezet, a thin band of black slate intervenes between it and the underlying dolomites and cherts. Since along its upper limit the quartzite very often develops a whitish cherty conglomerate, and also makes a faint, but definite feature, it is a useful indicator for the fibre belt. From this band the downwards succession is as follows:—

Sucession 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, indicates 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.

A persistent *basic sill* serves as the second (or lower) indicator: it rarely forms more continuous outcrops, but more often shows up in isolated rounded dark blocks, traceable across the Diepgezet Valley, in the same relative horizon to the Rooihoogte Quartzite, being clearly defined also e.g. on Goedverwacht and Silverkop. In the Diepgezet 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. Fresh samples a little below the upper contact show an evenly fine-grained basic rock, assignable to the dolerite 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

* Bibl. No. 26, p. 49.

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.

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 thorough decomposition of the accompanying rocks. It is not excluded that they are very compact basic dykes, such as were 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 breaks.

In view of the limited and intermittent production it is very difficult to work out the average *fibre length.* Exceptional instances of several inches were observed, but commonly the values fell between ½ and ¼ inches. 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.

The various fibre grades were distributed and stated to show the proportions indicated thus :—

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

Cirkel (Bibl. No. 9, p. 242) records that during the twelve months ended September, 1908, 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.

Diepgezet fibre is of good *quality* and shows the common delicate pale green or olive green tint, when in lumps; it can be readily fiberized into flexible strands of high tensile strength. Such material presents the clean white appearance of best cotton wool, has a brilliant silky lustre and the unctuous "feel" typical of high grade chrysotile. The chemical composition (see Table No. 1) shows the characteristic high percentage of magnesia and water of constitution.

Market preparation was essentially by means of hand cobbing, coarse hand worked sieves being the only mechanical appliances used.

Finally, it may be pointed out that the hard nature of the country rock, combined with the fact that as development proceeded further on the dip, the proportion of fibre of economic length decreased to beyond the limit of payability, were most probably the principal grounds for production ceasing; the same experience, however, applies to other deposits of this type, which is specially unfortunate, since the fibre usually shows very promising lengths nearer the surface, and is of superior quality.

4. *Goedverwacht No. 32.*—The beds associated in the preceding fibre horizon are directly continuous southwards into the adjoining farm Goedverwacht, where the Andes Prospecting Syndicate 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.

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 shown in Fig. 22 which also illustrates the influence of the harder bands on the surface features.

The same reliable indicators as on Diepgezet are again found; of these the Rooihoogte Quartzite is even more marked. 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 in petrographical characters, order of magnitude, fine-grained selvedges and relationship to the overlying chrysotile seams. The latter are also arranged with the dip of the country, i.e. inclined from five to ten degrees into the hill towards

* They are not drawn in Fig. 21; the first and second sills appearing in that section (below the Rooihoogte quartzite) are the same as the two lower ones of Fig. 22.

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 is probably near 25 feet thick.

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

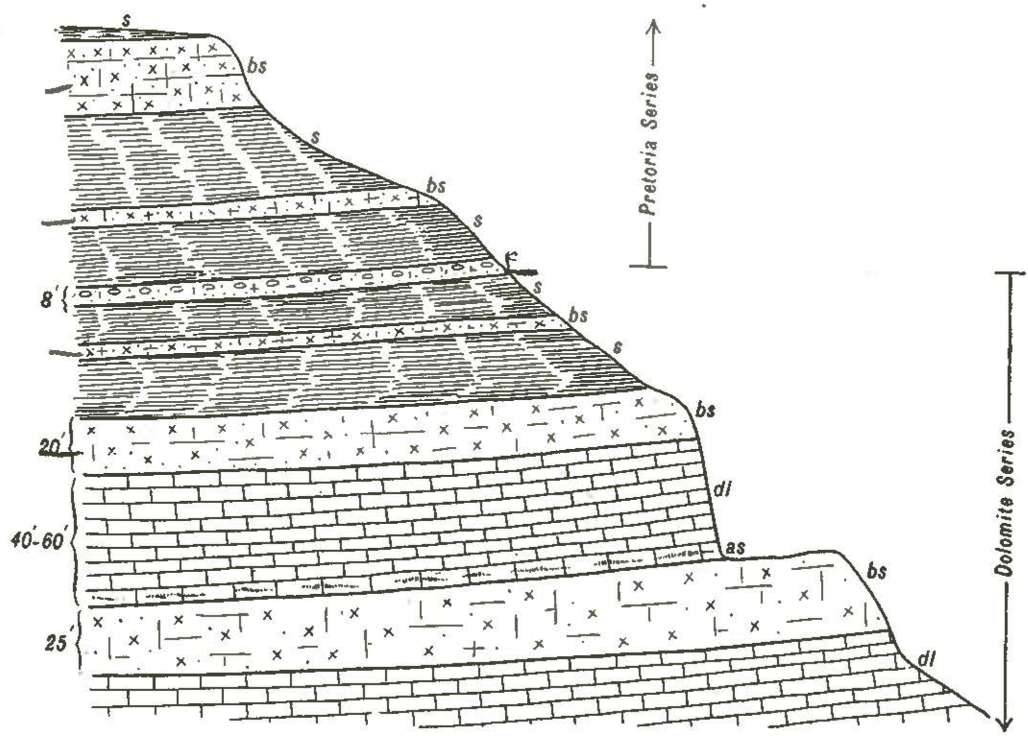


Fig. 22.

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.

From the surface the fibre veins were followed in five adits, the furthest workings being some 250 feet into the hill on the dip, while the surface cuttings between the mouth of the adit gave an almost continuous exposure of the upper (selvedge) contact of the igneous sheet, fibre being proved for a total length of about one quarter of a mile.

Production began in the middle of 1915 and some 200 tons of chrysotile were recovered by August, 1917, the output averaging some 10 tons per month; this comparatively trifling output was based on the labour of some 70 natives.

Development proceeded in such a manner as to keep the solid upper contact plane (selvedge) 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.

It was often found that a better fibre display was associated with more strongly marked green colouration of thickly bedded country rock, whereas very much less or even no fibre was contained in the whitish more thinly bedded dolomite, a point no doubt of genetic significance. The chrysotile horizon consisted in places 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, these veins show great similarity to the same fibre horizon elsewhere in the Carolina dolomite belt.

The *fibre length* varies from about ½ inch or 1 inch down to the minutest dimensions; the highest value observed was 6 inches, quite an exceptional occurrence. In *quality*, there was no essential difference as compared with Diepgezet fibre. Market preparation depending on hand picking, cobbing, screening by means of suspended "cradles" constituted the simple methods of recovery and grading; these—in the absence of any drying machinery—were sometimes delayed through misty weather.

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.

5. *Silverkop No.* 31.—This farm adjoins Goedverwacht on the east; the workings—which have not so far gone beyond the prospecting stage—lie high up on the northern portion of the farm overlooking the Buffels Spruit valley, in superb scenery. They consist of a conspicuous cutting, as seen from the Barberton main road in the floor of the valley—following the upper contact plane of an intrusive sill which most probably occupies a position within the succession similar to that of the sill below the fibre line on Diepgezet and Goedverwacht; the detailed downward sequence is as follows :—

Succession at the Fibre Horizon on Silverkop.

Shale.	
Rooihoogte Quartzite.	
Dolomite with much Chert.	
Basic Sill, highly weathered near the base.............	10 feet.
Compact dark Chert, weathering light grey............	13 feet.
Light coloured fine-grained altered Dolomite-streaked green with a thin layer of brown Manganese earth..........	9 feet.
Serpentinized Dolomite with occasional interbedded seams of Chrysotile..	5 feet.
Basic Sill.	

The fibre is restricted to a few feet of the beds resting directly on the sill, but the display of chrysotile seams is very disappointing.

6. *Rietfontein No.* 70 lies directly on the west side of Goedverwachting and in similar highly dissected country belonging to the valley of the Zeekoe Spruit, which cuts across the centre of the farm from west to east; the workings are about 22 miles due east of Carolina. Prospecting operations have been carried out on several narrow parallel strips each some 3½ miles long from north to south, into which the area is subdivided. The principal work has been done by the Kalkkrans Asbestos Company, on the strip known as C over a steep bare slope facing to the west. Here the whole of the Dolomite Series is well defined from the Rooihoogte quartzite on the top down to the Black Reef quartzite which forms a thin but well marked krantz almost in the floor of the valley on the left side of the Zeekoe Spruit.

The Kalkkrans main development forms a large open-cast working, continued by short adits into the hillside (on the dip of the fibre horizon). Plate XV shows a general view of this quarry, the dip amounting to about 10° directed into the hill. From the original surface the fibre horizon has been followed for about 90-100 feet on the dip. The clearly defined floor of this working is formed by the fine-grained selvedge of the upper contact of a basic doleritic sill, which is not the one underlying the fibre line on the farms described above, but occupies a horizon about the middle of the Dolomite Series. (See Fig. 21.) The detailed succession shows a band of serpentinized altered dolomite resting directly on the underlying dolerite selvedge and up to 5 feet wide, in which lie several interbedded cross fibre seams, the lowest one being in places up to 2 or 3 inches thick and in direct contact with the footwall sill. Along the strike the width of the fibre belt varies a good deal, and is locally only about half the value given above. Overlying the fibre belt is light-coloured altered dolomite (without fibre) or in places much chert associated with dark brownish black wadlike earthy matter. (See Fig. 23.)

The quality of the fibre is very superior and some 20 tons of very fine snow-white chrysotile of high tensile strength were obtained (all over 1 inch long) from the portion of the workings at or close to the surface; some of the fibre from this portion of the workings measured up to 2½ inches in length. An examination of the faces of the adit, where the fibre belt may thin down to 20 inches, shows the fibre display somewhat disappointing and leaves the impression that persistence in depth is doubtful.

Adjoining Lot C on the west lie workings of another set which fall into Lot D of a Belfast Syndicate. The general geological conditions are as before, but the fibre belt rests on the upper edge of yet another basic sill showing a very marked chill phase and belonging to a horizon below that marked by the sill of the Kalkkrans workings. (See Fig. 21.)

At the time of the writer's examination, no fibre belt had been demonstrated at the base (or lower contact) of the two sills concerned.

7. *Summary of the Principal Features of the Chrysotile Deposits in Altered Dolomite.*—The following is a summary of the more important aspects in the chrysotile deposits found in altered dolomite :—

(*a*) The fibre invariably lies in serpentinzed dolomite and is restricted to the fibre contact (or to within a few feet of the contact) between this altered dolomite and an intrusive sheet or sill of doleritic affinities, and persists along the strike—with intermittent non-payable zones—more or less as far as the sill or sills continue.

(*b*) The deposits are of the usual cross fibre type and are disposed with the dip of the sill (and country formation). In the workings so far made, the asbestos seams are at the upper contact of the sills.

(*c*) The principal developments up to the present, are those in the Dolomite Series east of Carolina, but other occurrences of the same nature are to be expected (and have actually been found) in other areas where the Dolomite Series is found, and intruded by basic sills. (Chapter VII.)

(*d*) The fibre is of very superior quality, but as a rule distinctly longer at or near the surface, the number and thickness decreasing somewhat rapidly in the direction of dip, though the alteration of the dolomite itself persists.

SECTION ACROSS THE FIBRE HORIZON AT THE KALKKRANS ASBESTOS COMPANY'S WORKINGS, EAST OF CAROLINA.

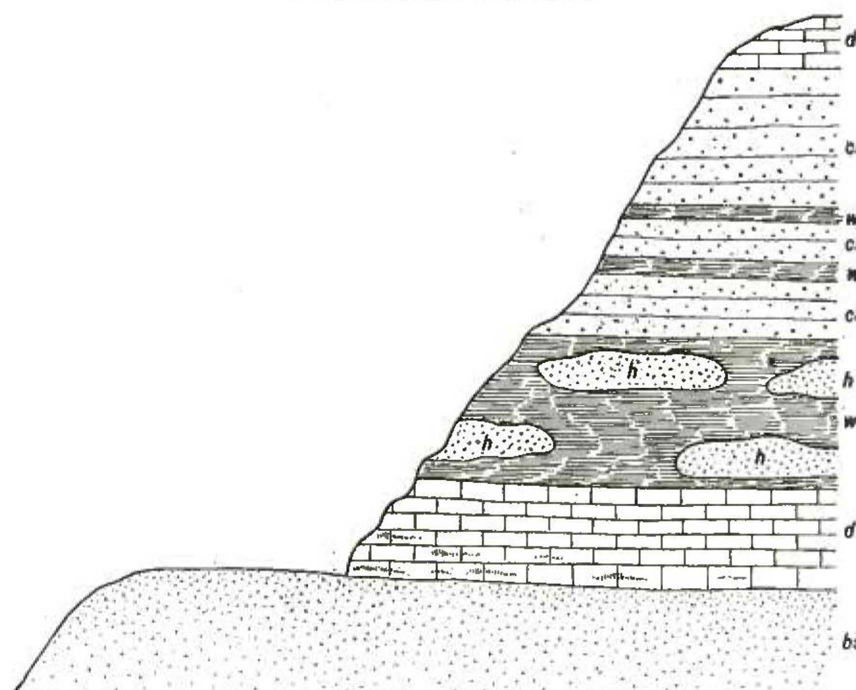


Fig. 23.

bs = top portion of a basic sill, overlain by *d* = altered dolomite (5 ft. thick) with cross fibre seams of chrysotile; *h* = hard rudely lenticular masses of chert (*ch*) in soft dark manganiferous earthly matter (*wad* ?) w; from the top of the *bs*. to the base of the topmost chert represents approximately 20 feet of the succession.

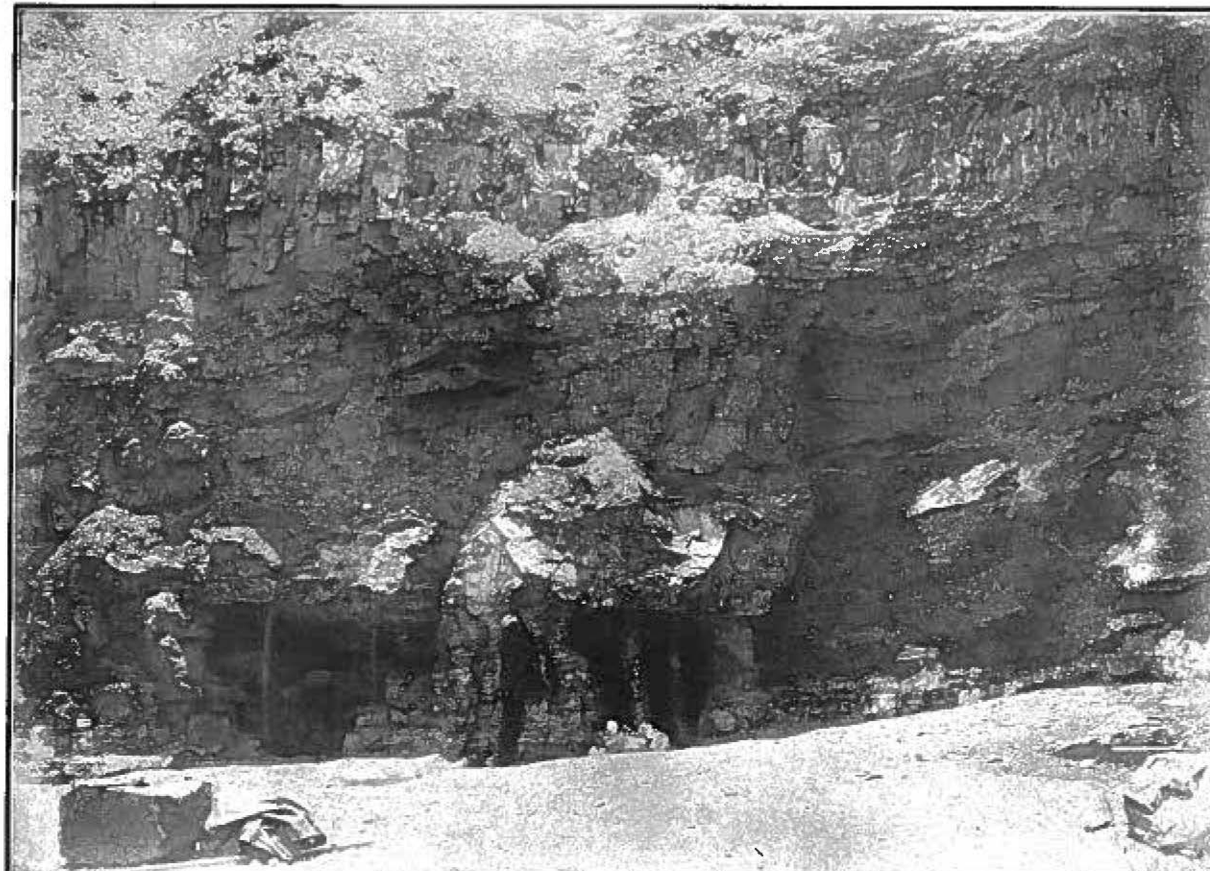


PLATE XV.—*General View of the Main Workings of the Kalkkrantz Asbestos Co.*, on Rietfontein, East of Carolina. The prominent face consists of chert and dolomite; at its base are cross fibre seams of chrysotile interbedded in serpentinized dolomite, which rests on an almost horizontal footwall due to the selvedge of the underlying dolerite sheet.

Chapter V.

PRINCIPAL ASBESTOS DEPOSITS IN THE TRANSVAAL (Continued).

IIa.—Amosite (Lydenburg Asbestos Fields).

1. *History and Distribution.*—The term Lydenburg Asbetos Fields is here used to denote the portion of the Lydenburg District—characterized by *large deposits of amosite*—extending from the Steelpoort River northwards to the right bank of the Olifants River and covered by the lower portion of the Pretoria Series from the Timeball Hill Quartzite down to the top of the dolomite. Mainly for practical reasons, it is convenient to have a distinctive term for this area, although it merges northwards into the Pietersburg Asbestos Fields, with which it is geologically continuous; the latter fibre area, however, lies along the left bank of the Olifants River and carries both amosite and crocidolite—being furthermore based on Pietersburg from the point of view of exploitation; thus the Lydenburg Asbestos Fields extend through some 20 miles from south to north.

The actual discoverer of the important amosite deposits in this district is not known, but the first record of it is in the Annual Report of the Transvaal Geological Survey for 1907 (p. 58), where its location is described on the right bank of the Olifants River in Eastern Sekukuniland on farms including some at present worked. This was during the writer's survey of that area in 1907, when several old prospecting pits were found showing thoroughly decomposed brownish fibre of remarkable length. On that occasion the late T. H. B. Wayne, who became the general manager of the Egnep and Amosa Mines (subsequently taken over by the Cape Asbestos Company) accompanied the writer. These deposits were found as cross-fibre seams invariably confined to a country formation of banded siliceous ferruginous slates (Pretoria Series) essentially similar to the bulk of the Lower Griqua Town Series of the Cape Province, described in Chapter II.

Between the rediscovery of the new variety of asbestos and its final establishment in the world's market—after more extensive and successful development of the deposits—an interval of some seven years elapsed, owing to the many difficulties encountered in marketing. The first material available was not very fresh, while its composition did not agree with chrysotile or crocidolite, and the very fact of its unique average length of 5 inches or thereabouts was considered to indicate an exceptional phenomenon, not likely to be followed by large and continous outputs. Inaccessibility, the difficulty of inducing manufacturers to try a fresh source of raw material—common in the case of new base metals that seek to compete with known sources already well established—were further causes in delaying the entry of amosite in the international asbestos industry; here the predominating position held by chrysotile, and its large regulated output told heavily against the new variety. These difficulties were gradually overcome, a result with which the perseverance of the late T. H. B. Wayne will always remain associated, so that the final establishment of amosite was soon reflected in the Transvaal fibre output, which rose from 55 short tons in 1915 to 3,192 short tons in 1917, due to the amosite developments in the Lydenburg Fields. To-day, this fibre is securely established on the markets of the world, and the existence of enormous quantities has been placed beyond any doubt.

2. *Situation.*—Veins of amosite are found on the farms 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 and Streatham, and have led to the establishment of a fully developed mine—the *Penge Mine*—on these farms; the last term is sometimes used to denote the workings in both localities, which really cover two constituent mines, one being the *Egnep Mine* (on Penge No. 780) and the other the *Amosa Mine* (on the adjoining farm Streatham No. 1083).

The above properties are situated in Eastern Sekukuniland,* i.e. in the portion of the Lydenburg District running along the right bank of the Olifants River from its confluence with the Steelpoort River north-westwards, at a distance of 50 to 60 miles north of Lydenburg. Burgersfort Station, on the recently completed Lydenburg-Steelpoort branch line, as well as the bridging of the Steelpoort River, have brought the deposits to within some 28 miles of railhead and greatly improved their accessibility otherwise. The fibre belt falls into fairly densely wooded low veld and cuts across rather broken hilly country from 2,000 to 2,500 feet above sea-level, and, on the whole, poorly watered, the Olifants River forming the only reliable perennial supply. The surroundings of the Penge Mines are associated with very striking and beautiful scenery, due to the alternating succession of hard (quartzites) and soft formations (slates, etc.) belonging to the Pretoria Series; Plate XVIII gives the general position of Penge, as it first comes into view from the main road of approach. Other aspects are shown in Plates XIX to XXI; the superb scenery round the floor of the Olifants River valley (as seen from Amosa Hill) can hardly be fully realized from Plate XXI.

* Sheet No. 13 (Olifants River) of the Geological Survey, gives their position and the general geology of this area.

PLATE XVI.—*Typical Cross fibre seam of Amosite,* interbedded in banded ironstones, Amosa Mine, Lydenburg District.

3. *The Succession Across the Principal Asbestos Horizon and Mode of Occurrence of the Fibre Veins.*—What is here called the " Principal Asbestos Horizon " forms the fibre deposits actually worked in the Egnep and Amosa Mines, but there are a series of additional seams, not so far of economic importance.

The sequence of beds across the lower portion of the Pretoria Series is shown in Fig. 24, which is taken at right angles to the strike, the dip being from 15 to 25 degrees to the south-south-west. The Timeball Hill Quartzite stands out as a prominent high and regular escarpment on the west and makes a striking feature in the scenery surrounding the mine. (See Plate XIX.) It is overlain by highly altered staurolite and chiastolite slates and rests on a great succession of altered slates and siliceous ironstones, which become predominant near the base of the series (good exposures of the altered slates below the quartzite occur alongside the main road a little distance from the base of the Timeball Hill ridge). The ironstones (carrying amosite deposits) are specially marked below the narrow Bevets Conglomerate, which is some 10 feet thick, and directly underlain by a thin band of pale greenish-grey fine-grained dolomite about 25 feet wide; the main mass of the dolomite, however, is not permanently established until below the ironstone beds. Two thin basic sills occur in the latter; from the top of the main dolomite to Bevets Conglomerate represents about 300 feet of the succession.

It follows, therefore, that the exact position of the Principal Asbestos Horizon may be described either as falling into the lowermost portion of the Pretoria Series or into the uppermost portion of the underlying Dolomite Series, according to where one decides to draw the base of the former. The wide persistence of Bevets Conglomerate throughout the Eastern and Northern Transvaal indicates a regional stratigraphical break and since no dolomite occurs *above* this conglomerate, it would appear best to draw the base of the Pretoria Series at the bottom of that conglomerate, so that the Principal Asbestos Horizon would fall into the Dolomite Series. It must be clearly understood, however, that the fibre does not lie in dolomite itself, but in a band of siliceous ironstones that lies interbedded in the dolomite. In the Pietersburg Fields there are at least three distinct intercalations of these ironstones in the Dolomite Series—and, in so far as any definite correlation is possible, the country formation of the Penge fibre belt would probably correspond to the uppermost band of ironstone met with in the Dolomite Series east of Chuniespoort. (See Chapter VI.)

Throughout the interval between Bevets Conglomerate and the top of the underlying main mass of dolomite (i.e. between *d* and *D* in Fig. 24) many amosite seams occur and show a great range in width, but the Principal Asbestos Horizon keeps a fairly definite position—approximately 100 feet below Bevets Conglomerate or some 200 feet above the main mass of dolomite (*D* in Fig. 24).

SECTION ACROSS THE ASBESTOS HORIZON ON PENGE.

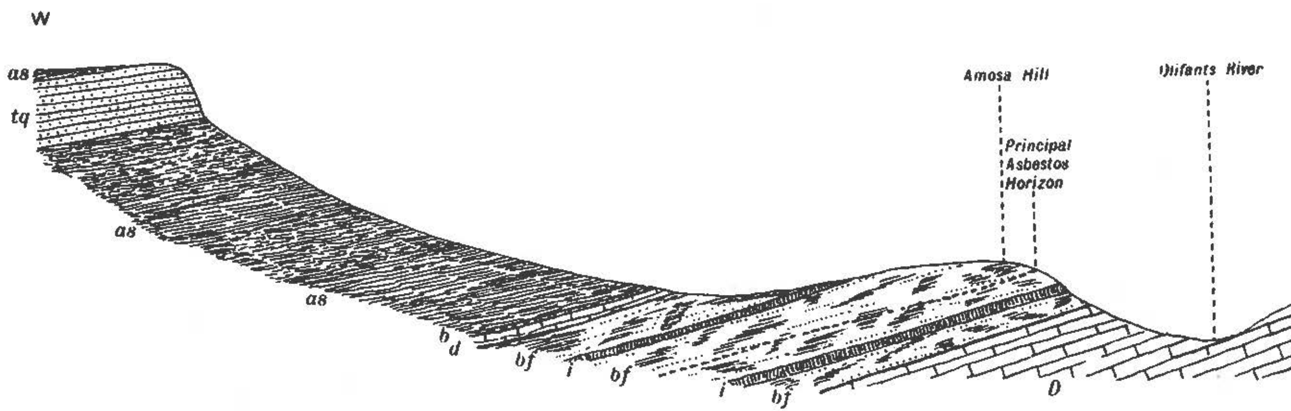


Fig. 24.

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.

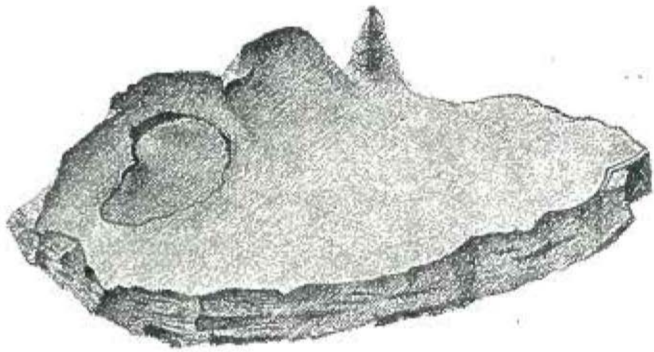


Fig. 1.—From Hurley, South of Kuruman.

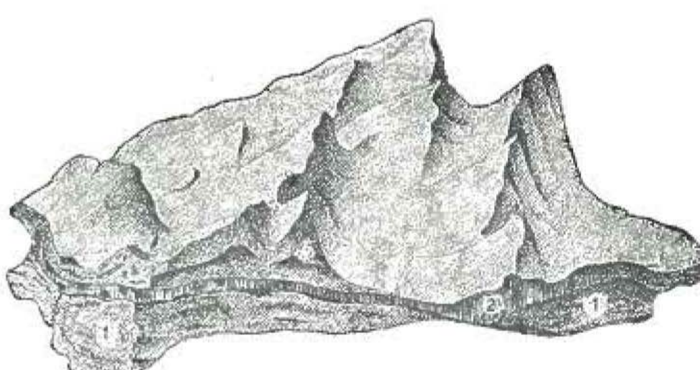


Fig. 2.—From Westerberg, near Koegas. 1. Country Rock. 2. Asbestos Seam.

PLATE XVII.—Moulds of banded ironstone left after complete removal of a crocidolite seam having "cone and corrugated" structure.

(Drawings by Eric H. Banks.)

As stated above, the asbestos builds cross-fibre seams bedded with the dip of the associated ironstones and always restricted to that formation. This is a more thinly bedded (banded) ferruginous siliceous rock, built of alternating hard and soft layers, the former due to compact dark bluish black material with silicified hematite or magnetite, the softer layers having an earthly brown or rusty appearance nearer the surface. Due to various stages of oxidation of the iron ore, the colour and general appearance vary a good deal. In the lower levels the asbestos country rock is sometimes much softer and often more like a ferruginous shale, though in the deepest part of the Egnep Mine (VIIth Level) it is at times very hard. There is a strong general resemblance to the banded ironstones of the Lower Griqua Town Series of the Cape Fibre Belt and many of the lithological characters of the group—given in Chapter II—hold good for the Lydenburg Fields also.

Metamorphosed Shales, forming part of the Banded Ironstone formation, are fairly common both in the amosite workings themselves, and at other horizons where no fibre is observed. On Penge, Streatham and Kromellenboog (and elsewhere) certain layers in the ironstone series are less siliceous, softer, and approach slightly siliceous ferruginous shales in appearance. Their colour is usually dark dirty-greenish, or sometimes almost black; typical outcrops are seen along the footpath leading up the southern side of Amosa Hill, where these rocks are well exposed at the entrances to several of the surface workings. Other good examples occur on the footslopes of the eastern flank of the Egnep valley behind the Boarding House south of the donga, in which the ventilation shaft lies.

These altered shales are readily identified by the presence in them of scattered nests built up of aggregates of slender fibrous dark brownish or pale grey to greenish grey crystals, sometimes without orientation, sometimes arranged as delicate stellate groups, tufts or rosettes of needles up to about 1/8 of an inch across, and distributed through the rock in a manner very closely imitating the habit typically displayed by argillaceous rocks, that have undergone thermal metamorphism with the formation of contact minerals (e.g. spotted slates, etc.). In other outcrops the crystals do not occur scattered, but form narrow elongated aggregates confined to the bedding planes.

Thin sections indicate fine-grained to compact sediments of an argillaceous type, with some admixture of siliceous material, and as a rule much of the matrix is irresolvable, but the conspicuous tufts are seen to be built of commonly stellate groups of a pale brownish amphibole, here and there giving clear and typical prismatic amphibole cleavage, while the extinction is sensibly straight; very probably, therefore, the mineral is rhombic hornblende and identical with amosite. In some sections one finds extremely delicate colourless fibres very intimately associated with, and now and then feathering out from, the amphibole needles. Scattered very plentifully throughout the section are many small crystals of yellowish green or greenish-brown strongly pleochroic *biotite*—with a typically metamorphic habit like that so commonly found in the contact aureole of the Bushveld Complex.

The same class of rock, but very fresh and hard—was observed in the Principal Asbestos Horizon in the VII Level of the Penge Mine, composed of layers of chert alternating with others rich in pale grey needles, which in thin section show almost perfect prismatic amphibole cleavage and an extinction up to 20°; this mineral is the monoclinic iron hornblende grunerite.

These metamorphosed rocks may be conveniently referred to as "*Amosite Slate*" and "*Grunerite Slate*"; the former were also found at many points more or less all through the Pietersburg Asbestos Fields, from the Montana Mine in the East to near Chunies Limited in the west, with characters very similar to those of the Penge and Streatham occurrences. The presence of these slates within a formation that has been found—on other grounds—to fall within the outer contact belt of the Bushveld Complex—is of exceptional interest from the point of view of amosite genesis, in view of their intimate association with asbestos seams.

All the amosite veins are of the cross fibre kind; in width they vary from 11 to 12 inches downwards, and fibre round 5 to 6 inches in length is very common, so that these deposits are certainly unique as regards asbestos length.

4. *The Principal Amosite Horizon*—as developed in the Egnep and Amosa Mines—shows three sets of fibre seams disposed parallel to one another and in conformity with the dip of the ironstone country formation, each group consisting of a series of parallel seams rather than of one seam. Plate XXXIV at the end of the volume shows a measured section across the principal fibre horizon as seen in No. 1 Level, B Section, Egnep Mine; this displays a combined fibre length of 30 inches distributed over 9 seams, which range from 7 inches to ¾ inch over a thickness of approximately 21 feet of the succession. The *upper group* often comprises from 3 to 5 seams, underlain by some 7 feet of banded ironstone; it is not exploited since the veins are much thinner, though in a chrysotile deposits they would be regarded as of very favourable thickness. The *middle* or *main group* consists of several seams, most of which—sometimes all—of commercial width (as judged by amosite standards). It is this middle belt that is being developed at both mines and supplies practically the entire output, but the lower group is also (occasionally) seen in the underground workings, below the I Level. Finally, the *lower group* appears some 10 feet lower down in the succession; as a rule it has only one seam, in places of good economic width. Apart from occasional thin veins of magnesite, the banded siliceous ironstone is the only formation in between the seams.

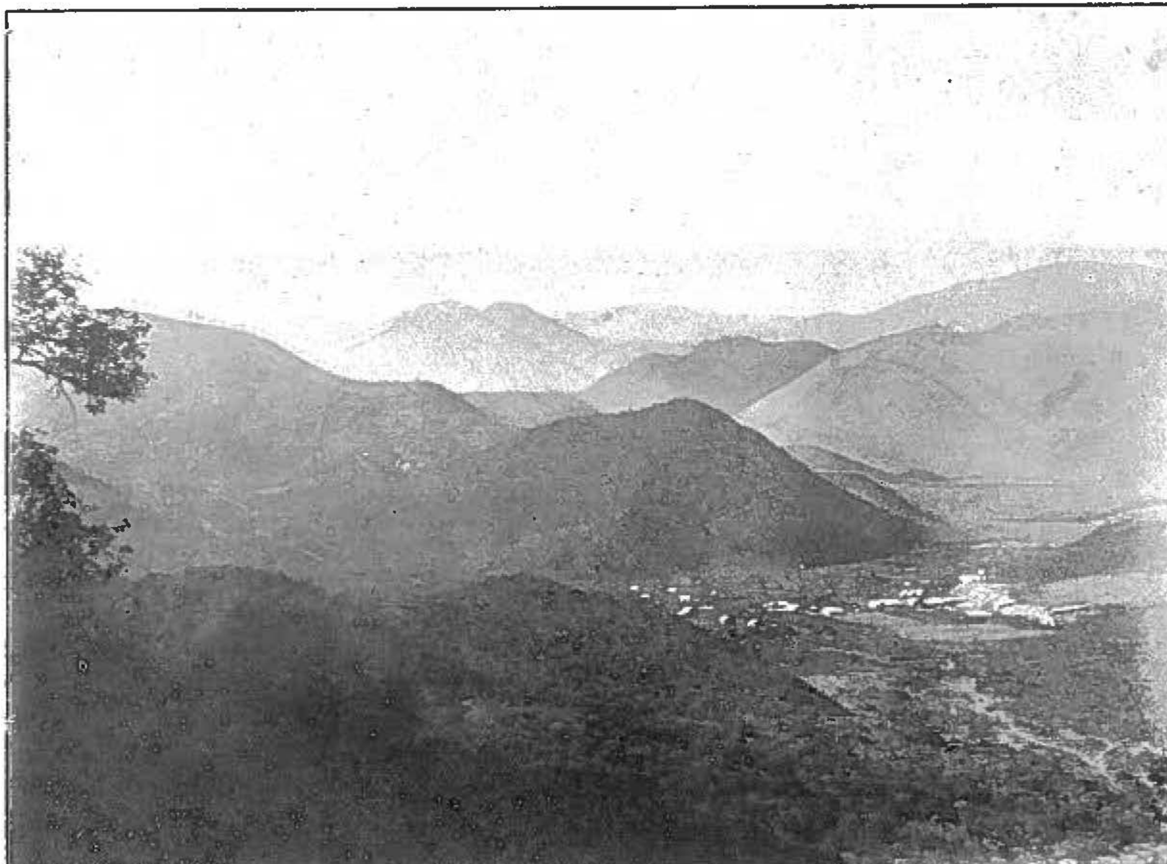


PLATE XVIII.—*Bird's-eye view of the Egnep Mine* (on right) and the Amosa Mine (on left) taken from the main road, and looking eastwards towards the hilly country of the Transvaal Drakensberg. The prominent Amosa hill in the centre shows the workings along the outcrop of the main amosite horizon.

5. *The Egnep and Amosa Mines.*—The above fibre belt—in particular the middle group of seams—is well opened up in two extensive mines, known as the Egnep and Amosa Mines, distant about one to one and a half miles from one another. A general view of the *Egnep** Mine is represented on Plates XVIII and XIX; the mine lies in the floor and over the lowest easterly flanks of a fairly open valley, hemmed in on the west by the Timeball Hill Quartzite Escarpment and extending roughly north and south across the western portion of the farm Penge. The common boundary between this and the adjoining farm Streatham on the north runs over the summit of a low but well-marked Kopje, known as Amosa Hill (seen in the centre of Plate XVIII) and easily recognized by its many surface workings (Plate XX); those on its southern side belong to the Egnep, while the Amosa Mine embraces the other workings on the northern face (not seen in Plate XX) of this hill over Streatham.

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

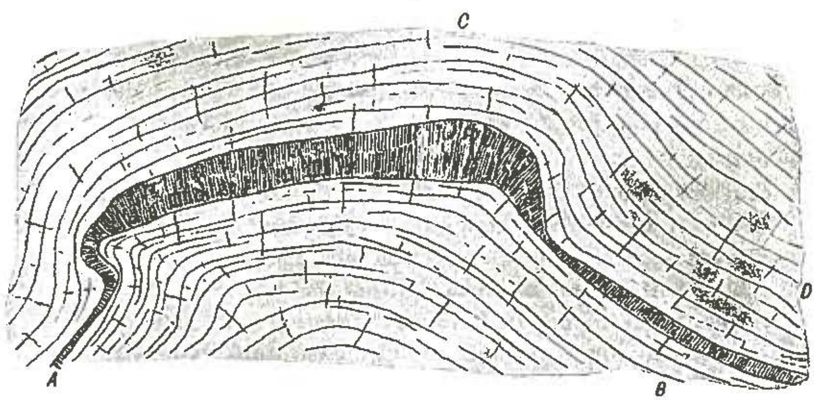


Fig. 25.

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*.

The layout of the Egnep Mine comprises three sections: Section C covers the surface workings on the southern face of Amosa Hill: Sections A (earliest developments) and B lie a little to the south under the floor of the valley and its lowest eastern slopes, and cover both surface and underground workings. The principal development (and production) is now centred in B Section. There are seven levels, numbered consecutively downwards, No. VII being the lowest. The original mining policy was to maintain between successive levels a stope block 100 feet long in the direction of the dip, which ranges from about 15 to 22 degrees, in a general westerly direction. The normal alignment of the levels (drives) is along the strike, and in them the

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

position of the middle group of seams is very commonly shoulder high for great distances. Table No. 28 shows the advanced state of development reached, and incidentally also the enormous fibre tonnages available :—

TABLE No. 28.—*Summary of Development Extent, Egnep Mine.*

No. of Drive.	*Length. in Feet.*	*Winze.*	*Length of Winze in Feet.*
7	630	7–6	100
6	1,140	6–5	72
5	1,100	5–4	95
4	2,200	4–3	40
3	1,640	3–2	70
2	1,500	2–1	60
1	1,150	1–1A	100
1A	1,180	1A–2A	150
2A	1,150		
TOTAL	11,690	TOTAL	687

A vertical shaft 215 feet deep connects the surface with the seventh level, and is also joined to the sixth level by a cross-cut; the lowest workings are now some 20 feet below ground water-level, necessitating pumping.

The workings of the *Amosa Mine* lie on Streatham (adjoining Penge on the north) and extend from close to the summit of Amosa Hill down its northern slopes, while prospecting has also revealed the persistence of the fibre belt further northwards from Amosa Hill. Both surface and underground developments have been carried out, exposing the fibre continuously all round the hill and demonstrating its persistence on the dip (round 20 degrees) for some 1,200 feet. The deposits are opened up by a series of some eleven adits (drives) starting from the outcrop along the strike and ranging from 80 to 1,140 feet in length, so that over 5,000 feet have been driven on the " reef "; these adits are spaced at distances of some 120 feet measured in the direction of the dip. There is also an incline shaft 320 feet long, which corresponds to a vertical depth of 290 feet, situated near the northern foot of the hill. None of these workings have so far reached ground water-level; their position agrees closely with that of the Egnep Fibre Belt, i.e. in both mines the same principal fibre horizon is being developed, that of the Amosa Mine also corresponding to the middle group of seams shown in Plate XXXIV.

6. *The Amosite Veins and Fibre Length.*—The amosite veins invariably show cross-fibre habit, in which the fibres extend regularly and transversely across from one to the other containing wall in the usual manner. On the whole, the disposition of the seams is very

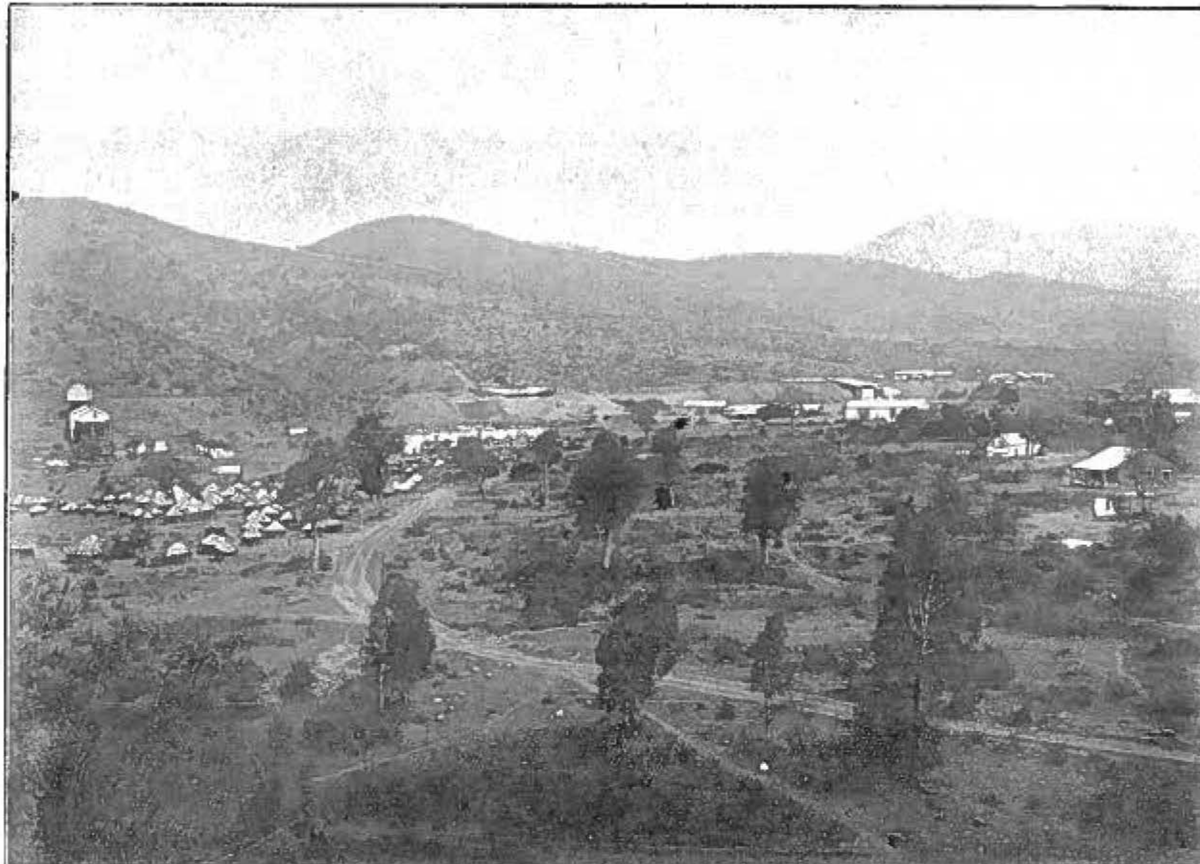


PLATE XIX.—*General View over the Egnep Mine* (Amosite), North of Lydenburg, with the mill on the extreme left; banded ironstone hills in background, with the Timeball Hill quartzite in the far distance on the right.

regular and faults or other disturbances are rare, but an occasional local minor roll is sometimes observed, of which Fig. 25 illustrates a typical example.

The seams are usually free from scattered iron-ore particles, and are built up of tightly packed well-oriented fibres; a single vein may persist with sensibly constant width for several feet or yards, when it gradually tapers out or dies down to a delicate film prolonged for some distance. Often several parallel seams occur associated together, the amount of intervening country rocks being subject to all kinds of variations, or one seam overlaps another, and begins at a slightly different level to carry on the general continuity of the fibre deposit; in this

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

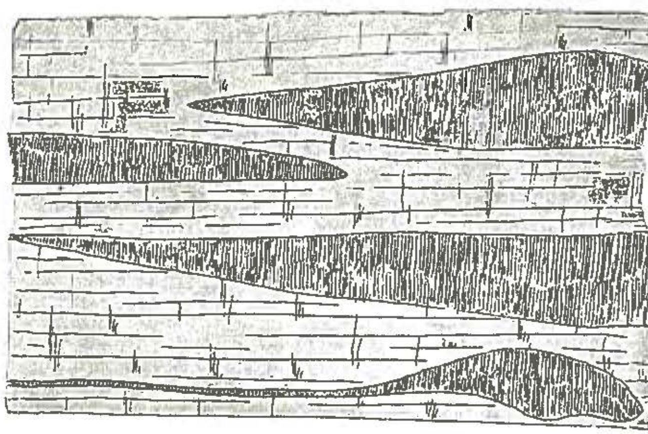


Fig. 26.
Scale 1 inch = 12 inches (approx.).

way the seams are never entirely lost for any greater stretch in the various levels (Fig. 26). A virtual coalescence of several seams in the lowest levels furnishes a local combined seam thickness of 20 inches, broken only by one or two thin dark bluish clayey partings (Fig. 27). Not infrequently the traces of the upper and lower edges of a seam appear as wavy or otherwise irregularly bulging lines, or the country rock both in the hanging and in the footwall shows more or less cone-shaped projection into the seam—closely analogous to the so-called "Cone and Corrugated Structures" described in Chapter II from the Cape Fibre Belt (see Figs. 4 to 7 and Plate XVII). Such projections are composed sometimes of normal country rock, but elsewhere consist of fibrous iron oxide, the fibres of which are oriented in conformity with the fibrous structure of the amosite seam itself.

In some of the upper levels and in many surface workings, irregular veins, stringers, or nests or 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

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

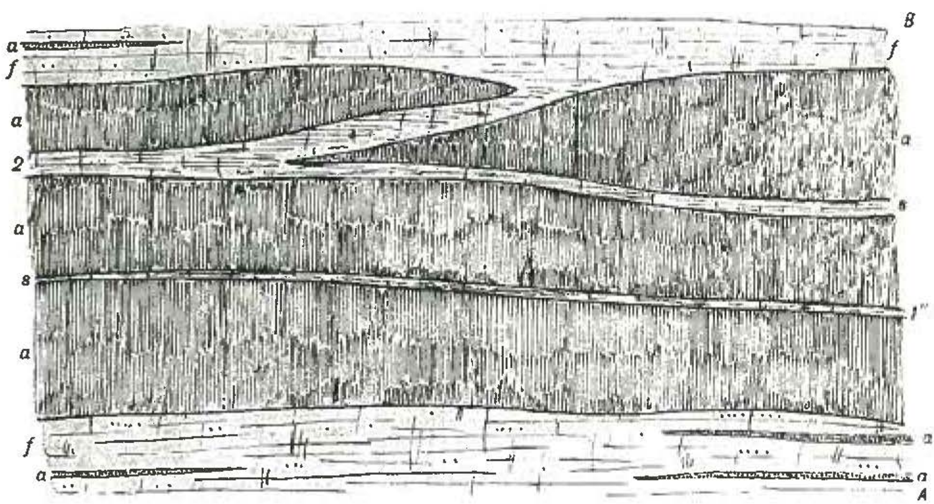


Fig. 27.

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

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.

Nontronite (hydrated iron silicate) is found in thin films of soft earthy looking greenish yellow material coating the joint planes or bedding planes of the ironstones associated with the fibre belt; it is characteristic of the zone of weathering and agrees closely with the mode of occurrence referred to in the geological features of the Cape Belt (Chapter II); nontronite has been noted throughout both the Lydenburg and the Pietersburg Asbestos Fields.

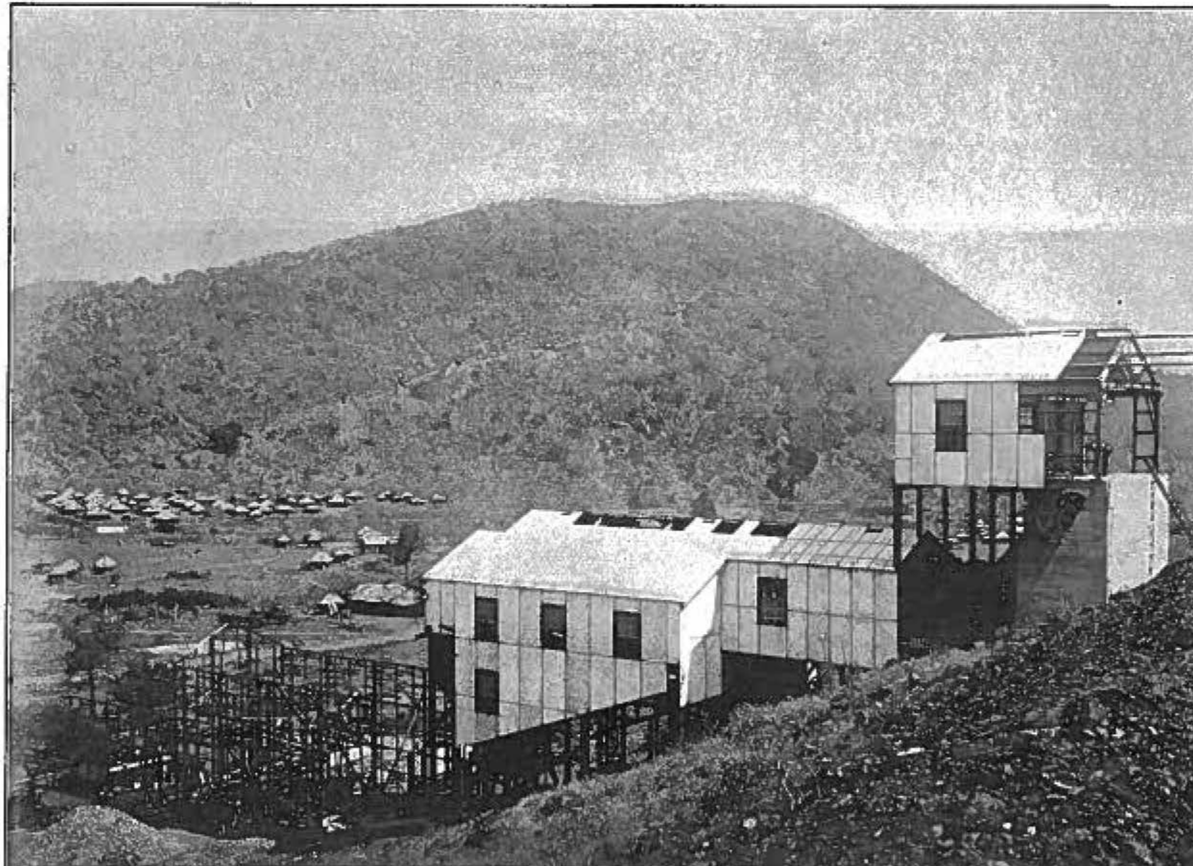


PLATE XX.—*Amosa Hill at the Egnep Mine*, north of Lydenburg; in the foreground the new mill; in the background are seen the entrances to the series of adits aligned along the outcrop of the principal amosite horizon.

Dykes occasionally interrupt the continuity of the fibre horizon; they are fine-grained basic intrusives cutting obliquely from north-east to south-west, e.g. across Amosa Hill. Thus in No. II Level of the Amosa Mine there are three such dykes some 40 to 50 feet thick; since they cut the seams and alter them, the intrusions appear to be of an age subsequent to the period at which the seams were formed. On approaching such a dyke the asbestos undergoes a progressive change, most pronounced over a distance of one to two feet from the contact, the fibre becoming very hard and stony without altogether losing its asbestiform habit, until beyond the gap occupied by the dyke, the seam is picked up at the other contact with the same altered appearance; similar features are noticed in the Westerberg Mine in the Cape Belt.

The behaviour of the dykes does not indicate a direct mode of origin of the fibre veins, as the result of igneous intrusions of this character.

The most striking feature of the Lydenburg Amosite Deposit is the extraordinary *length of fibre,* found not as an exceptional occurrence, but maintained over great stretches along the principal fibre horizon. From the maximum length of 11 inches there is every gradation down to the thinnest films. At the same time there are many seams from 4 to 7 inches thick, and no difficulty has been experienced in maintaining a large output of fibre round 4 or 5 inches in length. In many sections of both the Egnep (Fig. 28) and Amosa Mines the so-called " top seam " just below the hanging wall consists of very long fibre, often 6 inches and more in length, so that although a true average length is difficult to determine, a study of Plates XVI and XXXIV and Figs. 26 to 29 (which illustrate typical appearances of the horizon recurring over and over again) indicates that, in the matter of fibre length, this amosite belt holds a greatly superior position, in comparison with chrysotile and crocidolite deposits, and unique in the mineralogy of asbestos.

7. *Nature and Variation with Depth.*—The physical and chemical properties of amosite have been given in Chapter I, but may be supplemented by particular aspects noticeable in the course of mining developments.

The fibre seen in the old prospecting pits—referred to above—showed the usual remarkable length, but was very brittle and also dirty rusty brown in colour, so as to present an altogether unpromising appearance. As developments proceeded there was a distinct improvement in quality, the fibre being less brittle and much lighter in colour. In the lower levels the fibre appears permanently in pale greyish or ash grey tints and shows higher flexibility and tensile strength, can be easily separated into most delicate strands and worked up into a soft silky mass; varieties from Streatham have also been obtained, almost pure white and comparable to chrysotile when thoroughly fiberized. The deeper earthy-brown colour of the fibre nearer the surface is due to oxidation and hydration of the iron, of which a large percentage enters the constitution; thus it has been shown that such amosite, after treatment with acid for several hours, assumes a much lighter pale grayish colour.

MEASURED SECTION ACROSS THE FIBRE BELT IN THE VII LEVEL, EGNEP MINE.

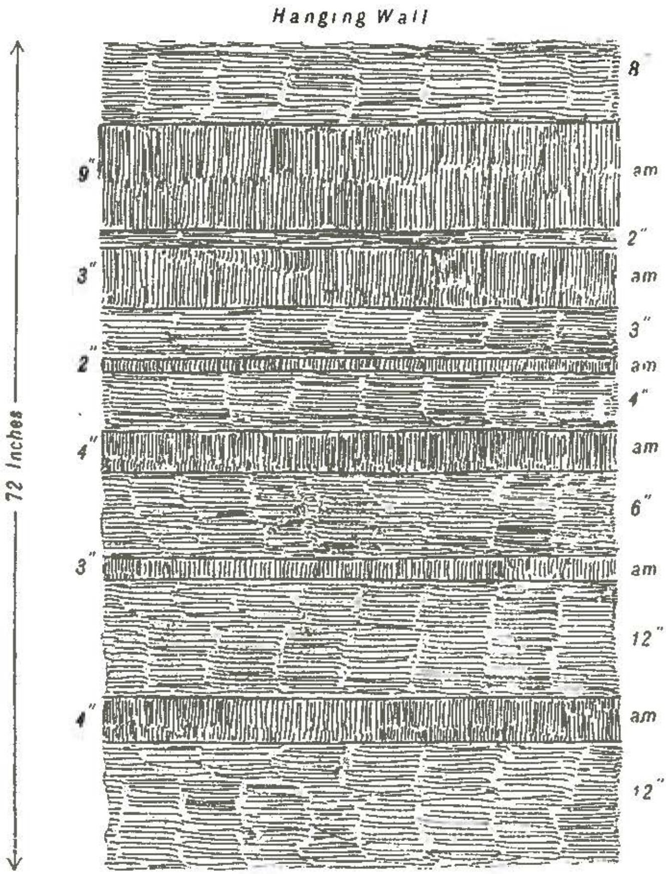


Fig. 28.

am = Cross fibre amosite seams, totalling 25 inches over 72 feet.

There is no definite indication in the deepest workings now reached of any general decline in the number, width or quality of the seams, or of the fibre display being adversely affected by proximity to ground-water level. Fibre lumps from the seventh (lowest) level have a very beautiful and striking appearance with an almost black colour, and are

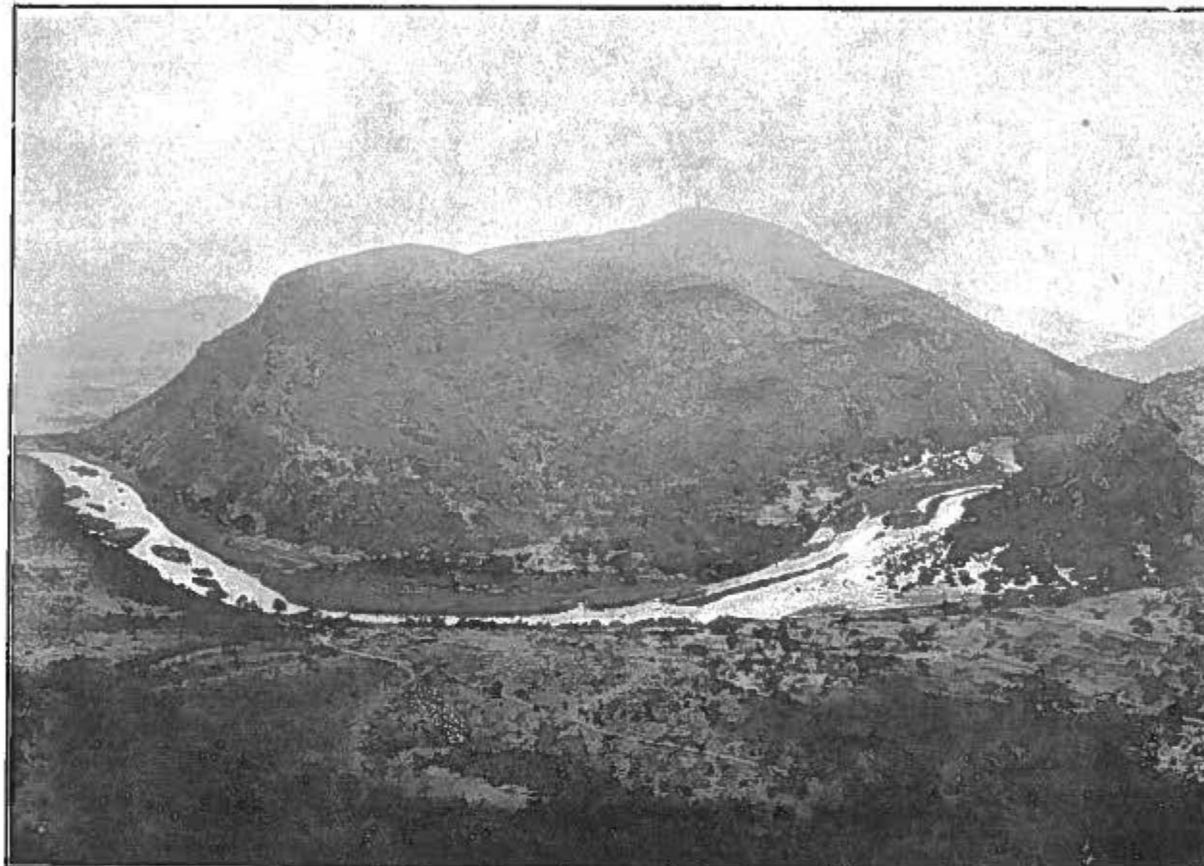


PLATE XXI.—*The Olifants River* as seen from Amosa Hill, north of Lydenburg, following approximately the boundary between the banded ironstones of the Pretoria Series (in foreground) and the underlying dolomite (on far side of river).

still readily fiberized into finely fibrous pale grey material. At the same time, thin strands from this working differ somewhat in their flexibility and are "springy"—not unlike whalebone. Any change in quality depending upon varying depth below the present surface should be gradual, but no signs could be observed of initial stages of general deterioration. Similarly there is no indication of any tendency for amosite to pass in depth into crocidolite, though cases occur in the Pietersburg Fields where blue and grey fibre are directly associated in the same piece of country rock.

8. *Persistence, Percentage of Fibre to Rock, and Resources.*—The principal fibre horizon has been traced along the strike for approximately 2½ miles; this does not, strictly speaking, represent a continuous persistence, since between the southern end of Amosa Hill and the northernmost end of the Egnep Mine developments there is a short stretch over which the fibre belt is not yet exposed. On the other hand over Amosa Hill true continuity is established over not less than one mile of strike, the corresponding value for the Egnep Mine being approximately half a mile. In the direction of dip the proved persistence amounts to 680 feet for the Egnep and about 1,200 feet for the Amosa Mine. In the former mine the maximum depth reached measures 210 feet vertically below the surface.

The *ratio of fibre to rock* is obviously very high and unique both among all known amosite deposits as well as for other varieties of fibre deposits. Thus figure 28, which represents a measured typical section in the VII Level shows a combined fibre length of 25 inches over a face 6 feet high, while Fig. 29, a measured section typical of the Amosa Mine, shows 20 inches of fibre over a 6-foot face, indicating asbestos percentages respectively of 35 and 28 (round figures). Even though these values cannot be taken as reflecting the actual final recovery factor, they justify the conclusion that the ratio between fibre and rock is remarkably high.

Even without making the unsatisfactory attempt of working out a numerical estimate of the total amount of fibre available, the *magnitude of the fibre resources* may be gauged by taking only 6 inches as the combined fibre length in the Egnep Mine—obviously a most conservative figure; a section 500 feet in length and 100 feet on the dip there corresponds to 25,000 cubic feet of fibre. The economic significance of this result must be considered in the light of the figures given above, of the proved persistence on strike and on dip. It is also interesting to note, that in some of the stopes the amount of waste rock has at times not sufficed for packing in a stoping width of 40 inches. At one stage in the history of the Amosa Mine, when the lowest workings had reached 300 feet on the dip, the mine surveys pointed to a tonnage of over 100,000—based on a combined fibre length of 6 inches.

MEASURED SECTION ACROSS THE FIBRE BELT IN NO. II LEVEL, AMOSA MINE.

Hanging Wall.

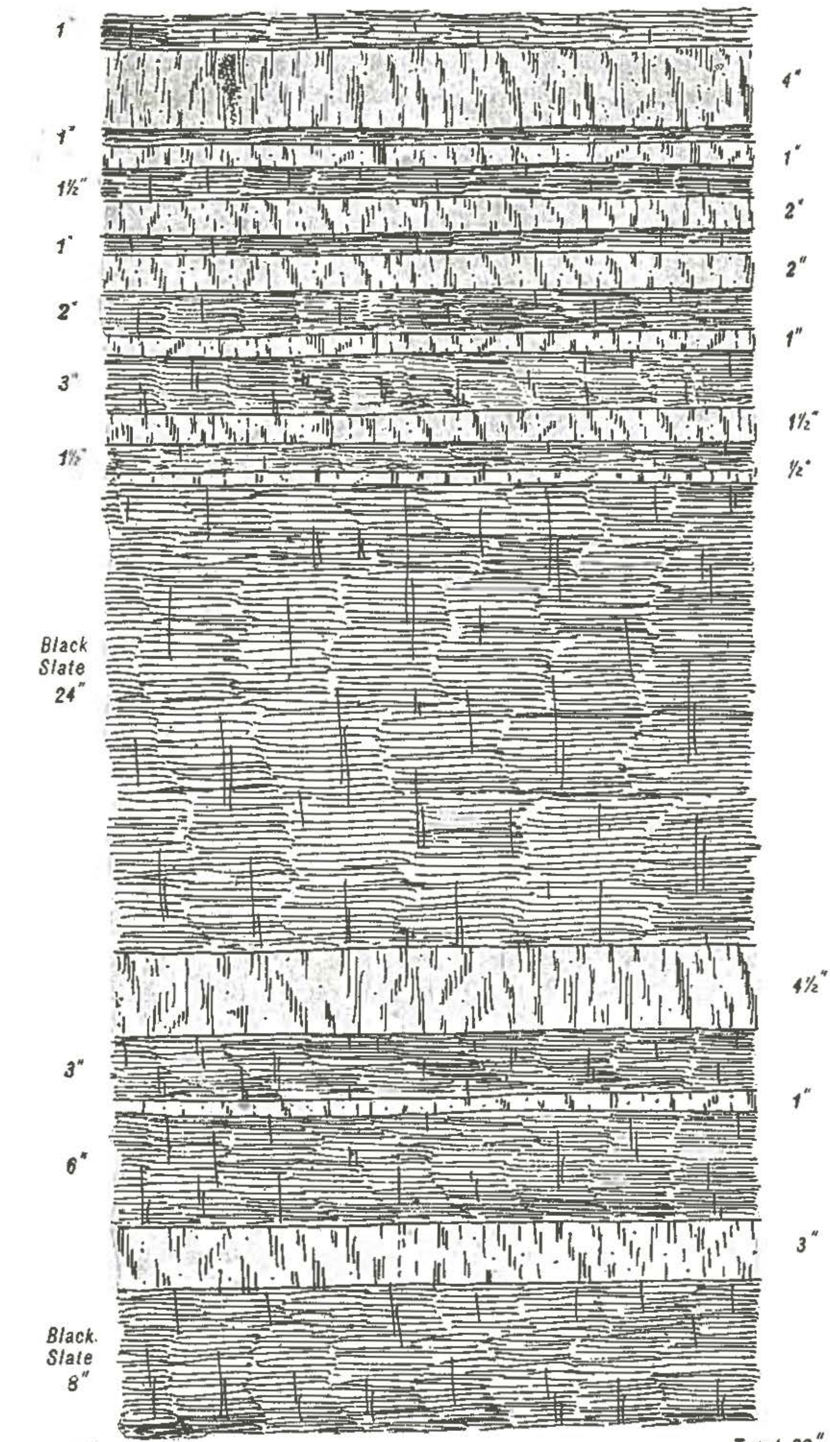


Fig. 29.
Approximate scale 1 : 10.

9. *Market Preparation, Output, Disposal and Prices.*—In the market preparation, hand cobbing is an important factor, when dealing with an output in which the great bulk consists of long fibre, but a mill for mechanical preparation is in course of erection. The prepared fibre is dried and classified according to a grading scheme that depends principally on length and colour, e.g. the best grade is defined as over 3 inches in length and ash grey in colour. The phenomenal length of the amosite has necessitated cutting the fibre down, to suit the requirements of some manufacturers.

Through the courtesy of Egnep, Ltd., it is possible to include the instructive Table No. 29 which shows the grades and their relative percentages in the total for 1929. It is expected that the grade D1 from Amosa (which was nil) should be near 15 per cent. of the total output for 1930. The apparent identity of some specifications, e.g. for grade B1, B2, and B3 means that they are based on other criteria (e.g. colour) besides length :—

TABLE No. 29.—*Amosite Grades and Percentages.* (*Egnep, Ltd.* 1929 *Output.*)

Egnep Mine.			Amosa Mine.		
Name.	Description.	Percentage.	Name.	Description	Percentage.
B1	3 in. upwards....	24·5	D1	3 in. upwards...	Nil.
(II)	Under 3 in......	10·5	D2	Over 2½ in......	10·25
B2	3 in. upwards....	2·5	DII	Under 2½ in.....	44·75
B3	3 in. upwards....	50·0	D3	Over 2½ in......	45
(3)	Under 3 in.......	12·5			

The *output* has varied with market and other economic conditions, but normally a monthly production in the neighbourhood of 1,000 short tons is maintained.

The finished product is *disposed* of in the form of 20 bags to the ton, with Burgersfort Station as the railhead. It goes to the United States, Japan, the Continent and elsewhere, while it is also consumed in the Cape Asbestos Company's own factories.

The *value* ranges from £18 to £38 per short ton free on board.

10. *Summary of the Outstanding Features of the Lydenburg Fields.*—The following are the principal geological and economic

aspects characteristic of the Lydenburg asbestos deposits, with special reference to the Penge-Streatham area :—

(*a*) Amosite is the only fibre variety available, and restricted to the banded ironstone group, interbedded in the uppermost portion of the Dolomite Series.

(*b*) The fields extend for some 20 miles from south to north, and include within the farms Penge and Streatham the Principal Fibre Horizon with a proved continuity of over 2 miles; further north the Lydenburg Fields merge without any break into the Pietersburg Asbestos Fields.

(*c*) The Principal Fibre Horizon is well developed at the Egnep and Amosa Mines, where it forms three sets of interbedded cross fibre seams with a total fibre width of over 30 inches. Single seams of five inches (and over) in thickness are common.

(*d*) Enormous tonnages are available and their persistence has now been proved for a distance of up to 1,200 feet on the dip.

(*e*) The deepest workings of the Egnep Mine are about 210 feet vertically below the surface, are, i.e. 20 feet below ground water level, and show no general decline in the number and thickness of the seams.

(*f*) The quality of the fibre is of commercial grade and shows no deterioration in depth, beyond the fact that it tends to develop a certain "springiness."

(*g*) The Principal Asbestos Horizon falls into the outer contact belt of the Bushveld Complex—a point most probably of genetic significance.

Chapter VI.

PRINCIPAL ASBESTOS DEPOSITS IN THE TRANSVAAL (Continued).

IIb.—Amosite (Pietersburg Asbestos Fields).

1. *History, Extent, and Situation.*—Within the area commonly referred to as the Pietersburg Asbestos Fields, amosite constitutes the most important productive fibre; crocidolite is also found, but is of more limited occurrence, while chrysotile has been located along one horizon, which has not yet been exploited.

The earliest record of the existence of asbestos in the Pietersburg Fields (and in the Transvaal) dates from 1905, when Prof. G. A. F. Molengraaff, in a paper read before the Geological Society of South Africa (Bibl. No. 54), described a specimen of silicified crocidolite obtained from the farms Jobs Kop No. 589, situated on the right bank of the Olifants River near its junction with the M'Thlapitsi River (see Plate XXXVI at the end of this volume); the mineral was described as occurring in a highly ferruginous quartzitic sandstone, and Molengraaff pointed out that the existence of mineral in the Transvaal,

> "constitutes an additional proof of the correctness of the theory that the Pretoria Beds may be correlated with the so-called 'Jasper Beds' of Griqualand West, which last overlie the Dolomite of the Campbell Rand . . . . . a theory, advanced by Mr. David Draper * some ten years ago, long before the existence of highly ferruginous banded quartzites in the Pretoria Beds of the Transvaal has been recorded."

In the course of the survey of the Haenertsburg Goldfields and the adjoining portions of Eastern Sekukuniland during 1907 and 1908, further occurrences of crocidolite were noted, e.g. on Lot No. 263 between the Malips and Molapatsi River, in the banded ferruginous ironstones forming the lowermost portion of the Pretoria Series; in 1908 other localities were also found, where asbestos was observed in thin seams in the banded ironstones that occur intercalated in the dolomite.

* The late Dr. David Draper.

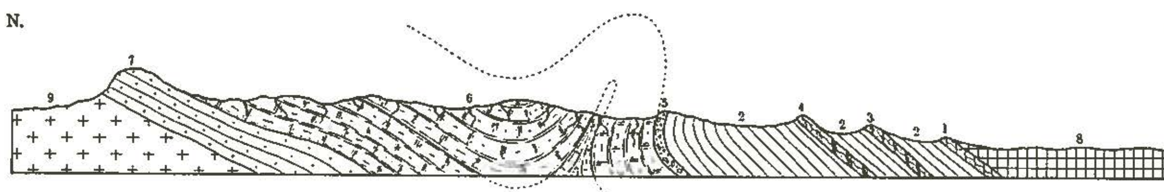
These discoveries remained for a long time merely records of mineral occurrences, and it was not until the developments of the amosite deposits on Penge (Chapter V) had established the economic importance of the asbestos deposits in the banded ironstones at or near the base of the Pretoria Series, that attention was directed to this area as a possible fibre source; by 1917 the existence of both amosite and crocidolite deposits under economic conditions was definitely established in the Malips River Valley, e.g. amosite was proved on the farms Uitval No. 1791, Holkloof No. 1581, and Krantz Kloof No. 1786, and crocidolite deposits were opened up on Lot No. 244. The first occurrences of Pietersburg asbestos that enjoyed systematic and sustained development, eventually securing a permanent footing in the market, are the amosite deposits on the east side of the Malips River, e.g. on Lot No. 120, where they were originally explored in 1917—and have maintained an output ever since—by Mr. W. McBean, who is therefore the pioneer in the amosite asbestos industry based on these fields.

Further prospecting—stimulated in part by the sustained success of the phenomenally rich deposits of the Penge-Streatham area in the Lydenburg Fields (Chapter V), in part also by a general revival of base-metal activities due to post-War conditions, together with an increasing demand for asbestos—led to the discovery of many fresh fibre occurrences, which ultimately extended from the known Malips River Valley Fields westwards almost as far as Chuniespoort, and eastwards or south-eastwards into the Lydenburg District. As a result of these activities, the known fibre resurces of the Pietersburg Fields—more so in the case of amosite than for crocidolite—have greatly increased. In about 1928, at the high-water mark of the prospector's enthusiasm, a long list of companies and syndicates had taken shape, which it is not without interest to record (see Section 4 below). Unfortunately, recent developments in the world's asbestos markets have to some extent affected the prospects of the Pietersburg Fields adversely, so that most of the concerns shown in the list referred to have been forced to curtail, or altogether suspend, operations. While there may be room for improvement in the selection of fibre for treatment and the methods of market preparation, it is at any rate satisfactory to find that as regards available resources and general quality, the asbestos deposits of these fields have come up to expectations, and that the adverse result alluded to is probably one of those temporary setbacks, which seem to arise from time to time in the fluctuating activities of a base metal industry.

As here defined, the "Pietersburg Asbestos Fields" are *situated** wholly within the Pietersburg District and stretch along the left (north)

* See Geological Survey Sheet No. 13, Olifants River, and Plate XXXVI at the end of this volume.

DIAGRAMMATIC SECTION ACROSS THE TRANSVAAL SYSTEM EAST OF CHUNIES POORT.



1. *Magaliesberg Quartzite.* 2. *Shales.* 3. *Daspoort Quartzite.* 4. *Timeball Hill Quartzite.* 5. *Conglomerate.* 6. *Dolomite.*
7. *Black Reef Series.* 8. *Norite.* 9. *Older Granite.*

Fig. 30.

side of the Olifants River, their centre—along the Molapatsi River—being some 34 miles in a direct line south-east from Pietersburg. They *extend* from Chuniespoort in the west along a general easterly direction across the Malips River Valley to the M'Thlapitsi River, but continue beyond the latter stream southwards as far as the farm Lucerne No. 2651, on which the banded ironstone formation (carrying the fibre deposits) crosses the Olifants River into the northern end of the Lydenburg Fields. The area, as limited, forms an elongated strip of country, gradually increasing in width from 5 miles at the Chuniespoort end up to 12 miles in the central portion, and dropping to a width of some 8 miles at its south-eastern end; the above amounts approximately to 440 square miles of potential asbestos country, if the Dolomite Series (chrysotile) is included. Taking only amosite and crocidolite into consideration, the distribution of which is strictly limited to the banded ironstones, the potential asbestos source covers some 190 square miles, ranged along nearly 50 miles of strike.

2. *The Geological Succession.*—For the most part the Pietersburg Asbestos Fields form *highly broken country with great relief,* and large sections of it are thoroughly mountainous, with deep and narrow, sometimes kloof-like valleys, hemmed in by steep and extensive slopes. Largely due to the resistant nature of the great succession of banded ironstones and the various quartzites, the surface is strikingly dissected and otherwise diversified by long conspicuous ridges, and highly complex groups of hills, locally rising abruptly from the valley floors to a height of nearly 6,000 feet above sea-level, so that a study of the many asbestos workings and of their associated geology requires constant negotiation of physical obstacles. During the course of the original survey in 1907 and 1908, this country was to a large extent almost unknown in any detail and very little inhabited, while roads were very few and far between. The recent mining and prospecting activity has greatly improved the accessibility of the fields, and a good deal of additional and more correct information has consequently become available on the geology; this is embodied on Plate XXXVI at the end of the volume.

Geologically the area belongs to the Transvaal System, of which the entire succession (see Fig. 30) is represented from the base of the Black Reef Series up to the top of the Magaliesberg Quartzite (Pretoria Series). The usual approach to the fields from Pietersburg by the main road through Chuniespoort to Malips Drift affords a good view of the sequence of the beds, which forms the type section of the system as developed in the Eastern Transvaal. The downward succession is as follows :—

Norite and allied Basic Intrusive Rocks	Bushveld Complex.
Upper or Magaliesberg Quartzite	Pretoria Series.
Altered Slates	
Contemporaneous Volcanic Tuffs	
Altered Slates	
Middle or Daspoort Quartzite	
Contemporaneous Basic Lavas	
Altered Slates	
Lower or Timeball Hill Quartzite	
Banded Ironstone	
Bevets Conglomerate	
Dolomite and Chert	Dolomite Series.
Interbedded Banded Ironstones	
Dolomite and Chert	
Quartzites with Flagstones	Black Reef Series.
Quartzites with Conglomerates	

At the base of the Black Reef Series the Transvaal System rests with a purely sedimentary junction (basal conglomerates and arkoses) on an eroded surface of the Older Granite; throughout the succession, more especially in the Pretoria Series, but less so in the Dolomite Series, are thin intrusions of medium to fine-grained basic rocks (dolerite, etc.) in the form of sheets (rarely as dykes), which are most probably the sill phase of the basic margin of the extensive Bushveld Igneous Complex.

The three major series of the Transvaal System extend right across the Asbestos Fields in the form of subparallel bands, though their distribution is rendered locally complicated through folding and faulting.

The *geological structure* of the area as a whole is fairly simple, but very intricate in local detail, owing to the intense pressure to which the region was subjected consequent upon the emplacement of the great Igneous Complex of the Bushveld. Normally, where not folded, *the dip of the sediments* is to the south from Chuniespoort to the M'Thlapitsi River, beyond which it gradually becomes south-westerly in conformity with the curvilinear strike of the system. The inclination shows a steady increase in passing from the northern edge of the Fields—defined by the conspicuous escarpment of the Strydpoort Range (Black Reef Series)—southwards, i.e. from a few degrees up to 35 or 40, in places as much as 60 along the northern limit of the Bushveld Complex. In places, the banded ironstones interbedded in the Dolomite Series, are even more steeply inclined, and may at times be nearly vertical (Chunies Asbestos, Ltd.). This variation in the dip and its steady direction towards the centre of the Bushveld Complex is an important result of the emplacement of the latter, which had the effect of pressing downwards its floor—built of the Transvaal System—a structural feature traceable all round the Bushveld. This is of special interest as an incident in the genetic history of the asbestos deposits (Chapter IX).

Apart from the direction and progressive increase of the dip, the intense pressure due to the intrusion of the Bushveld Igneous Complex, referred to above, also found relief in extensive *Folding and Faulting,* in the latter case both major and minor. The most striking major dislocation may be referred to as the *Wonderkop Fault,* after the peculiarly-shaped prominent bare hill built of the Timeball Hill quartzite which ends abruptly against this fault on the farm Bakenkop No. 1795. (See Plate XXXVI.) It will be seen on the plate referred to that in a southerly direction the Wonderkop Fault is traceable across M'Phatlele's Location, where the sudden termination of each of the three Pretoria quartzites is well shown in the scenery; the same three bands are terminated along the northerly extension of the fault beyond Wonderkop, but it is not certain how far the dislocation continues in that direction. The Wonderkop Fault belongs to the same group of displacements which have cut up the Black Reef Series into more or less distinct segments over the most northerly portions of the Transvaal Drakensberg (e.g. Wolkberg); further details will be found elsewhere (e.g. Bibl. No. 25). Many minor faults are also met with, e.g. in the more intensely folded banded ironstones below the Timeball Hill quartzite, or across the Dolomite-Black Reef contact round the old Scandinavian Camp, and elsewhere.

More or less intense *folding* is a fairly common feature throughout the fields, but more specially in the lower portion of the banded ironstones within the Malips River basin and in the underlying Dolomite Series. The latter is sometimes thrown into a series of synclines and anticlines, now and then clearly traceable, where that series is associated with mountainous scenery, e.g. when looking from the neighbourhood of the Molsgat Police Post eastwards towards the left flank of the M'Phatlele's River valley. The principle of the folding is illustrated in Fig. 30. Countless minor folds occur in the banded ironstones and have thrown them, as well as the included asbestos seams into sharp synclinal and anticlinal arrangements, some of which are illustrated on Plates XXIV, XXV and XXVII. Here, as in the lithological characters, there is a very close resemblance to the folded Lower Griqua Town Series of the Cape Fibre Belt.

The formation * directly concerned with the amosite (and crocidolite) occurrences is the *banded ironstone group,* forming a great succession of somewhat monotonous thinly bedded rocks—hence

* For details of the remaining formations in the succession, the writer may be referred, e.g., to Bibl. No. 25.

" banded "—essentially ferruginous in characteer, and variously referred to by different writers as ferruginous slates, banded quartzitic slates, ferruginous slaty quartzites, or merely as " ironstones." They extend right across the Fields and pass eventually without any break into the Lydenburg Asbestos Fields, with identical lithological characters.

The ironstones fall into *two groups*, according to their distribution, i.e. their position in the succession of the Transvaal System. The *first body* of ironstones forms a great thickness of beds reaching from (or a little below) the base of the Timeball Hill quartzite down to the top of the Dolomite Series and attains its maximum development—some 5,000 feet of the succession—in the floor, and along both flanks of the Malips River Valley, while the *second body* is much thinner and forms several (usually three) distinct bands intercalated, i.e. interbedded in the Dolomite itself; this latter group is very clearly seen along the main road leading from Chuniespoort to the Molsgat Police post; the above distribution can be readily appreciated in Plate XXXVI, when comparing the geology along the Malips River Valley with that of the country west of the Wonderkop Fault. Both groups of ironstones are identical lithologically, yet the first clearly belongs to the Pretoria Series, while the second undoubtedly falls into the Dolomite Series, and since both groups become merged into one continuous body of ironstones over the upper (northerly) parts of the Malips River valley, it looks at first sight as if to the west of the Wonderkop Fault the lowermost beds of the Pretoria Series extended laterally, as if sending out thin bands, into the Dolomite Series; a corresponding anomaly is suggested on the M'Thlapitsi River side of the Fields.

Some uncertainty, therefore, appears to exist—notably over the central and western sections of the area—where to draw the base of the Pretoria Series, a difficulty also felt in the Penge-Streatham area of the Lydenburg Fields—and referred to in the preceding chapter. It has long been known from other areas of the Transvaal System, e.g. in the Central Transvaal, that the lithology in portions of the Dolomite Series, specially near its contact with the Pretoria Series, is subject to rapid and repeated variations, e.g. thin intercalations of dolomite are found in the basal shales, etc., at the Capital, while changes of facies along the strike have also been clearly traced elsewhere. It seems, however, that in the Transvaal System, as developed over the Pietersburg Asbestos Fields, these variations reach their maximum display, on an almost regional scale. It is instructive in this connection briefly to recall the lateral variations met with in the Eastern Transvaal.

In the Pilgrims Rest area the Timeball Hill quartzite (as at Pretoria) is underlain by a great thickness of shales, but in the succeeding dolomites there are also established three thin but well marked bands of argillaceous rocks known as the Upper, Middle and Lower Shales. These features continue northwards, until at or close to the Steelpoort

River a change in facies is established, whereby the soft normal shales become sandy and ferruginous, a change which first begins at the base of the Pretoria Series, but rapidly extends upwards until almost the entire thickness up to the Timeball Hill Quartzite has passed into banded ironstones; a corresponding change no doubt explains the gradual establishment of ironstones along the slate horizons in the dolomite. In this way most probably arose the three intercalated bands of ferruginous slates seen in the dolomite between Chuniespoort and the Wonderkop Fault—and elsewhere. It is interesting to note the same ironstones, e.g. in the dolomite of the Potgietersrust Platinum Fields. The alternation of dolomite and ironstone thus seems characteristic of wide areas of the Transvaal System in the North-Eastern and Northern Transvaal, as shown by the succession at the Buffelspoort iron ore deposits north of Brits, etc. One of the trenches of the London African Tins on the farm Stylhoogte No. 559 on the left bank of the M'Phatleles River, placed across the strike of the lower banded ironstone belt near its base shows this formation regularly interleaved with narrow bands of dolomite, so as to supply a kind of miniature replica of the facies changes ** which the Asbestos Fields exhibit on a regional scale.

In drawing the base of the Pretoria Series the principle has been followed of assigning to the former the whole of the succession from the edge of the basic margin of the Bushveld Complex (top of Magaliesberg quartzite) down to the first appearance of dolomite; the latter horizon is commonly marked by a definite band of highly sheared coarse conglomerate—*Bevets Conglomerate*—but this cannot always be traced, so that some ambiguity remains, specially in the central section of the fields.

West of the Wonderkop Fault the *Lower Ironstone Band* intersects the Chuniespoort–Malips main road on the extreme northern portion of Uitloop No. 514, a short distance south of the Chunies River Drift; a very good outcrop is seen in the bed of the river close to the road. This exposure shows highly ferruginous thinly bedded and contorted rocks, easily traceable along the sharply crested high ridges bordering the valley westwards along the northern boundary of Morgenzon No. 1878 and eastwards through Baviaanskop No. 513 and beyond. The banding is due to alternate layers of hard yellowish impure jaspery quartz (chert) and black or deep brownish bands of iron ore. Further east, the Lower Ironstone Band becomes much thicker and carries amosite seams, developed e.g. at the workings of Chunies Asbestos, Ltd.

** Corresponding variation in lithological characters occurs at the base of the dolomite, where that formation forms thin bands alternating with various layers of quartzite. (Passage Beds north of Pilgrims Rest, described in Geological Survey Memoir No. 5.)

Proceeding further southwards along the main road referred to, the *Middle Ironstone Band* is very well exposed on the left (east) side, almost directly behind the Molsgat Police Post in the northern part of Boomplaats No. 1659. It very closely resembles the Lower Band lithologically and shows occasional very thin films of amosite, but is thinner and approximately between 100 and 200 feet thick, and also traceable over the ridges both to the west and to the east, increasing somewhat in thickness in the latter direction.

The *Upper Ironstone Band* is not exposed on the main road, but becomes well marked, e.g. on Kaffirpoort No. 562, some 5 miles west of the Wonderkop Fault. (See Plate XXXVI.)

The ironstone bands, taken as a whole, are essentially similar in character throughout the area and strongly recall those of the Lower Griqua Town Series in the Cape Province, in their thinly bedded character, repeated minor folding, frequent local formation of irregular veins of magnesite (notably at the asbestos horizons), abundant occurrence of nontronite (like that referred to in Chapter V from the Penge-Streatham area), though there are also some differences, not essential, however, from the asbestos point of view. Compared with the lower Griqua Town Series, red jaspery layers are very rare in the Pietersburg (and Lydenburg) Fields, while the rock described as "potential" crocidolite, likewise the vivid blue hard layers, referred to as "Hurley Blue" and typically developed, e.g. at the Westerberg Mine, are also almost unknown in the Transvaal Amphibole-asbestos Fields. The frequent occurrence of the rocks described in Chapter V as "Amosite-slate," is a very striking feature in the Pietersburg Fields, and appears to have no exact counterpart in the Cape Belt.

The "Amosite-slates" just referred to are found in many asbestos workings more or less throughout the Pietersburg Fields and appear as a typically metamorphic formation, with scattered tufts or stellate groups of needle-crystals of amosite, exactly as they do in the Lydenburg Fields (Chapter V). There are good grounds for the conclusion that the contact belt of the Bushveld Complex embraces the entire succession from the top of the Magaliesberg Quartzite to a short distance below the base of the Pretoria Series—a result of great importance from the point of view of asbestos genesis (Chapter IX).

The thickness of the individual ironstone bands interbedded in the Dolomite Series varies considerably in going from Chuniespoort eastwards, and rises from about 150 to 1,000 or 1,500 feet.

East of the Wonderkop Fault the Timeball Hill Quartzite is sometimes directly underlain by a thin development of intensely altered staurolite and other metamorphosed slates, but these very soon give place northwards to a very great succession of banded ironstones, which are exactly like those of the three individual bands just described; they are much folded and vary in inclination from horizontal to nearly vertical, so that an accurate determination of their total thickness is impossible. It is probably that an estimate of not less than 5,000 feet of succession is not excessive. It is the great prevalence of these highly resistant ironstones—in strong contrast with the relatively easily eroded basic margin of the Bushveld Complex on the south over the low-lying flat of the Olifants River Valley—that mainly determines the highly mountainous character of the more central portions of the Asbestos Fields with their great and concentrated relief.

3. *Mode of Occurrence and Distribution of the Amosite Seams.*—The deposits of amosite are invariably found as *cross-fibre seams* interbedded in the banded ironstones, and their mode of occurrence is very similar to that in the Lydenburg Fields, described in the previous chapter. Very commonly a series of parallel seams are found spread out over an ore-channel usually ranging from one to two feet up to two or three yards in thickness. As in the Penge–Streatham area, so in the Pietersburg Fields, individual seams show much variation in lateral persistence and die out sooner or later, when the fibre continuity is carried on by another seam beginning to appear a few inches above or below the previous one. Where the strata are folded, a thickening of the seam is sometimes observable in the arches of the folds.

All the three belts of banded ironstone found interbedded in the Dolomite Series west of the Wonderkop Fault show seams of amosite, and these are also occasionally found in the succession of banded ironstone underlying the Timeball Hill Quartzite.

The *Main Amosite Horizon*—which forms the basis of the productive occurrences—consist of several distinct fibre belts restricted to the Lower Ironstone Band, which extends from Chuniespoort eastwards to the Malips River, where it becomes merged with the great succession of ironstones that reach southwards up to the Timeball Hill Quartzite. Amosite deposits high up from the base of the Pretoria Series in the Malips River Valley are practically unknown, since the fibre horizons to keep nearer the top of the dolomite. Thus the occurrences—in the majority of the workings—lie within a few hundred feet or yards south of the top of the dolomite, i.e. above the base of the Lower Ironstone Band. It is very difficult to arrive at any exact correlation between the various fibre belts; thus west of the Malips River the many workings of the Northern Asbestos (Pty.), Ltd., shows a number of amosite horizons, separated by hundreds of feet of banded ironstone, while east of that river the workings of Seelig's Asbestos Mines, Ltd., have also exposed several fibre horizons, but, with the probable exception of the "Pylkop Line," it is impossible to establish an exact correlation between these sets of fibre channels. Further east, the close proximity of the Malips Drift (Egnep, Ltd.) to the workings of the South African

Consolidated Mines, Ltd., enables one to establish a common link through one of the horizons. Still further east, at the Montana Mine, there are another set of amosite seams, which cannot be satisfactorily correlated with those referred to above, but appear to belong to a distinctly higher horizon in the banded ironstone.

One thus arrives at the main conclusion, that amosite is liable to occur anywhere in the banded ironstone formation, but that the deposits of economic importance tend to occur not far above the contact between that formation and the underlying dolomite; the exact relative position of amosite seams within the succession of ironstone, as established for a given mine, does therefore not necessarily hold good, except in a general way, for other mines.

It would be unreasonable to expect that asbestos with a mode of origin, still a long way from being thoroughly understood and certainly very different from that of many " ore " deposits, should show persistence in its distribution comparable, e.g. to that of Rand Banket, and much waste of thought and energy would appear to have sometimes resulted in the neglect of this principle.

4. *List of Asbestos Companies, Syndicates, etc., in the Pietersburg Asbestos Fields.*—The following schedule is here recorded as an interesting chapter in the history of these fields; it refers approximately to the second half of the year 1928, when exceptional activity was noticeable in connection with the asbestos resources of the Union; the writer is indebted to Mr. G. H. Trevelyan, at that time Mining Commissioner at Pietersburg, for this record, in which the order is roughly from west to east:—

(*a*) *Chunies Asbestos, Limited.*—Stylhoogte No. 559, Stylkop No. 535, Langkloof No. 575, Langbaken No. 540, Koedoeskloof No. 608, Bovenop No. 571, and Uitkomst No. 603: Amosite.

(*b*) *London African Tins.*—Stylhoogte No. 559, Bovenop No. 571, Uitkomst No. 603, De Hoogte No. 567, Kaffirpoort No. 562, Bergplaats No. 569: Amosite.

(*c*) *Central Asbestos, Limited.*—Holkloof No. 1581, Wolvekop No. 1792, Uitgedracht No. 611, Plaatrand No. 1784, Topfontein No. 534, Slaapkloof No. 547, Koedoeskloof No. 608, Langebaken No. 540, Langkloof No. 575, Stylhoogte No. 559, Middelrand No. 480, Wonderkop No. 503: Amosite.

(*d*) *Northern Asbestos Mines (Prop.), Ltd.*—Mooihoek No. 576, Bovenop No. 571, Wolvekop No. 1792, Middelrand No. 480, Kranskloof No. 1786, Uitval No. 1791, Zamenloop No. 470, Pylkop No. 471, Donkerhoek No. 677: Amosite.

(*e*) *Chalmer's Prospect.*—Wonderkop No. 503, Toornkop No. 463: Amosite.

(*f*) *Seelig Asbestos Mines, Ltd.*—Lot No. 119, Pylkop No. 471, Wolvekop No. 1792, and Middelrand No. 480: Amosite.

(*g*) *Egnep, Limited,* i.e. Cape Asbestos Cos., formerly known as McBean's Malips Drift Asbestos Mines.—Lots Nos. 119, 120, 244, 245: Amosite and crocidolite.

(*h*) *Hancock's, Limited.*—Lot No. 245: Amosite.

(*i*) *Warren's Syndicate.*—Lot No. 245: Amosite.

(*k*) *South African Consolidated Asbestos, Ltd.*—Lots Nos. 120-3, 125-6, 130, 245: Amosite.

(*l*) *Pietersburg Asbestos, Ltd.*—Lots Nos. 123, 126-30: Crocidolite and amosite.

(*m*) *Montana Mine.*—Lots Nos. 123-4, 127, 135 and 312: Amosite. (Subsequently acquired by Turner and Newall, Ltd.)

(*n*) *Island Asbestos Company.*—Nots Nos. 278 and 299: Crocidolite.

(*o*) *Major Brand and Mr. Addie.*—Lots Nos. 229, 304, 295-7: Crocidolite.

(*p*) *Standard Asbestos Mines, Limited.*—Eton No. 2644, Cork No. 2643, Dalton No. 2646, Dublin No. 2647, Geneva No. 2648, Lucerne No. 2651, Gemini No. 2574.

5. *Mining and Prospecting Developments in Amosite Deposits.*—Although the majority of the developments listed above have at present * curtailed or suspended their activities, it was already mentioned that this is not primarily due to lack of quality or quantity, but largely a result of adverse market conditions prevailing at the moment. On the other hand, these activities have added a good deal to our knowledge of the geology of these deposits, so that it will be useful to refer briefly to the principal features of some of the more important groups of workings, concerned mainly or exclusively with amosite deposits. Those developing crocidolite are referred to in a later section of this chapter.

Chunies Asbestos, Limited.

The main mining activities of this company are on the farm Stylhoogte No. 559 on the lower portion of the southern face of a deep narrow kloof-like valley joining that of the Chunies River from the east. The workings lie approximately in the centre of the Lower Ironstone band, which is underlain and overlain by dolomite, and strikes almost due east and west across Stylhoogte. Plate XXII illustrates the view looking from the mine eastwards and shows the lower portion of the ironstones creeping up the northern face of the valley; the dip

* June, 1930.

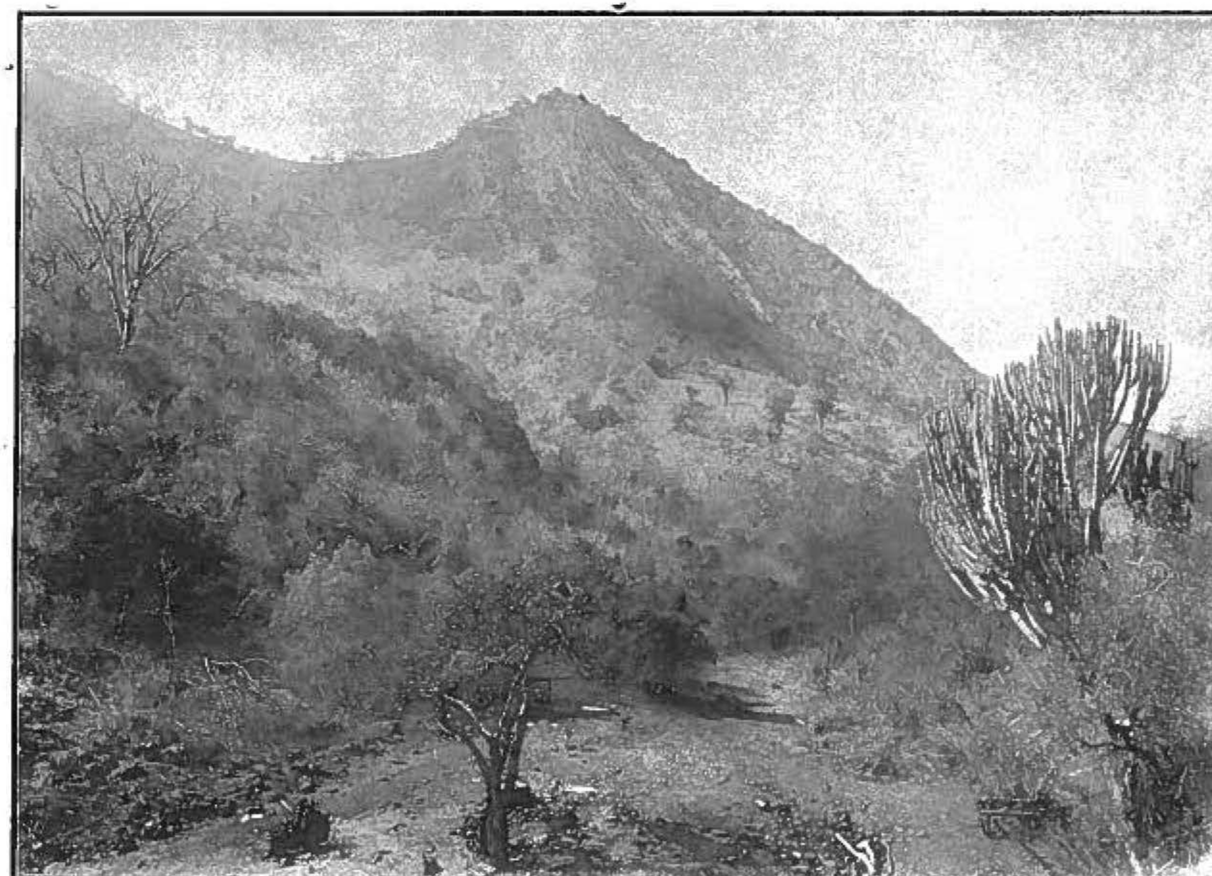


Plate XXII.—*Portion of the Chunies Asbestos Mine,* south-west of Pietersburg; the sharp peak in the centre is built of steeply inclined amosite-bearing banded ironstones, underlain and overlain by dolomite.

is to the south at high angles, and in some of the workings almost vertical. (See Plate XXIII.) The total thickness of the Lower Ironstone band is probably not less than 1,000 feet.

The most important group of workings—essentially opencast—form the Central Section, in which there are five groups of cross fibre amosite seams, disposed parallel to one another and occurring within some 300 feet of the succession of banded ironstones, their outcrop running along the lower slope of the southern face of the valley. Each group of fibre veins consists of a series of parallel seams interleaved with thinly bedded ironstone, often coated with films of yellowish green nontronite. In No. 2 Group Central (furnishing the bulk of the production) the fibre channel has a width of from 10 to 12 feet, with clear sharply defined hanging and footwalls (see Plate XXIII) and showing a large number of parallel seams of variable width. Fibre over three quarters of an inch is rare, except in No. 5 workings, where it is not uncommonly over 2 inches long.

The proved lateral extension is about 1 to 1¼ miles along the strike, which includes the workings known as No. 2 Seam East, some 800 feet from the Central Section; in these workings there is a fair proportion of fibre exceeding one inch in length. Both to the north and to the south of the productive fibre channels there are additional but non-payable seams.

While the fibre neither in length or quality comes up to the best grades obtained in these fields, it is found quite suitable as raw material in the manufacture of asbestos goods, as carried out by the parent company of Chunies Asbestos, Ltd., at their Newtown factory. The production is principally in the form of small fibre lumps, graded to the approximate size of " nuts," from which the adhering country rock is removed at the factory. The clean fibre satisfies the requirements essential in this manufacture—freedom from metallic particles, which would destroy the tensile strength, etc. A simple mill exists to secure efficient market preparation. When at the height of its activities, the mine was producing round 70 tons of amosite per month, of which some 60 per cent. represented " nuts," the remainder being cleaned (cobbed) electrical matting fibre over 1 inch in length. It seems clear that the possibility of consuming this output in the company's own works places the Stylhoogte type of amosite occurrence in a superior position.

London African Tins.

Towards the end of 1928 the London African Tins were opening up a block of claims falling within the extreme western end of Stylhoogte, as the direct extension of the eastern portion of that farm, held by Chunies Asbestos, Ltd. The amosite workings here also lie in the

Lower Ironstone band and consisted of opencast developments, known as the Upper or Southern Mine and the Lower or Northern Mine. The former exposes practically vertical beds of ironstone in which three sets of amosite seams are spaced over a fibre channel totalling 12 feet in width; the latter is only a few yards above the top of the dolomite that underlies the ironstones, while neither horizon exactly corresponds to those worked by Chunies Company. Most of the seams range from ½ to ¾ inch in thickness, and in its general characters, the fibre closely resembles that produced by the neighbouring company further east. At the Northern Mine lies a trench some 60 feet long, showing thin layers of dolomite alternating with banded ironstone, including soft bluish carbonaceous slate, thus illustrating the rapid facies changes associated with the contact between the dolomite and its interbedded ironstone formation—as referred to above.

Central Asbestos Mines of South Africa, Ltd.

From the mines just described the Lower Ironstone band is easily traceable towards the east, over the eastern limit of the Chunies River basin across its watershed into the basin of the Malips River. A long narrow deep valley runs from west to east across the farms Topfontein No. 534, Donkerhoek No. 677, Holkloof No. 1581, Kranskloof No. 1786, Uitval No. 1791, and Zamenloop No. 470, and over its eastern portion the contact between the base of the banded ironstones and the underlying dolomite runs more or less along the floor of the valley. The main prospecting and development activities of the Central Asbestos Mines of South Africa, Limited, fall into the southern side of the valley on Holkloof No. 1581, where a large amount of work has been done amounting to many thousands of feet of trenching, etc. The country formation of ironstone is folded in a somewhat complex manner and just north of the valley floor round the common boundary of Holkloof and Kranskloof is a small boss-like outcrop of dolomite (covering the summit of a small hillock), surrounded by ironstone.

The work done by this company has located some eight fibre zones over the southern flank of the valley, but probably some of these are repetitions due to folding. One set of workings near the floor shows a fibre horizon most likely identical with the so-called Rosskop lines proved by the Northern Asbestos Company on the adjoining property Kranskloof No. 1786, while another set, lying well to the south and higher up the slopes may perhaps be correlated with the so-called K Line, established by the Northern Asbestos Company further east.

A small but complete milling plant (including cyclones) was erected on Holkloof, the output at one time being at the rate of 50 tons per month, stated to have been valued from £15 to £35 c.i.f. Amsterdam per ton.

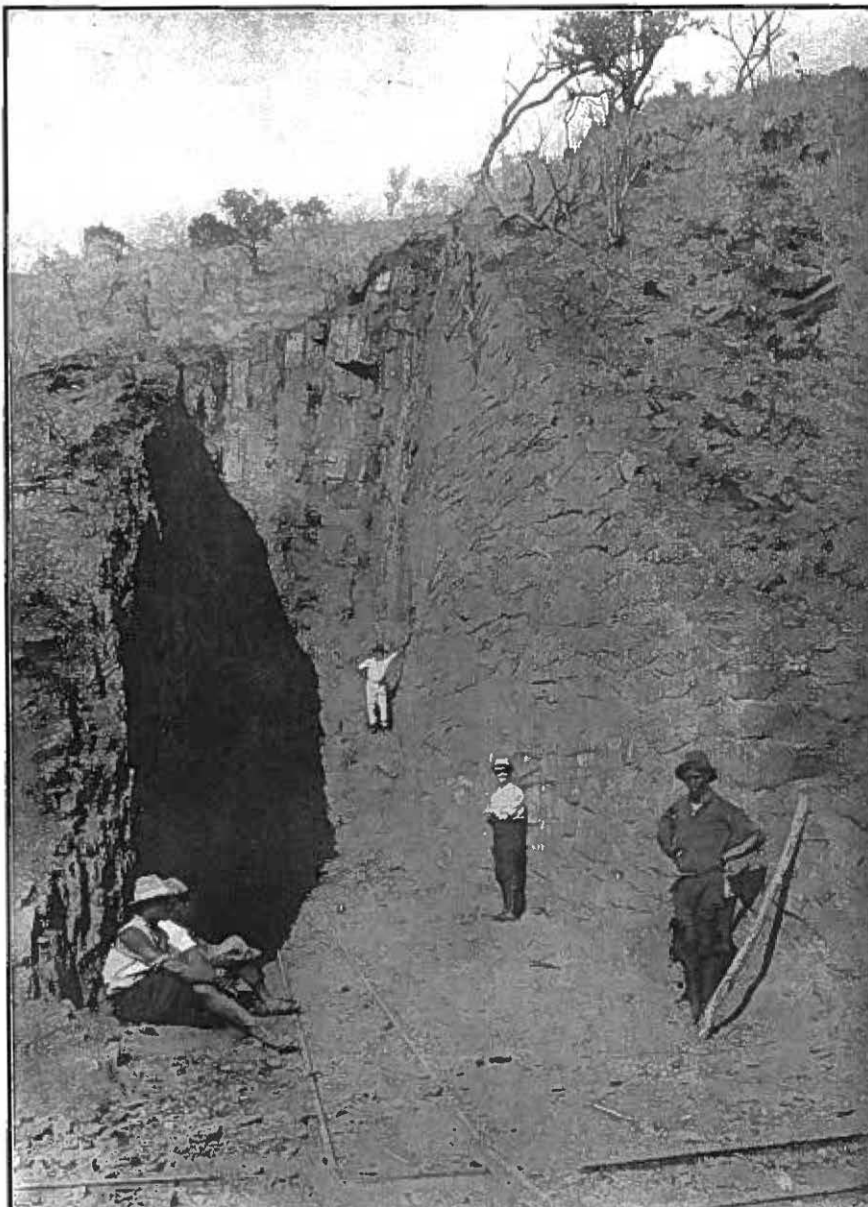


PLATE XXIII.—*Portion of Chunies Asbestos Workings,* south-west of Pietersburg, showing a series of amosite seams in nearly vertical banded ironstone, intercalated in the Dolomite Series.

The Northern Asbestos Mines (Prop.), Ltd.

In the direct easterly continuation of the belt of banded ironstone carrying the fibre deposits of the Central Asbestos Mine, lie the workings of the Northern Asbestos Mines (Prop.), Ltd., which have not yet reached the producing stage; a large amount of prospecting work has, however, been carried out. This is spread out for the most part over the southern side of the Holkloof valley from the southern boundary of Kranskloof eastwards through Uitval, Zamenloop and Pylkop to near the right bank of the Malips River—corresponding to over 3 miles of strike.

The company's headquarters camp lies on Uitval just south of the valley floor, and the distribution of the numerous workings, to which distinctive names apply, may be conveniently given with reference to the main camp, as shown in Table No. 30. The dip of the ironstones is on the whole regularly to the south, but the beds are strongly folded in places, e.g. at Rosskop and Kramersgasp—illustrated on Plates XXIV and XXV; the folding affects the asbestos seam equally with their country formation. The mode of occurrence throughout is the usual

TABLE No. 30.—*Distribution of Asbestos Workings. Northern Asbestos Mines (Prop.), Ltd.*

East of Uitval Camp.	West of Uitval Camp.	
South of Valley Floor.	South of Valley Floor.	North of Valley Floor.
Leopoldsire (on Zamenloop) Mambakop (on Pylkop)..... Steynskop (ditto.).......... K Line (ditto.)............	Rosskop East.......... Rosskop Central........ Rosskop West.......... (All on Kranskloof)	Hellsgate (on Kranskloof). Kramersgasp (ditto.). Donkerhoek Workings (on Donkerhoek).

cross fibre type of amosite deposit, interbedded in the banded ironstone, the dip of which is to the south and varies from about 30 up to 60, in places nearly 70 degrees. These fibre zones have been explored at various localities shown in Table No. 30 and several thousand feet of trenching and other prospecting work has been done in following up the seam horizons.

Of the four sets of workings situated *east of the Uitval Camp,* that known as *Leopoldsire* is the most northerly one, and lies on Zamenloop close to a new road which hugs the floor of the valley near the right (south) bank of the streams; it included one surface working consisting of a trench some 150 feet long that follows the strike and exposes one seam up to 6 inches thick in places, as well as several narrower seams. A winze goes down about 100 feet in the direction of the southerly dip to meet an adit level, some 500 feet in length which passes under the trench and exposes three fibre channels—additional to the one seen in the trench, spaced as shown in Fig. 31.

Each channel carries as a rule a number of amosite seams distributed commonly over several feet of the succession of ironstones. Possibly the three horizons, referred to as the uppermost, upper, and middle in Fig. 31, may correspond to the three principal asbestos zones on the Malips Drift (Egnep or McBean's) mine and perhaps also represent the Frost and Madden Reefs of Seelig's Mines, but definite correlation is very difficult, if at all possible. The Leopoldsire seams show the usual lateral variations in width and persistence, which are a common feature in most of the amosite workings throughout these fields.

East of Leopoldsire and slightly to the south of it follow the *Mambakop* workings of *Pylkop;* the surface development shows a trench some 200 feet long and aligned along the strike; here is one seam from 3 to 4 inches wide, interrupted by blank zones, and interbedded in the ironstone formation which dips some 55 degrees to the south. Under this trench is an adit cutting the hard country rock through some 280 feet at right angles to the strike. It intersects four fibre zones, but does not touch the one seen in the trench, and work ceased here before the K Line (see below) was intersected. At the eastern end of the Mambakop trench lies a cutting across the strike, showing occasional fibre indications.

Proceeding southwards from the cross trench just referred to one reaches the *Steynskop* (on Pylkop) developments, which consist of a group of short winzes, etc., enabling this channel to be traced laterally eastwards right up to Seelig's Pylkop Line, with which it appears to be continuous, so that probably the Steynskop Line must be correlated with the Gifter Line of Seelig's Company; since both the K Line (see below) and the Steynskop Line lie well to the south of Leopoldsire—in the same way as the Gifter Line of Seelig's Mine lies distinctly to the south of the Frost and Madden Reefs (Leopoldsire?) it appears that the following four fibre occurrences (enumerated from east to west) lie more or less along one and the same horizon :—Seelig's Gifter Line—on the east side of the Malips River, Seelig's Pylkop Line—on the west side of the river, the Northern Asbestos Company's Steynskop Line, and lastly—still further westwards—the same company's K Line. This is probably the only amosite horizon which can with any degree of confidence be correlated and traced from one side of the Malips River valley to the other.

Asbestos Horizons, Leopoldsire Adit, Northern Asbestos Mines (Prop.), Ltd., west of the Malips River, Pietersburg District.

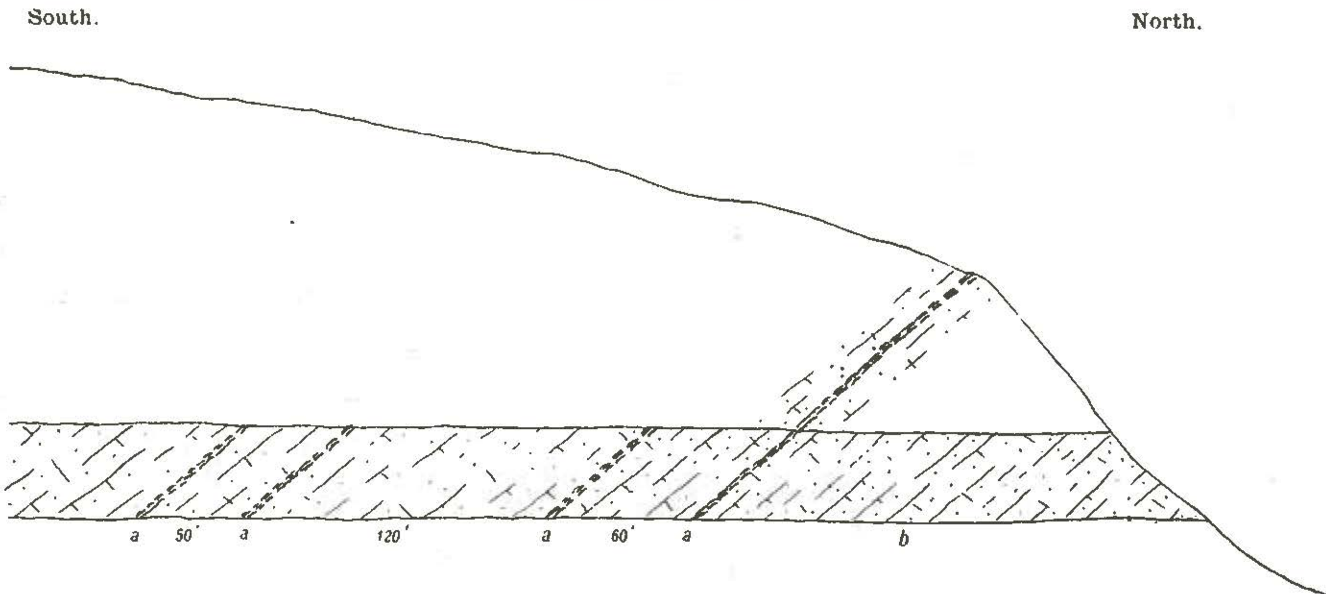


Fig. 31.
a = Amosite seams; *b* = banded ironstone.

SECTION ACROSS THE AMOSITE HORIZON OF THE K LINE; PYLKOP, NORTHERN ASBESTOS MINES (PROP.), LTD., AT TOP OF K1, VIIIA WINZE.

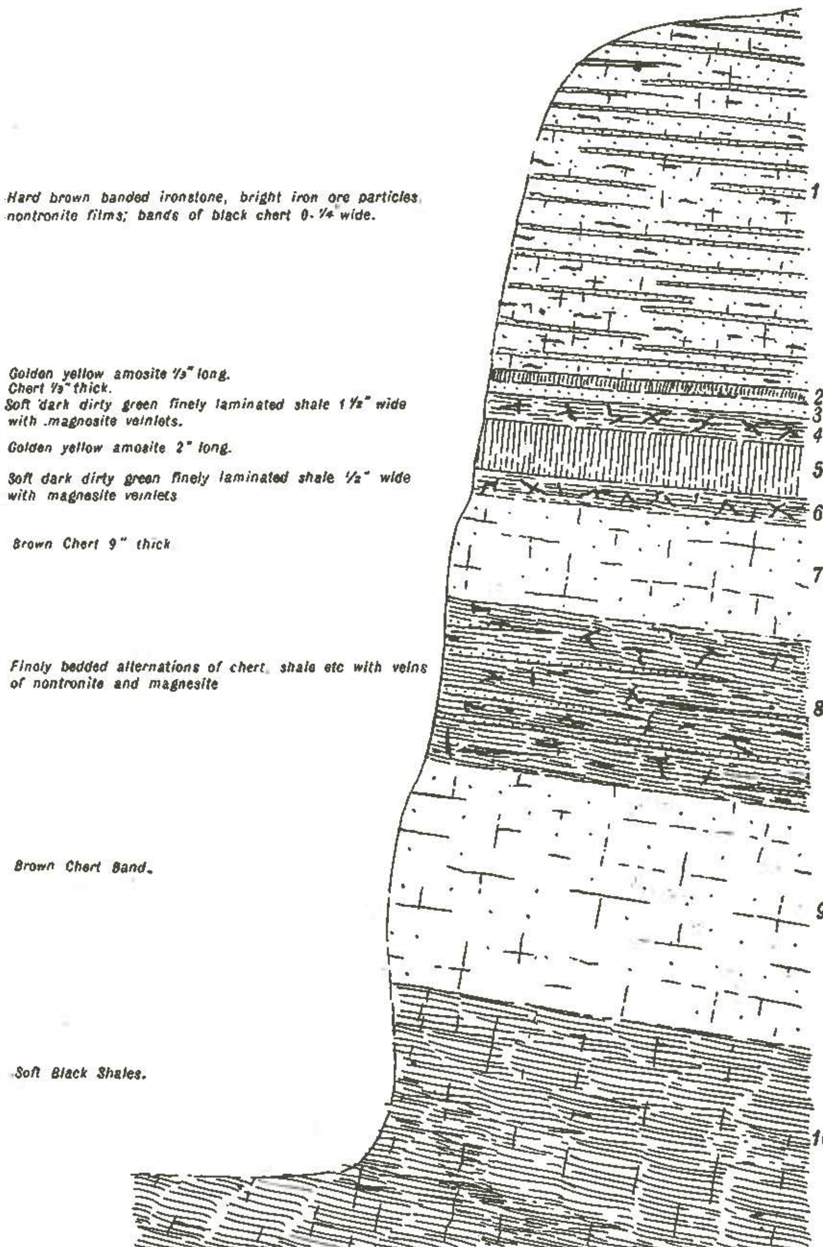


Fig. 32.

Approximate scale 1 : 15.

PLATE XXIV.—*Thick Seam of Amosite*, interbedded in, and folded with banded ironstone, Northern Asbestos Mines (Prop.), Ltd., Malips River basin, south-east of Pietersburg; Kramersgasp working, on Kranskloof.

Well to the south—i.e. some 1,700 feet horizontally across the strike from Leopoldsire are the workings of the *K Line* on Pylkop, corresponding closely with Seelig's Gifter Line—as explained above. The K group of seams belong to some four fibre channels, known as K South, K 2, K 1, and K North, showing a series of cross fibre amosite seams interbedded in ironstones that dip southwards from 30 to 40 degrees. The various channels are spaced over some 200 feet of the succession, and show a fibre length locally up to 2 inches and more, though most of the seams are below that in thickness; they are again associated with thin irregular veins of magnesite and dirty greenish yellow nontronite films. The former is claimed as forming not infrequently a useful indicator of the proximity of amosite. Characteristically, thin layers of chert and dark bluish black soft shaly material are often seen in direct association with the asbestos—as at Rosskop and elsewhere, while scattered whisps or stellate rosette-like tufts of amosite occur in the associated shales; this is the " amosite-slate " described from the Penge-Streatham area, and also found at Rosskop, Malips Drift (Egnep) Mine, Seelig's Mine and in many other places practically throughout these fields. In some workings it can be observed that although a given seam has died out, the amosite slate persists across the blank portion of the fibre channel, and that the seams are sooner or later re-established, so long as the amosite slate has not been lost: hence the latter serves as a kind of pointer, a conclusion probably of genetic importance.

An exceptionally instructive section is exposed at the top of a winze, known as K 1, VIIIA, clearly showing this association of amosite with chert and dark shale. (See Fig. 32.)

West of the Uitval Camp and almost in the valley floor on its *south side,* are the *Rosskop Workings* on Kranskloof; they consist of three sets of prospecting developments, described as *Rosskop West, Rosskop Central* and *Rosskop East. The* last-named spot shows a single surface cutting almost on the right bank of the stream and exposes one seam of exceptionally long fibre. *Rosskop Central* at one point exhibits the banded ironstones sharply folded—illustrated by Plate XXV; here are some 4 short adit workings in steeply inclined ironstone, each showing a group of parallel seams, with fibre up to some 3 inches long, though more often distinctly shorter. The direct association with chert and spotted greenish amosite slate is very marked and repeats the evidence referred to above from the K Line (and elsewhere); see also Fig. 33. At Rosskop west there are also several prospecting workings; in one of these the ironstone is almost vertical and scored with narrow seams, so that in general appearance this occurrence—situated close to the Holkloof boundary—recalls the type of deposit seen at Chunies Asbestos Mine.

A more recent development at *Rosskop West* forms an adit level 580 feet long, in which some 6 or 8 sets of fibre channels are met, interbedded with the ironstone dipping about 40 degrees to the south (locally folded). In some channels there is only a single seam; in others a group of parallel amosite bands are associated. Along the adit referred to the normal ferrugions country formation is varied by much dark almost black shale—in places resembling soft very poor coal; this rock is marked by abundant scattered tufts and rosettes of amosite blades, not true amosite fibre; in some varieties the crystals are irregularly distributed throughout the rock after the manner of altered (meta-

AMOSITE ROCK, SHOWING CROSS FIBRE ASSOCIATED WITH CHERT AND AMOSITE-SLATE; ROSSKOP, NORTHERN ASBESTOS MINES (PROP.), LTD., WEST OF THE MALIPS RIVER, PIETERSBURG DISTRICT.

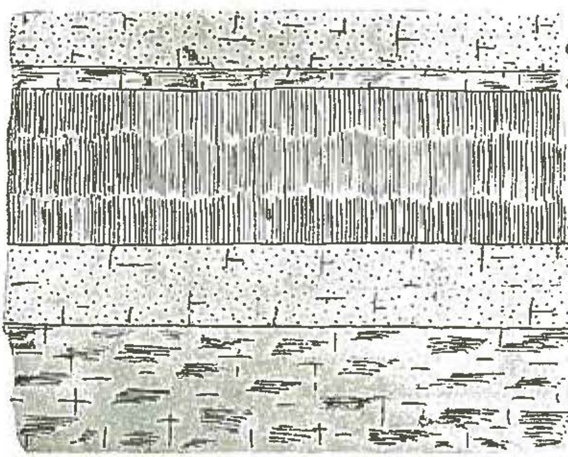


Fig. 33.

a = Cross fibre amosite; *ch* = chert; *as* = dark greenish spotted amosite-slate. Approx. ⅔ natural scale.

morphosed) slates; in others, the mineral is almost restricted to certain very delicate layers. This dark shale is a very good example of the "Amosite-slate" previously referred to and in its general habit, microscopic characters (including minute but abaundant deep brown mica), there is a strong resemblance to altered shales found in the outer contact belt of the Bushveld Complex.

It is probable that the fibre channels of Rosskop West are continuous with those of Rosskop Central, and if this can be confirmed by actual exploration, a fibre continuity of about 1,000 feet along the strike would be demonstrated.

PLATE XXV.—*Sharply folded Banded Ironstones*, Northern Asbestos Mines (Prop.), Ltd., south-east of Pietersburg; face seen near Rosskop Central, on Kranskloof.

Also west of the Uitval Camp, but on the *north side* of the valley floor are the *Kramersgasp Workings** on Kranskloof, comprising an eastern and a western set. The more easterly set lies lower down on the northern side of the floor of the valley and consists of a series of open-cast and short-tunnel workings in contorted ironstone, in which two thick seams of amosite and several thin ones are seen, while dark bluish laminated shale in places occupies the footwall position; locally, the amosite is up to 4 inches long, and in places the fibre display indicates an approximate percentage of 10 over a width of about 4 feet. Occasional changes of facies—referred to in this chapter—are illustrated by the occurrence of narrow bands of dolomite in the succession of ironstones. The more westerly group lies on the right bank of a short gulley descending from the north to join the main valley and covers several open-cast workings; the most striking one forms a short irregular cave-like opening on the right bank of the gulley, displaying at its mouth two conspicuous very long fibre amosite seams (see Plate XXIV). At the back of the cave, the high ground (common to Holkloof and Kranskloof) includes the boss-like outcrop of dolomite, previously referred to as being surrounded by ironstone. On proceeding upstream from the cave-working alluded to, the gulley leads to a remarkable feature, due to a large outcrop of secondary carbonate rock, fantastically weather into something like a network of irregular hollow spaces and extending for many yards up the steep southern flank of the valley; this feature appears essentially a solution phenomenon due to the gradual erosion of the underlying dolomite, with formation of much secondary calcareous tufa.

Also on the north side of the valley floor and a little west of the Uitval Camp are the old abandoned workings known as *Hellsgate,* near the common boundary of Uitval and Kranskloof, which were in existence already in 1917.

Some 3-4 miles almost due west from the Uitval Camp lies the farm *Donkerhoek* adjoining Holkloof on the west, and served by an indifferent road along which one has to negotiate no fewer than 22 drifts up to the workings. These lie some 200 feet above the valley on its northern flank and in a series of shallow trenches expose a number of amosite seams, but the display is disappointing.

The *economic prospects* revealed by these various fibre occurrences on Donkerhoek, Kranskloof, Zamenloop, and Pylkop appear to point to the existence of considerable quantities of amosite, some of which of commercial grade, but the distribution of the occurrences is somewhat scattered, so that the concentration of larger tonnages at any one working or set of workings is not the conspicuous feature that it is in the Lydenburg Fields, or sometimes also in the Pietersburg Fields.

* Neither at these workings nor on Holkloof was any formation found that definitely revealed a volcanic origin.

Seelig Asbestos Mines, Limited.

The asbestos occurrences described are all situated west of the Malips River, but the ironstones that carry them pass without a break to the east side of the river, and several mines also occur in the latter portion of the fields. The one next to the Northern Asbestos Mines (Pty.), Ltd., and also nearest to the left (eastern) bank of the Malips River is that of *Seelig's Asbestos Mines, Ltd.*, which falls on Lot No. 119.

The mill and local headquarters lie almost in the floor of the valley (Plate XXVI), but the mine workings are scattered over the rather steep high ground which starts almost directly behind (north of) the main camp and rises upwards through several hundred yards to the top of a prominent ridge, which extends from the river in an almost due easterly direction and marks the contact between the base of the ironstone and the top of the underlying dolomite.

The distribution of the amosite occurrences shows the following three principal fibre channels enumerated from north to south, i.e. in the upward order of the succession: The *Lower* or *Frost Reef*, the *Upper* or *Madden Reef*, and the *Gifter Line;* in all of these the amosite is found in the normal type of cross-fibre deposits with the seams interbedded in the banded ironstones. The development consists of a Western Section, nearest to the Malips River, an Eastern Section situated some 1,900 feet from the former, and the workings of the Gifter Line, over 1,000 yards to the south of the Eastern Section. The Lower or Frost Reef lies roughly about 200 feet stratigraphically above the base of the ironstones, which are normally inclined to the south at some 35 degrees, but since they are locally folded, the position of this reef is difficult to determine exactly. The Upper or Madden Reef is found to lie about 50 feet stratigraphically above the Frost Reef. Since the country is one of great relief, forming extensive slopes falling away in a general southerly direction with the dip of the ironstones and fibre channels, the mining facilities are very favourable, which has made it possible to tap the amosite resources in a series of adit levels; these e.g. prove the continuity of the Madden Reef for some 500 feet on the dip.

The Frost Reef channel often shows only a single seam, up to a length of 5 inches, and in one of the stopes of the Madden Reef a combined fibre length of from 7 to 9 inches could be observed over a width of 30 inches; fibre lengths of 4 to 5 inches occur in this reef. Folding is occasionally well displayed and affects the seams in the manner illustrated on Plate XXVII. The amosite has the usual ash-grey or pale brownish colour in lumps, but is sometimes of a greyish green tint. Locally it may become rather stony, while a thicker seam is sometimes observed to pinch out into ribbon fibre.

PLATE XXVI.—*Looking down the Malips River Valley* (south-east of Pietersburg) from Seelig's Asbestone Mine, showing the complex of smooth hills and ridges due to the amosite-bearing banded ironstones of the Pretoria Series.

The Gifter Line is very distinctly well to the south of the above reefs and almost certainly continues westwards across the Malips River into Pylkop to pass into the K line of the Northern Asbestos Mines, as explained above; the Gifter Line has been opened up by some 10 adit workings, while a little to the south lies another amosite occurrence, referred to as the Golden Reef, after the characteristic appearance of the fibre, some of which is, however, spangled with iron-ore particles.

The ore from the various more northerly workings is concentrated at the top of the hauling line, which conveys it down to the mill below; at the bottom of this line is the so-called Pietersburg adit. The position of the Frost and Madden Reefs with reference to the top of the dolomite to their north, as indicated above, suggests that the horizon of these fibre channels agrees more or less with that in which the Leopoldsire workings on the west side of the Malips River are situated, but the correlation is only tentative.

The Malips Drift (Egnep, Ltd.) or McBean's Mine.

About one and half miles east-north-east from Seelig's Asbestos Mine is the *Malips Drift (Egnep, Ltd.) Mine* on Lot No. 120 (see Frontispiece and Plate XXIX). As stated above, this is the oldest amosite mine in these fields, originally worked independently as the Malips Drift Asbestos Mines, Ltd., when it was first laid out, developed, and brought to the producing stage by Mr. W. McBean. A few years ago it was acquired by Egnep, Ltd. (Cape Asbestos Co.), so that it* has now been producing amosite for at least 12 years. The original company began operations by developing the crocidolite deposits on Lots Nos. 244-245, referred to below. The present headquarters and mill (Plate XXVIII, Fig. 1) are on the left bank of the Malips River on Lot No. 244, but the mine itself lies about 2 miles to the north-east on the northern side of a very deep and narrow kloof, in the floor of which runs the road leading from the mill to the bottom of the mine workings.

Within the great succession of ironstones, which have generally a steady southerly or south-easterly dip (Plate XXVIII, Fig. 2) round 40 to 45 degrees, but are locally thrown into minor folds, are the following principal fibre channels, enumerated in stratigraphical upward order (i.e. from north to south):—

(*a*) The Lower or Tet Reef.
(*b*) The Middle or Sil Reef.
(*c*) The Upper or 120 Line Reef.

* The Egnep Co. Malips Drift Mine must not be confused with the Egnep Mine (on Penge) in the Lydenburg Fields, described in the previous chapter.

A horizontal interval of approximately 120 feet measured across the strike separates (*a*) from (*b*) and the corresponding value between (*b*) and (*c*) is about 60 feet, while the mean position of the three channels is probably less than 2,000 feet measured across the strike from the top of the underlying dolomite; it appears therefore that the horizon of these fibre channels is well above the Frost and Madden Reefs of Seelig's Mine. At the same time the theoretical easterly extension of the Gifter–Pylkop K Line probably falls into the high ground on the south or opposite side of the kloof, so that the Tet, Sil, and 120 Line Reef would belong to a horizon between the Gifter on the one hand and the Frost–Madden channels on the other. Attention has already been called to the folded character frequently seen in the ironstones generally; it is also in evidence at this mine, and the structural features seem to indicate that possibly all three principal channels pass through a synclinal arrangement in such a way that the Sil Reef and the 120 Line turn upwards to air, but for the Tet Reef this is not clearly demonstrable. The proved fibre continuity along the strike is not less than one mile and in the Tet Channel, now the mainstay of the production, the persistence is at least 500 feet in the direction of dip; the configuration of the mining area with its steep and fairly regular slopes of considerable extent falling nearly with the inclination of the ore channels offers exceptionally favourable mining conditions.

The Tet Line is opened up by means of some 6 adit levels (drives on the reef), spread at intervals of approximately 100 feet measured along the dip and up to some 430 feet long, the total amount of driving now amounting to over 2,000 feet, exclusive of development on the other fibre channels. These adit levels are numbered from below upwards.

The developments on the Tet Reef may show minor sharp folds or occasional monoclines, but the disposition of the ironstones is on the whole very regular, and normally the fibre horizon carries a series of parallel interbedded cross-fibre seams of variable thickness, some of which are too thin for economic working. Others may be up to 6 or even 8 inches thick, but not infrequently such a very wide seam has very fine ferruginous partings, suggesting the coalescence of distinct bands. The width over which the seams are spread varies somewhat, but is often round 30 inches. Directly under an amosite seam one sometimes observes the same type of compact chert that was referred to above in the Rosskop workings of the Northern Asbestos Mines (compare Fig. 33), and under this comes soft greenish blue shale or slate carrying abundant scattered tufts, whisps, or rosettes of amosite needles or narrow blades, which are not oriented—the "amosite" slate previously mentioned. Such altered slate persists, even after the associated amosite has pinched out (analogy with Penge, Seelig's Mine,

PLATE XXVII.—*Sharply folded amosite seam* in banded ironstone, Seelig Asbestos Company; Malips Drift, south-east of Pietersburg.

Kranskloof, Rosskop, etc.). Fig. 34 represents a typical association of this "incipient" amosite formation, which strongly recalls the habit of a metamorphosed shale.

Near the mouths of several adits (see Frontispiece) the economic-horizon may consist of a single thick seam 4 to 6 inches wide, but pass further along the drive into multiple bands, marked off by ferruginous partings. It is significant in connection with the question of origin and persistence in depth that the further development follows a channel along its strike into the hill, so as to lie at a gradually increasing depth vertically below the surface, the greater is the tendency for the more prominent seams to pinch out, though they usually come in again, when they are thinner, and maintained over gradually shorter lengths

AMOSITE ROCK, SHOWING CROSS FIBRE, ASSOCIATED WITH CHERT AND AMOSITE-SLATE. EGNEP, LTD. (MALIPS DRIFT MINE.)

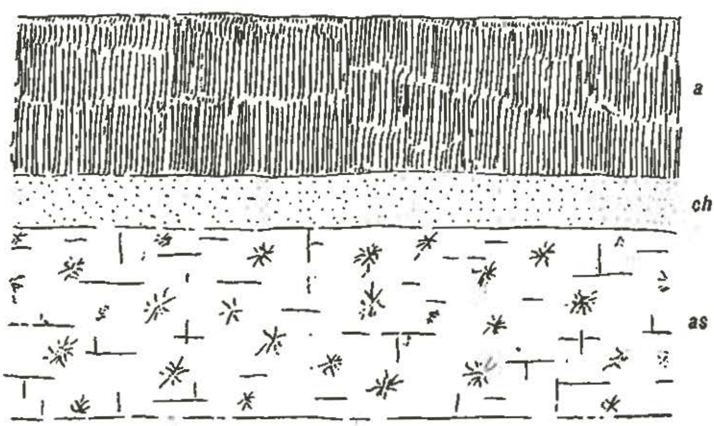


Fig. 34.
a = Cross fibre amosite; *ch* = chert; *as* = Amosite slate.
Natural scale.

of strike; at the same time the blank stretches increase in length. Within the latter one can sometimes find indications of the amosite-slate. Near the mouth of No. 2 Level, the drive shows some 60 feet of dark slate with films of pyrites.

A very interesting intermediate stage in the formation of an amosite seam was found a little west of where No. 6 Level is situated; it occurs on an old sleigh-road leading from the old S.A.P. Mine down into the main valley. This rock shows broad bands (see Fig. 35) of dull brownish roughly oriented amosite in ironstone, against which the bands terminate along a very irregular line of contact; probably this represents a stage in the formation of amosite, subsequent to that of "amosite slate," but the evolution of fibre has not yet entered the final stage, where the fibrous character and exact orientation reaches true asbestos structure.

The ground under development at this mine clearly belongs to a belt of ironstone that passes without a break from the floor of the Malips River Valley eastwards through the Malips Drift (Egnep) Mine direct into the workings of the South African Consolidated Asbestos Mines, Ltd.; though a direct correlation with the more westerly amosite deposits cannot be definitely established, it is probable that the Tet Line on Lot No. 119 corresponds to S.A.P. Line of the South African Consolidated Workings (Lot No. 120), which adjoin those of the Malips Drift (Egnep, Ltd.) Mine on the west and include a small triangular portion of Lot No. 119.

AN INTERMEDIATE STAGE IN THE FORMATION OF AMOSITE, MALIPS DRIFT MINE (EGNEP, LTD.).

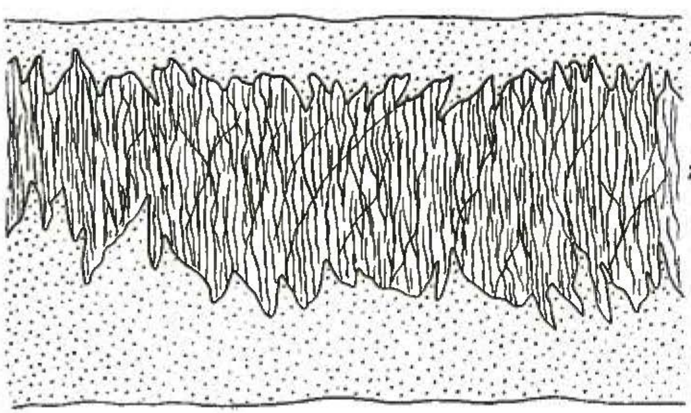


Fig. 35.

1. Banded ironstone. 2. Imperfectly oriented crystals of amosite. Natural scale.

The South African Consolidated Asbestos, Limited.

Directly adjoining the workings of the Malips Drift Mine (Egnep, Ltd.) on the east lies the South African Consolidated Asbestos Mine over the extreme north-eastern portion of Lot No. 120 and over Lot No. 121 on the northern side of the long deep valley previously referred to, at a distance of some 12 miles from the Malips Drift Post Office. The topography round the Consolidated Mine is very similar to that round the Malips Drift Mine, with the same very extensive and somewhat steep slopes rising from the floor of the valley upwards through well over 1,000 feet, so that the general inclination of the fibre channels with the southerly aspects of these slopes furnish exceptionally favourable mining conditions, superior to those existing west of the Malips River.

PLATE XXVIII. *Fig.* 1.—*Looking North* from the mill of the Malips Drift Asbestos Mine (Egnep, Ltd.); in the background high ridges along the ironstone-dolomite contact. Photo by G. McBean.

PLATE XXVIII. *Fig.* 2.—*Narrow amosite seams* in banded ironstone, Malips Drift Asbestos Mine (Egnep, Ltd.). Photo by G. McBean.

Three major gullies descend roughly from north to south towards the main valley, and with the intervening rises furnish the following conspicuous surface features, enumerated from west to east:—

McBean's Gully (across which run the outcrop lines of the three reefs referred to above, viz., Tet Reef, Sil Reef, and the 120 Line); then comes McBean's Hill, leading to West Gully (intersecting the principal fibre channels of the South African Consolidated Asbestos Mine, viz., the T.T. Line, the G. Line, and the S.A.P. Line); the surface then rises eastwards into Haskel Hill (round which contours the main track line, which delivers the ore to the top of the hauling gear for sending it down to the mill in the floor of the main valley); still further to the east follows East Gully, from which the surface once more rises into Compound Hill.

This complex topography, combined with an approximately east and west strike of the fibre channel and the general disposition of the latter, provides an extensive piece of ground over which the asbestos deposits are tapped at a series of workings, enabling some of the outcrops in West Gully to be matched in the East Gully in positions corresponding to the normal strike; this incidentally points to the probability of the fibre channels maintaining their underground continuity through the intervening hill.

The normal dip of the country averages some 32 degrees to the south, but varies as usual, locally rising up to vertical, while folding also occurs. Within these ironstones lie at least three principal fibre channels, each showing a series of parallel or sub-parallel interbedded cross-fibre seams of amosite, at an horizontal distance—very difficult to determine accurately—of probably not less than 2,500 feet from the underlying dolomite on the north. The following enumeration gives these main fibre channels in order from north to south:—

S.A. Consolidated Asbestos. (On the East.)	*Malips Drift (Egnep), Ltd.* (On the West.)
(*a*) T.T. Line..................	?
(*b*) G. Line....................	?
(*c*) S.A.P. Line................	Tet Reef.
?........................	Sil Reef.
?........................	120 Line.

The stratigraphical interval between (*a*) and (*b*) or (*b*) and (*c*) is approximately 200 to 250 feet, but in the nature of the case these values cannot be determined with much accuracy. Along the strike the fibre channel continuity is probably not less than 1,500 feet, while the persistence in the direction of dip is not likely to be far short of 1,000 feet; these figures, however, do not necessarily hold good, for all the three channels equally. These cannot be definitely paralleled with the three fibre channels found to the west at the Malips Drift (Egnep), Ltd., Mine, though most probably the Tet Reef in the latter occupies an horizon very near, if not identical with, that of the S.A.P. Line of the Consolidated Asbestos Mine.

Here the T.T. Line is the main source of present production; it is very regular in its distribution and is opened up in many workings, 6 levels of it being situated above the track line; this fibre horizon is traceable in a normal manner on both the west and the east side of West Gully; the same observation holds good for the overlying G. Line. In some of the adit levels on the T.T. Line, the fibre seams have been driven on for over several hundred feet and often form a considerable number of parallel bands, in places as many as 30 over a width varying between 3 and 5 feet. Some of them are up to 3 inches thick, but more often below that value. Underlying the T.T. Line, i.e. to the north, is a ribbon zone over some 50 feet in width. Exceptionally one may observe a combined fibre length corresponding to 30 per cent. over a width of 60 inches, but as pointed out in an earlier chapter, estimates of percentages and recovery based on measuring the combined fibre length over a given stoping width do not form a safe guide to actual yield. It is stated that the recovery from this mine is to be reckoned as 10 per cent. on 40 inches of stoping width. In the S.A.P. Line there is often a single conspicuous seam of very long fibre, though this channel is rather variable.

A very instructive occurrence of altered dolomite is found in the floor of the main valley above the mine compound near the point where the Kloof divides. This outcrop lies almost at the foot of the northern side of the valley and consists of massively bedded dolomite inclined to the south, but no evidence of its continuation towards the west was found, and apparently it forms the extreme westerly end of a band of that formation which continues from here eastwards past the workings of Pietersburg Asbestos, Ltd., through the main camp of the Montana Mine and further (see map, Plate XXXVI at end), so that the ironstones, which to the north underlie the dolomite outcrop at the compound referred to, take the form of a belt underlain and overlain by dolomite. The grey weathered surfaces of the latter show conspicuous and abundant scattered crystals of actinolite and phlogopite; the general habit is remarkably like that of the metamorphosed dolomite found, e.g. between the Molsgat Police Post and the M'Phatlele's River, where it falls into the extreme outside limit of the exterior contact belt of the Bushveld. Exactly similar rocks with the same abundant metamorphic minerals were observed above the Montana Camp (see below) and their occurrence in intimate association with the ironstone carrying asbestos and "amosite-slate" is obviously of great importance in connection with the mode of origin of the amosite deposits. (See Chapter IX.)

PLATE XXIX.—Opening up amosite deposits in banded ironstone at the Malips Drift Asbestos Mine (Egnep, Ltd.).
Photo by G. McBean.

The Montana Mine.

Some 3-4 miles due east of the Consolidated Asbestos Mine is the Montana Mine recently acquired by Messrs. Turner and Newall, Ltd., and consisting of several hundred claims on Lots Nos. 123, 124, 127, 135 and 312, situated in extremely rugged country with tremendous relief, and cut up into long deep kloof-like valleys and gullies separated by very high hills and ridges, which rise in places to well over 5,000 feet above sea-level, or some 1,500 to 2,000 feet above the floor of the principal valleys concerned. This is the one running almost due south (see map, Plate XXXVI, at end) from Lot No. 130 through Lot No. 123 and further downstream across Lot No. 265 to Lot No. 266, where its stream joints the Olifants River. On its eastern side a long high ridge, for the most part built of ironstones, and more or less deeply dissected by lateral gullies, separates the principal kloof from a second parallel valley, which is a little more open and runs from Lot No. 127 southwards across the eastern portion of Lot No. 123 into Lot No. 263, eventually leading into Ganspoort No. 270, where its stream runs into the Molapatsi River. As in the case of the other mines, east of the Malips River, so over the ground controlled by the Montana Mine, the intricate topography with its greatly accentuated relief, offers excellent conditions for prospecting and mining developments, also favoured by the southerly directed steep slopes and inclination of the beds and fibre channels.

These form several sets of cross fibre amosite seams interbedded in banded ironstones, which normally have a dip of some 52 degrees to the south, but are locally intensely folded. Thus the steep slope overlooking the upper or No. 1 Level at No. 4 Mine shows a series of rather closely spaced parallel thrust planes along which the middle limbs of the folds are almost rolled or thrust out for stretches of some 20 to 30 feet, and another type of folding is well seen in the overlying dolomite in the principal valley above the receiving station not far from the main camp. (See Fig. 36.)

The amosite deposits fall into the uppermost portion of a broad belt of ironstones, which is both underlain and overlain by dolomite, i.e., into a band of ironstone that is intercalated in the Dolomite Series (see map), but since the main mass of the ironstone lies only a little to the south (as the basal portion of the Pretoria Series), the distribution of the narrow strip of dolomite appears in the scenery like a horizon of these carbonate rocks intercalated in ironstone; this appearance is emphasized by the folded character of the dolomite. (See Plate XXX.)

The *main camp* of the Montana Mine lies in the floor of the principal valley on Lot No. 123, at the point where a little tributary gully enters it from the north-east. The camp is more or less surrounded by conspicuous outcrops of dolomite, which give rise to a prominent krantz on one side, some 200 feet above the bottom of the valley. A steep path leads across this krantz and takes one some 1,200 feet up to the nearest mine workings. (No. 4.)

The *mining developments* lie over the northern portion of Lot No. 124 at a height round 5,000 feet above sea level, so as to command a superb view to the south over the complex of hills and ridges—due to the enormous succession of banded ironstone—down to the Timeball Hill quartzite ridge and far beyond across the Olifants River Flats to the Lulu Mountains in the norite of Sekukuniland, with the granitic

TYPES OF FOLDED STRUCTURE AT THE MONTANA MINE.

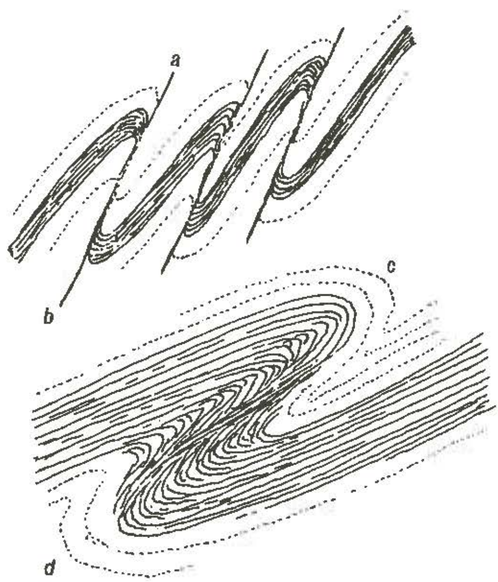


Fig. 36.

The Upper Figure shows folded ironstone (*ab* = approx. 25 feet); the lower figure shows folded dolomite (*cd* = approx. 200 feet).

Pokwani plateau in the far distance. The deposits of amosite form at least two, if not three, distinct horizons, which are as follows, enumerated in stratigraphical upward order, i.e. from north to south:—

(*a*) The lower or Main Reef, separated by a horizontal distance of about 250 feet (measured across the strike), from—

(*b*) the Middle or No. 2 Reef separated by a horizontal distance of about 250 feet (similarly measured), from—

(*c*) the Upper or No. 3 Reef; this lies at a horizontal distance of some 100 feet from the overlying dolomite (measured across the strike).

PLATE XXX.—*View looking from near the Montana Asbestos Mine* to the west; banded ironstone associated with folded dolomite.

GENERALISED SECTION ACROSS THE AMOSITE HORIZONS INTERBEDDED IN IRONSTONE, AT THE MONTANA MINE.

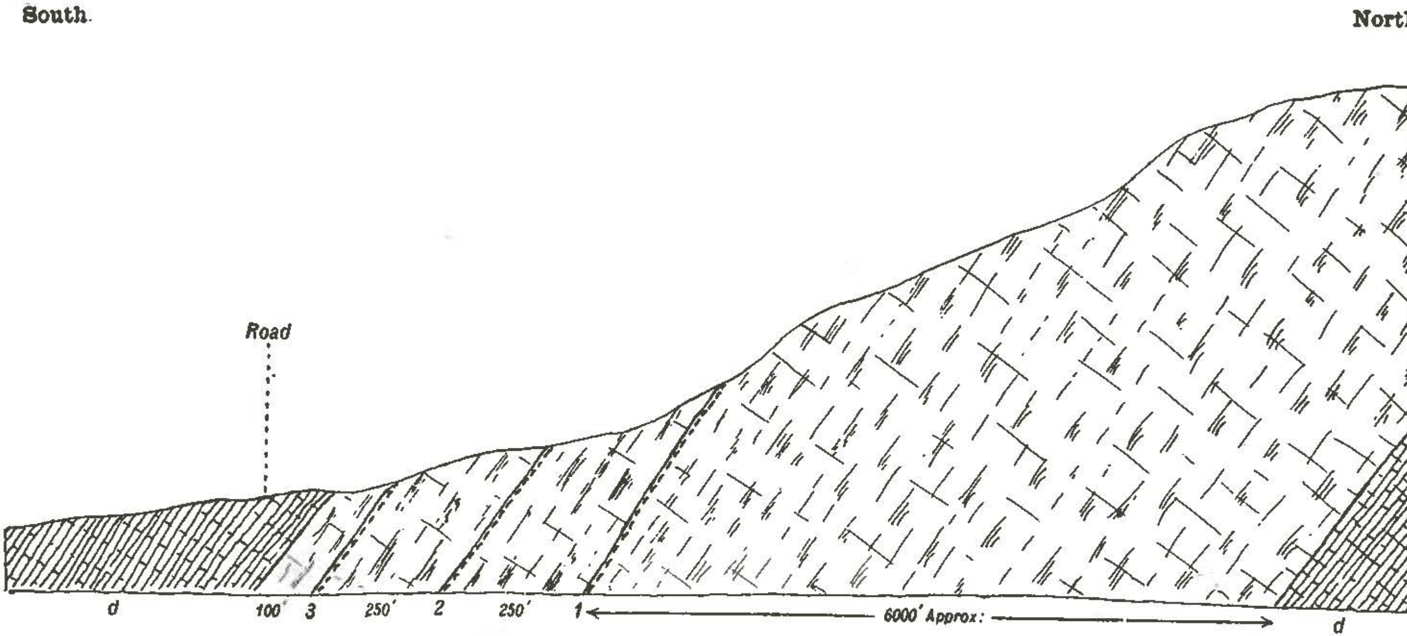


Fig. 37.

1 = Lower or Main Reef; 2 = Middle or No. 2 Reef; 3 = Upper or No. 3 Reef; *d* = dolomite; the three reefs are interbedded in banded ironstone.

The lowest or Main Reef is probably not less than 6,000 feet distant from the *underlying* dolomite. (See Fig. 37.)

Mining developments are concentrated in the following four sets of workings, given in order from west to east:—No. 4 Section; No. 3 Section; No. 2 Section and No. 1 Section. The fibre channel opened up in No. 4 is probably the same as that seen in No. 1, i.e., the Lower or Main Reef, but No. 2 appears to be in a separate horizon, i.e., the Middle or No. 2 Reef, while No. 3 section shows a fibre channel that may be an outlier or a displaced portion of one or other of the two lower reefs. Topographically No. 4 workings are the lowest and No. 1 workings in the most easterly portion of the mine are the highest. These prospecting and development operations point to a persistence in the direction of dip of approximately 1,000 feet; the indicated continuity along the strike amounts to about 7,000 feet, but the proved extent in this direction is roughly 1,500 feet. No. 4 Section has two levels, an Upper or No. 1, and a Lower or No. 2 Level placed 100 feet vertically below the former. These show a series of sub-parallel cross-fibre amosite seams in ironstone (sometimes accompanied by nontronite), spaced over a width of from 2 to 3 feet, but in the footwall portion of the ore channel black graphite shale—carrying a little pyrites, is conspicuous, and recalls some of the amosite associations in the K Line of the Northern Asbestos Mines West of the Malips River. The width of the seams shows the usual variations, and the proportion of fibre exceeding one inch in length is somewhat low. It was stated that after ruling out all seams under ¼ of an inch in thickness, the all round average of payable "ore" would probably be from 7 to 8 per cent., over a stoping width of 36 inches.

The general impression left after an examination of the workings is that the fibre display is not as great as that in some of the other deposits opened up in these fields, specially in comparison with fibre channels mined on the east side of the Malips River. On the other hand, the fibre is of a beautiful highly flexible quality, and has an almost silky lustre, when cobbed; in this respect the Montana is superior to any other amosite that has come under the writer's notice from these fields.

A new road has been cut across the country so as to lead from the western section of the mine to the edge of the dolomite krantz overlooking the main camp, from which an aerial gear is intended to lead to the loading station in the valley floor through a drop of some 250 feet. In some of the cuttings made by this road the dolomite is seen to be relieved by occasional bands of interbedded ironstone, only a few feet thick; these correspond to similar variations in lithological characters, already pointed out above, e.g. London African Tins, etc. A little above the dolomite krantz and near the path leading down to the main camp are good outcrops of metamorphosed dolomite, the weathered surfaces of which are studded with conspicuous crystals of actinolite or phlogopite; these rocks are indistinguishable from those referred to from the Consolidated Asbestos Mines (see above) and belong to the same band of dolomite.

Other Amosite Occurrences.

Further deposits of amosite have also been recorded beyond the Montana Mine eastwards and southwards to the southern limit of these fields, but their development is still more or less in the prospecting stage.

On the northern portion of the farm *Dublin* is a good outcrop of cross fibre amosite seams on the southern flank of a deep kloof-like valley, some 300-400 feet above its floor. This fibre channel is about 2 feet wide and runs along a fairly steep face of banded ironstone at a horizon roughly about 2,000 feet from the top of the underlying dolomite, so as to fall into the main body of ironstone that extends upwards to the Timeball Hill quartzite. This deposit shows a series of parallel seams traceable for some distance along the slopes and consists of fibre of promising quality and length, as there appears to be a good proportion that exceeds one quarter of an inch in length, while the mining conditions are also favourable.

On some of the other localities near this farm, e.g. in the M'Thlapitsi valley, crocidolite deposits have claimed the main attention (see below).

6. *Nature and Length of Fibre, Persistence, Variation in Depth, and Resources.*—The chemical and physical *properties of amosite* have been given above in Chapter I, which also includes an instructive table of comparisons between amosite and the two other principal varieties; further information will be found in a recent communication by G. J. V. Clarence (Bibl. No. 10). These data show that in some of its physical properties, including one or two of special significance in the fibre industry, amosite is below chrysotile and more or less equal to crocidolite, yet in the important factors of length and resistance to sea-water it is superior to chrysotile.

Attention was called in the Vth Chapter to the unusual *fibre length* of amosite, locally up to a little over 11 inches, from which maximum there is every gradation down to one-sixteenth of an inch, and finally down to mere films; very high lengths are almost common in the Lydenburg Fields, but rare in the Pietersburg Fields, where a fibre length of over 3 inches is exceptional, the majority of the seams falling within the limits of three to one-quarter of an inch; values from about half an inch to 1½ inches occur extensively in the majority of workings. In those mines that are producing or were doing so until quite recently, the limiting length of the longest grades is commonly round one and a half inch, and this class of fibre forms a substantial proportion of the total output.

Although chrysotile in general has a higher market value than amosite (or crocidolite) length for length, the latter fibre deposits have usually a much greater proportion of textile grades. Without, therefore, making the difficult and unprofitable attempt of working out the "average" fibre length for the whole of the Pietersburg occurrences, a figure in any case incapable of accurate determination, it is evident that a very high proportion of the available resources has good commercial length and that this is well in excess of the run of mine furnished by chrysotile deposits.

The distribution of the amosite seams over these fields as a whole, shows an interesting feature with reference to the fibre length. There would appear to be a tendency for the maximum display of asbestos to lie in the central portion nearer, and on both sides of, the Malips River, whence—in general—a gradual decline is noticeable, the further one goes westwards to Chuniespoort, or eastwards to the M'Thlapitsi area and beyond; no doubt, there are fluctuations in the display, so that the changes in the latter are not regularly progressive, but broadly speaking, a comparative study of all the workings does point to such a feature in the variations of the fibre deposits, amounting to a kind of regional fluctuation in their display and culminating in two maxima, one in the Malips River valley and the other in the Olifants River valley over the Penge-Streatham area. It is, however, impossible to say whether this feature is purely accidental, or whether it perhaps has some significance in the mode of origin of this asbestos.

The important question of *asbestos persistence* must be considered from three aspects:—Persistence along the strike, in the direction of dip, and in depth; the last refers to depth vertically below the present surface which is not necessarily the same thing as a difference of topographical level between two workings on the same fibre channel, of which one may be low down on the hillside and the other high up. The necessity of observing this distinction does not appear to be invariably appreciated.

The great extension of these fields along the strike has been emphasized above, i.e. the widespread occurrences of fibre almost from one end to the other, but this does not amount to actual continuity of a given fibre horizon. Nevertheless, the total proved persistence is certainly to be measured in miles. The highly mountainous nature of the country with its extensive slopes of ironstone has also been referred to, and on the east side of the Malips River especially, where the fibre deposits are disposed more or less with the natural slopes of the hillsides, the very favourable mining conditions have enabled an asbestos horizon to be proved at a series of points one above the other, so as to establish definitely a continuity not far short of 1,000 feet in the direction of dip; as pointed out, this is, however, not a measure of persistence in actual depth vertically below the surface, but means that development and exploitation are proceeding, as it were, along a slab of "reef" disposed roughly in conformity with the slope of the hillside and at a depth that maintains more or less the same order of magnitude. On the south flanks of the Holkloof valley west of the Malips River, for example, where the southerly inclination of the fibre channels is against the northerly slope of the hillside,* development in the direction of the dip would more readily throw light on the problem of persistence in true depth than is the case on the east of the Malips River.

None of the many asbestos workings in the Pietersburg Fields have up to the present reached a stage, where development has been pursued far enough underground to demonstrate what is the *variation* of the seams at a *greater depth* below the surface. It was explained above, that in some of the older workings there is a tendency observable for individual seams to persist for increasingly shorter distances and to alternate with gradually lengthening stretches of blank ground, the further development proceeds underground along the strike. As far as the evidence now available goes, it is therefore possible, if not probable, that an eventual limit may be reached at which the exploitation of a fibre channel will cease to be economic, owing to lack of adequate persistence in true depth; this aspect is closely bound up with the problem of asbestos genesis. (See Chapter IX.)

Not much evidence—for similar reasons—exists as to the extent to which *variations in quality* depend on depth. At the surface, amosite seams are often much deteriorated through changes depending on the zone of weathering, and a rapid improvement is commonly noticeable on following a seam underground. At greater depth, a distinct improvement in quality is sometimes found, the fibre becoming cleaner and whiter in appearance, while, on the other hand, the country rock is harder; at the same time, such good features may be accompanied by a drop in fibre length. Within a given seam there occurs hard fibre which passes laterally into tensile fibre and *vice versa*, but it is doubtful whether such a change is really dependent on depth and is not perhaps due to loss of water from some cause or other. In the Penge–Streatham area of the Lydenburg Fields—as pointed out in the previous chapter—no fundamental change in quality occurs at ground water-level.

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* The difference between disposition of the fibre channels with reference to the slope of the surface is shown by a comparison of Fig. 31 with Fig. 37; this difference would become even more striking, if comparison be made with easterly workings situated nearer the Malips River than the Montana Mine.

Any attempt to give an accurate numerical estimate of the total *asbestos resources* available in these fields is for obvious reasons out of the question, if only on account of the uncertain nature of the basic factors on which such an attempt must rest. On the other hand, it is possible to arrive at some indication of the potential resources by working out a suitable " unit of exploitation," which can be used as a convenient measuring rod for the whole fields, or any desired section of it. Thus, a unit of strike equal to 100 feet, taken in conjunction with a length of 10 feet in the direction of dip, and a combined fibre thickness (ruling out all seams less than one-quarter of an inch) of 3 inches, correspond to 25 short tons of amosite—taking the specific gravity of the fibre as 3.2. Those having a detailed knowledge of these fields, will admit that a combined fibre length of only 3 inches is a very conservative estimate. The arithmetically inclined reader will have no difficulty in applying this measuring rod on a larger scale, for which some of the necessary data are given in this chapter, though a note of caution must be sounded in attaching too much importance to what remains essentially an arithmetical phenomenon.

In interpreting the economic significance of such globular figures of potential resources, it is as well to remember the following:—

(*a*) The variable persistence of seams both in strike and dip.

(*b*) The consequent danger of relying too much on measured fibre percentages.

(*c*) The occasional completely blank stretches interrupting the fibre continuity of a given channel.

(*d*) The not uncommon discrepancy between the actual fibre delivered by the mill and the amount anticipated from the ore supplied to it.

(*e*) The local deterioration in fibre quality below the economic grade.

Nevertheless, after making allowances for all the above uncertainties, there is no doubt that enormous tonnages of commercial fibre are available in these fields, running comfortably into six figures, and the potential value of these deposits, in quality and quantity, is not to be altogether discounted on the ground of intervening stretches of poor quality fibre, any more than the economic importance of a productive goldfield is discounted, because it includes patches of unpayable ore.

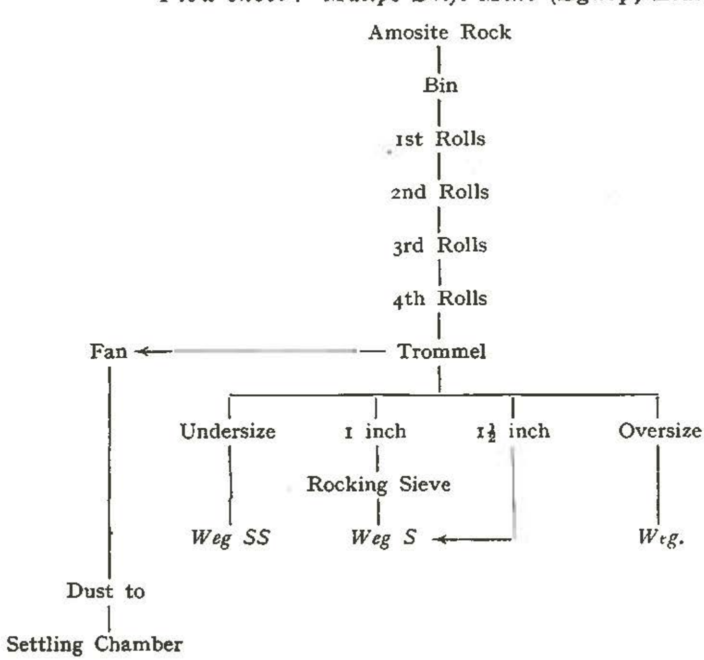
7. *Market Preparation and Grading.*—The methods in use for recovering the fibre from the rock and preparing it for the market, including the grading schemes, vary in detail to some extent, but depend, broadly speaking, on essentially similar principles. Since very few mines have been in the producing stage for any great period, the milling operations are still more or less in an experimental stage, so that market preparation, and in particular the specification of grades, are less uniform than will probably be the case in the future, when

standards of grading and quality have been more thoroughly stabilized and more closely adapted to the exact requirements of the market.

In some cases, where mode of occurrence, fibre length, and other conditions are suitable, a certain (usually rather small) proportion of the fibre rock is prepared by hand-cobbing alone, which method can be so applied as to form a long fibre grade suitable for the market either direct or after screening the hand-prepared fibre; in other cases, such as the S.A. Consolidated Asbestos Mines, no hand-cobbing is done. Milling is resorted to along a flow-sheet that varies with different producers, but depends on a series of successive operations, of which the principles are as follows:—Drying (where necessary), coarse crushing, followed by treatment in one or more sets of rolls, sorting, disintegrating or fiberizing, succeeded by screening trommels or screening tables; in some cases the suction principle and cyclone collectors are added. The exact process of milling is, however, too technical for these pages, apart from the fact that its design is for the most part not as yet permanent, while detailed information is for obvious reasons not—in general—available for publication.

Through the courtesy of the Cape Asbestos Company, which controls Egnep, Ltd., the writer is able to give the flow-sheet of their *Malips Drift Mine*; this is the oldest producer in these fields, and its simple mill has reached a stage of development that is now successfully adapted to the geological and other conditions of asbestos deposits exploited by that company.

Flow-sheet: Malips Drift Mine (Egnep, Ltd.).



Length is usually the principal factor determining grade, but other criteria may also enter into the grading schemes, which are not uniform throughout the fields, nor always finally settled, pending a return to more favourable conditions of the asbestos market.

The grading scheme in force at the *Malips Drift Mine* (Egnep, Ltd.) and the relative proportion of their grades in the total output are shown in Table No. 31.

TABLE No. 31.—*Grading Scheme and Percentages of Grades, Malips Drift Mine (Egnep, Ltd).*

Grade.	*Description.*	*Percentage Output.*
Weg	Over 1½ inch	40 approx.
Weg S	1½ inch and under	50 approx.
Weg SS	½ inch and under	10 approx.

In case of the S.A. Consolidated Asbestos Mines, Ltd., no hand-cobbing is resorted to, and none of the grades consist of fibre over 1½ inches in length. The first point in the mill discharging fibre yields a very fine but somewhat dirty product still containing some fine dust; this is classed as No. 3 (least valuable) grade. At later stages in the flow-sheet, Grade No. 1 and No. 2 are recovered, the latter being less fiberized than the former. The scheme and the approximate properties of each grade in the total output is shown in Table No. 32.*

TABLE No. 32.—*Grading Scheme of S.A. Consolidated Asbestos.*

Name of Grade.	*Proportion of Total Output.*
Sacal 1 (best grade)................................	60 per cent.
Sacal 2 (intermediate)................................	25 per cent.
Sacal 3 (least valuable)................................	15 per cent.

III.—CROCIDOLITE.

(*Pietersburg Fields.*)

1. *Mode of Occurrence and Distribution.*—The blue variety of hornblende asbestos is found in the Pietersburg Fields also in the form of cross fibre seams interbedded in the same type of banded ironstone in which the amosite seams lie, and under identical geological conditions.

* Information kindly placed at the disposal of the writer through Mr. H. Friedman, Manager.

The crocidolite fibre length is as a general rule less than in the case of amosite, and the amount available over the whole fields—as well as the intensity of its display at a given point, are also less than with amosite. Almost invariably only one type of fibre is developed in a mine, though it happens sometimes that both crocidolite and amosite are found in the same mining or prospecting area, but this is exceptional; in a few localities the association is very intimate, so that an individual seam may consist partly of amosite and partly of crocidolite, a fine parting, e.g. of iron ore, marking the dividing line, which runs more or less in conformity with the bounding walls of such a seam (Pietersburg Asbestos = Leather's Mine).

The distribution of the crocidolite does not show any marked restriction to certain horizons, since it is liable to occur almost anywhere within the ironstone from near the top of the dolomite almost to the base of the Timeball Hill Quartzite, though the occurrences lie mostly in the lower portion of the succession of ironstones, nearer the dolomite.

Among the localities * at which crocidolite seams lie lower down in the ironstone succession, not far above the dolomite may be mentioned : Lot No. 244 on the left side of the Malips River, worked prior to any of the present amosite developments, Lots Nos. 123 and 126, both situated east of the same river, the northern portion of Lot No. 278 in the valley of the Molapatsi River, Gemini within the M'Thlapitsi River basin, Cork, Dublin, Dalton, Lucerne and others. Crocidolite occurrences higher up in the ironstone succession include :—Benauwheid, Wonderkop and Toornkop close to the east side of the Wonderkop Fault, Lot No. 263 east of the Malips River, Tubex (Lot No. 298), etc.

2. *Mining Developments, etc.*—Apparently the earliest crocidolite developments are those on *Lot No.* 244 (abandoned some years ago in favour of amosite exploitation), situated near the left bank of the Malips River, a little way up the slope of the hill. The upper set of workings were close to the south-easterly beacon of Lot No. 244 and largely open-cast, exposing a fibre channel over 150 feet long in thinly bedded very hard siliceous ironstone; owing to minor folding the inclination of the latter was found to vary from horizontal to about 30 degrees to the south or north. The usual association of a series of parallel cross fibre seams was found conformably interbedded in ironstone, ranging up to 3 inches in thickness, but commonly only ¾ inch or less. These consist of generally dark lavender blue fibre with their long axes slightly inclined to the containing walls and very similar to typical Cape Blue; this also applies to their detailed distribution, variable lateral persistence, tapering habit of ending off, etc. Any one vein rarely persists for more

* This list is not exhaustive, and the mention of any locality does not necessarily mply crocidolite deposits of economic importance.

than a few feet or yards, and then dies out to be replaced by another one at a slightly different horizon. The lower set of workings included a drive along which cross fibre seams of both crocidolite and amosite were found. On Lot No. 244 one also meets with the " cone " and " corrugated " structures, typical of many seams within the Cape Belt. River on *Lot No.* 126, and comprises several sets of workings not far above the floor, and on both sides, of the long deep kloof-like valley, previously referred to as the principal valley associated with the Montana Mine main camp. Both amosite and crocidolite occur on Lot No. 126,

The mine * of the *Pietersburg Asbestos, Ltd.*, lies east of the Malips

INTIMATE ASSOCIATION OF AMOSITE AND CROCIDOLITE; PIETERSBURG ASBESTOS, LTD.

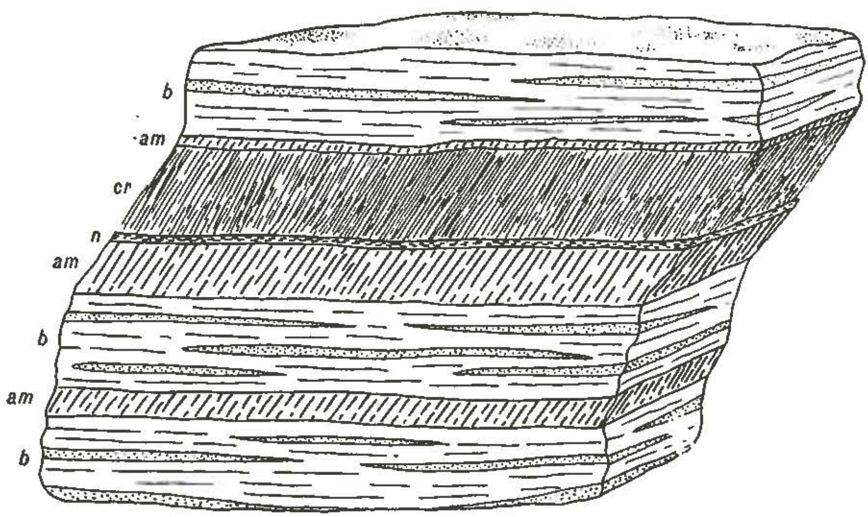


Fig. 38.

b = banded ironstone with chert layers; *am* = amosite; *cr* = crocidolite; natural scale.

but the principal developments are concerned with the crocidolite deposits; the major workings are known as the Western, Southern and Eastern Sections. Plate XXXI shows a general view of one of these lying on the west side of the valley. The principal fibre channel (crocidolite) has been proved over some 600 yards of strike and for about 100 feet in the direction of the southerly dip of the ironstone, which rises up to some 12 degrees. The common experience of a group of sub-parallel seams is also illustrated by this mine, a wider seam from ½ to 2 inches thick being accompanied by several thinner ones; the country rock is in places very hard. An intimate association of silvery grey relatively short fibre amosite with longer fibre crocidolite is a

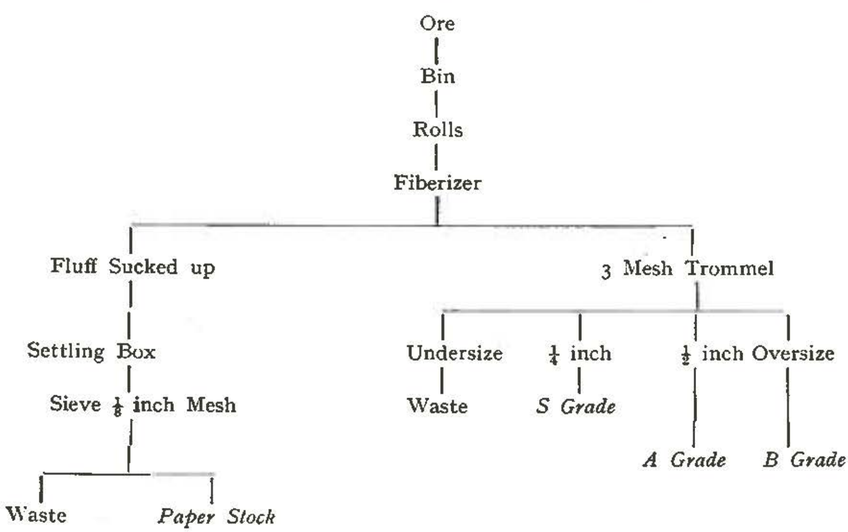
* Also known as " Leather's Mine."

PLATE XXXI.—*Crocidolite workings* in gently inclined banded ironstone; Leather's Mine (Pietersburg Asbestos, Ltd., east of the Malips River.

characteristic feature in these deposits: very commonly the axes of the fibres are not disposed at right angles to the walls of the seams but are more or less inclined to them. (See Fig. 38.) In most cases a seam of " blue " is separated from one wall by a narrow band of amosite, while on the other side there is only a very delicate film of " white " or no amosite at all. Almost invariably the amosite portion of such a compound seam is much narrower than its crocidolite portion, and the contact line is indicated merely by an abrupt colour change; elsewhere it may be marked by a thin film of dark highly ferruginous compact matter, while in still other cases a delicate zone intervenes built of somewhat coarse " needle " crocidolite.

At the Pietersburg Asbestos Mine the grading is based essentially on length :—Grade B is the best quality fibre, over 1¼ inches in length, grade A comes next, with ⅝ to 1¼ inch length, while grade S or Shorts is made up of fibre under ⅝ inch long; there is also a paper stock quality. A simple mill has been erected, of which the recovery is along the following outline :—

Crocidolite Recovery; Pietersburg Asbestos Mine.



On *Gemini*, in the M'Thlapitsi River valley, and on *Cork* to the south-east of the former farm, crocidolite deposits have been developed by the *Standard Asbestos Co.*, but amosite is also found in this portion of the fields. On the south-east side of the Cork valley some 300 to 400 feet above its floor, the workings are open-cast and show in places as many as 6 to 8 seams over a channel width of some 20 inches, interbedded in ironstones that are inclined some 70° to the south-west, and are on the whole very hard. Individual seams over 1½ inches wide occur here, and show the same very close association of white and blue fibre, similar to the compound seams described above.

TYPICAL EXPOSURE OF BANDED IRONSTONES WITH AMOSITE AND CROCIDOLITE ON CORK, EAST OF THE M'THLAPITSI RIVER.

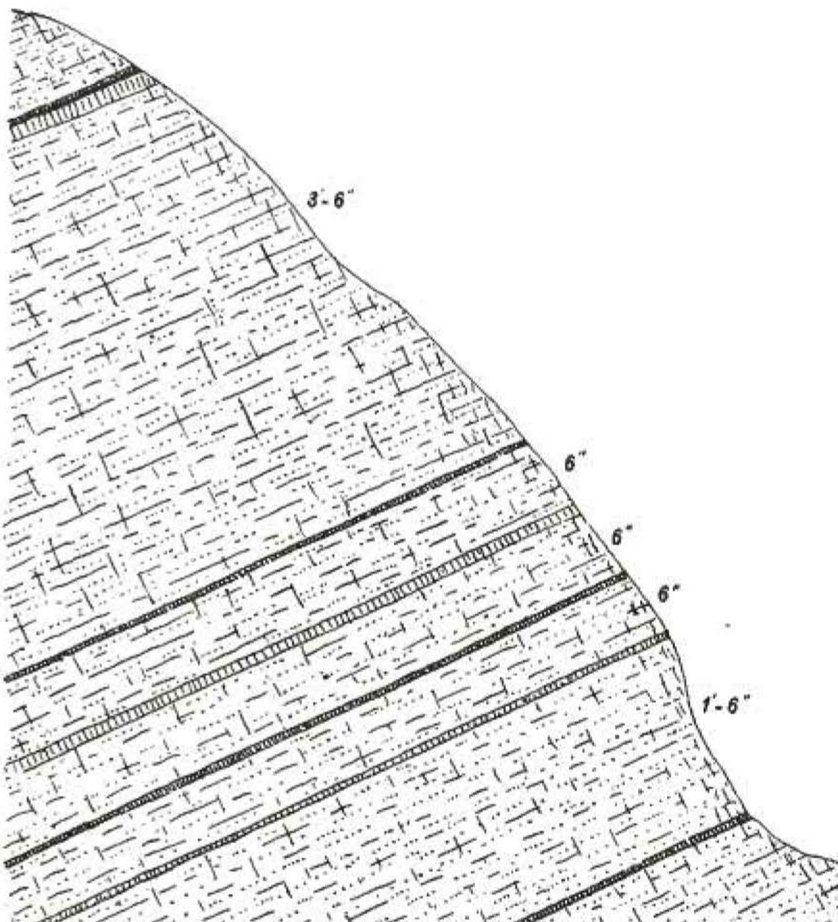


Fig. 39.

On the opposite or north-western side of the Cork valley a large amount of prospecting has been done high up on the hillside some 1,000 to 1,500 feet above the valley floor; both crocidolite and amosite occur here and are sometimes closely associated with one another in the same face, of which Fig. 39 illustrates a typical case.*

* Drawn from measurements made by Mr. A K. Parrott, Field Assistant.

Prospecting operations have also been carried out by the *Island Asbestos Co.* over an area that forms approximately the central portion of Lot No. 278. This locality is somewhat difficult of access, and lies about 12 miles due south of the Iron Crown (see Plate XXXVI at the end) in the valley of the Molapatsi River, where it is joined on its east side by a well-defined tributary coming from the north. The workings are best reached from Pietersburg via Smits Drift, where a road leads in a general southerly or south-easterly direction and gradually rises to the top of the Strydpoort Range, to continue southwards across the rolling and lower lying dolomite country over countless drifts. Lot No. 278 falls into highly dissected ironstone country, carved into narrow kloofs, some 200 feet deep, on the sides of which lie a series of crocidolite workings, for the most part opencast, but including one drive some 200 feet long. The ironstones of the country dip normally about 40 degrees to the south, but one locally more or less strongly folded. Some of the blue fibre is of promising quality, and sometimes shows a length round 2 inches; slip fibre also occurs, as well as a little amosite.

3. *The Quality of the Crocidolite.*—Some of the fibre in the Pietersburg crocidolite deposits is comparable in quality to that of the Cape Belt, but the bulk of it is inferior to the best " Blue," e.g. of the Westerberg and Kuruman sections. On the whole the Pietersburg fibre is harder and not nearly so finely fibrous in structure, while it frequently has a tendency to show scattered particles of iron ore. In the account given by H. L. Kirkman (Bibl. No. 43, p. 17) the relative fineness is based on a comparison between " horsehair to silk."

The variety from the Cape Fibre Belt referred to in Chapter II as *" needle " crocidolite* is rare, but it recalls the mode of occurrence in somewhat coarse deep blue acicular crystals seen in the compound seams of the Pietersburg Asbestos Mine, mentioned above. True *mass fibre* crocidolite (or " potential " crocidolite) so common, e.g. round Koegas north of Prieska or north of Daniels Kuil, has not—as far as the writer is aware—been exactly matched in the Pietersburg Fields. The only approach to this type was collected in the course of the original survey in 1907 on Lot No. 269 in the Molapatsi River valley. This is a very dark fine-grained rock, with no fibrous structure visible in the hand-specimen, but a thin section gives a slight indication of bedding planes and is crowded with strongly pleochroic crocidolite needles without orientation; the habit is markedly elongated and very much coarser than in the typical " mass " fibre rock of the Cape, in crystals exhibiting the typical amphibole cleavage, and extinguishing sensibly straight, while tending to a radial arrangement from larger iron ore crystals as centres.

Summary of Outstanding Features of the Pietersburg Fields (amosite and crocidolite).

The principal geological and economic features of these fields may be usefully summarized as follows:—

(*a*) The Pietersburg Asbestos Fields extend through some 50 miles of strike from Chuniespoort in a general easterly and south-easterly direction, and vary in width between 5 and 12 miles; these figures include the Dolomite Series, in which chrysotile occurrences are known, and on that basis the fields represent some 440 square miles of potential asbestos bearing country;

(*b*) Taking only amosite and crocidolite—as the more important types of fibre in these fields—the distribution of the ironstone formation to which these fibre varieties are restricted, shows the potential asbestos bearing country to extend over approximately 190 square miles;

(*c*) The fibre deposits form cross fibre seams mostly of amosite, less frequently of crocidolite; both types are interbedded in (and confined to) the siliceous banded ironstones, belonging to that portion of the Pretoria Series (Transvaal System) which lies between the Timeball Hill quartzite and the top of the underlying Dolomite Series. Identical ironstones also carrying asbestos are found intercalated in the Dolomite Series itself; the geological features of the ironstone formation strongly recall the Lower Griqua Town Series of the Cape Fibre Belt;

(*d*) The amosite seams tend to lie within a few hundred feet or yards above the underlying dolomite, and this applies specially to the more productive fibre channels; crocidolite seams are also not infrequently found low down in the succession, but this tendency is less striking, since one meets them at different horizons almost up to the Timeball Hill Quartzite.

(*e*) Amosite seams occur at a very large number of localities throughout the entire Fields, but at some of them the seams of commercial grade are not as concentrated, nor is the fibre as intense at any point, as desirable. The more favourable deposits appear to be more or less distributed with reference to the area bordering, or at any rate nearer, the Malips River Valley, while the fibre display falls off—broadly speaking—when following up the fields to greater distances eastwards and westwards;

(*f*) The proved persistence of a fibre channel along the strike is to be measured in hundreds of feet or yards, and in the direction of dip some deposits show a continuity up to a maximum of about 1,000 feet. To what depth vertically below the surface the amosite seams persist as commercial fibre, or may be expected to do so, is not known, but some of them leave the impression of the fibre display becoming feebler as their horizon is followed further underground along the strike;

(*g*) The very high relief of the country provides excellent mining conditions, particularly where the natural slopes run with the direction of inclination of the fibre channels;

(*h*) For the most part the quality and specially the length of the amosite fibre are of commercial grade, though in the latter respect commonly falling short of the exceptionally great lengths met with in the Lydenburg Fields. No difficulties are, however, experienced in securing a high percentage of the output, made of marketable quality 1½ inch in length, in case of the majority of productive centres;

(*i*) The amosite resources over the whole fields are undoubtedly very great, and even after making liberal allowance for adverse variations in display, length of fibre, quality, lateral persistence, lean patches, quality, etc., the available tonnage of marketable fibre should run well into six figures;

(*k*) Crocidolite is less abundant than amosite, and though some of it approaches (or perhaps equals) the best type of " Blue " from the Cape Belt, much of the fibre is inferior to that asbestos.

The broad conclusion is therefore warranted that the Pietersburg Asbestos Fields constitute a valuable asset in the Base Metal Resources of the Union.

Chapter VII.

MINOR OCCURRENCES.

This chapter deals with a series of different asbestos occurrences that are found under geological and economic conditions indicating more or less minor occurrences, compared with the majority of the Transvaal asbestos deposits described in previous chapters. It is not excluded, however, that some of these fibre horizons may eventually develop into promising deposits, but so far their examination has not had very encouraging results and their importance as potential asbestos sources is still negligible, with the exception of those dealt with in the appendix to this chapter. It appears to the writer nevertheless useful to have these occurrences on record; they are grouped as far as possible in their geographical relationships within each fibre variety.

A.—*Chrysotile in Serpentine.*

1. *Barberton District.*—The belt of the Jamestown Series, in which occur the serpentines associated with the chrysotile deposits near Kaapsche Hoop and described in Chapter III, extends in a general easterly direction to beyond Malelane on the Delagoa Bay Line, though the proportion of true serpentine becomes less, owing to the association with other magnesian rocks, e.g. talcose schists, etc.

Cross-fibre seams of chrysotile have been found in the serpentine at several points, e.g. near *Clutha Siding*, round *Kaapmuiden* near the right bank of the Kaap River, south of *Magnesite Siding*, etc. These occurrences are in some cases purely of mineralogical interest, in others their examination has not yet gone beyond the early prospecting stages; in one deposit the producing stage has been reached. This is some 4 miles due south of Magnesite Siding, where on the south side of a ridge of serpentine a large open-cast working cuts into the hillside with a more or less vertical face, some 30 feet high. The seams are scattered sparingly through the rock and are usually inclined at low angles, with occasionally a vertical seam. The fibre display is moderate, while the lateral persistence is also rather restricted. The seams are sometimes interrupted by fractures, and the fibre shows low tensile strength. Seams showing a fibre length of over one inch are rare, and the bulk of the output is round half an inch in length. This is prepared by hand and, though of poor quality for textile purposes, it has been found suitable as a raw material in the manufacture of asbestos in the factory of Messrs. Hancock & Co. in Johannesburg.

South of Tafelkop is another occurrence in serpentine (on Doornspruit No. 96?), known many years ago.*

2. *The Komati River Valley* (Carolina District).—On the north side of the Komati River over the eastern end of the Carolina District lies an irregular area of basic schists, associated with serpentine. Here chrysotile occurs on a number of farms †:—*Sterkspruit No.* 239, *Stolzburg No.* 202, *Doyershoek No.* 145, *etc.*

MODE OF OCCURRENCE OF CHRYSOTILE IN SERPENTINE, NO. 1 WORKINGS, STERKSPRUIT, IN THE KOMATI RIVER VALLEY (CAROLINA DISTRICT).

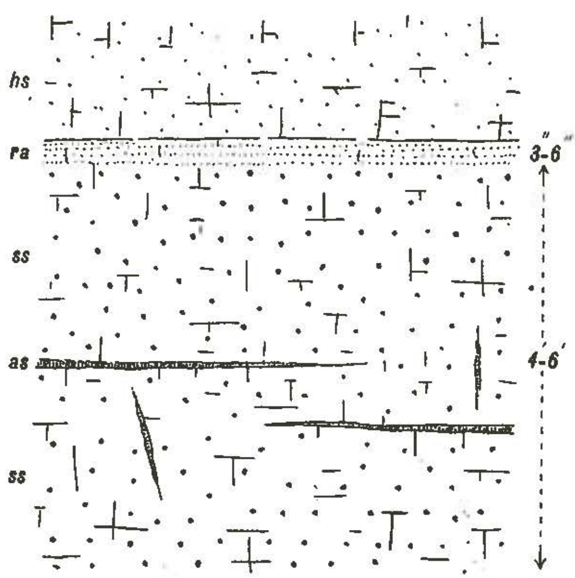


Fig. 40.

hs = hard dark serpentine; *ss* = soft green serpentine; *ra* = ribbon chrysotile; *as* = chrysotile seam.

In the easterly portion of *Sterkspruit* several short low ridges of serpentine rises above the general level of the Komati River Flats; some of these carry chrysotile seams, but the intervening lower-lying ground was also found to consist (in part) of asbestos-bearing serpentine. This locality is some 6 miles in a direct line east-south-east from the Komati River Bridge, over which passes the Carolina–Barberton Road, or some 12 miles to the east of the Kalkkloof Asbestos Mine (described in Chapter III). Prospecting was carried on at some five workings, including one in the flats, the remainder spread over the lower slopes of a serpentine ridge.

* Th. Kässner. "Gold Seeking in South Africa." London, 1902, p. 60.

† See the geological map accompanying Memoir No. 9 (Bibl. No. 28A).

The geological features closely resemble those seen at the Kalkkloof Asbestos Mine in showing alternate broad belts of soft greenish fibre-bearing serpentine (carrying a little stichtite) and hard dark bluish black serpentine without fibre; similarly, the soft mineralized serpentine tends to give rise to somewhat smooth slopes, in contrast with the rocky slopes built of the barren variety—which strongly recalls the Kalkkloof experience. The workings are essentially open-cast, and reveal three sets of fibre channels, roughly parallel to one another and striking north-east to south-west with an inclination of approximately 45 degrees. At the contact between the hard and soft serpentine is a narrow zone of ribbon fibre (see Fig. 40) composed of several very thin seams analogous to the Griffin Line of the old Amianthus Mine (Chapter III). The seams are usually disposed with the contact plane, but cross-seams occasionally occur. The display is on the whole disappointing in number and fibre length, though a few seams were met with well over half an inch in thickness and of good quality. No. 3 consists of a large cutting, several hundred feet above the general level of the surrounding country, on a hill about a mile from the other workings; it shows a fibre zone some 40 to 50 feet wide, in which there is a group of rather widely spaced seams, some of which are disposed vertically.

Prospecting work has also been carried out on *Stolzberg No.* 202, adjoining Sterkspruit on the east, where a series of trenches show seams inclined from 45 to 60 degrees to the north; the display is disappointing, and did not appear to improve in depth. On *Doyershoek No.* 145, directly north of Stolzberg, chrysotile has likewise been proved in serpentine, but the fibre display is not promising.

3. *Steynsdorp-Josefsdal Area* (Carolina and Barberton Districts).—Chrysotile is stated to occur in the serpentines found round *Steynsdorp* in the extreme eastern end of the Carolina District; some 12 miles north-east of Steynsdorp, on the eastern portion of the farms *Josefsdal No.* 35 (12 miles in a direct line south of Barberton) chrysotile has recently been found in a belt of basic rocks closely associated with chert bands; good quality fibre of fair length was located here, but at greater depths the display was not maintained.

4. *North of Krugersdorp.*—Some 6 to 7 miles north of Krugersdorp is an area of amphibolites, talcose schists, serpentines, etc., into which fall the farm *Honingklip* (or *Honingkloof*) *No.* 72 and the adjoining south-westerly portion of *Driefontein No.* 81, both carrying good outcrops of chrysotile-bearing serpentine.

Prospecting on *Honingkloof* appears to have been first attempted in 1912, but was not resumed until some 3 years ago; the serpentine gives rise to several low stony ridges on the northern portion of the farm, covered by large boulders having deeply pitted grey surfaces of weathering; the fresh fibre rock is a pale dirty greenish coloured soft serpentine with cross-fibre seams of chrysotile, occasionally also showing films of black iron-ore and fibrous pseudomorphs of the latter after asbestos. There is also some dark greyish black serpentine, which does not carry fibre. The large number of prospecting trenches and pits are roughly aligned east and west and spread over about one and a half miles of country. A westerly shaft exposed a more or less vertical fibre channel several feet wide, while another shaft, situated further to the east, showed a fibre zone some 8 feet wide with a foot-wall of grey serpentine. In most of the trench workings the display was disappointing, and at times appears to fail altogether at only very moderate depths. Now and then a group of closely spaced parallel and thin seams could be observed.

The serpentines and allied basic rocks on the adjoining farm *Driefontein No.* 81 are a direct continuation of the corresponding formation of Honingklip. The workings are scattered over the western portion, and include the Main or No. 3 Development as a larger irregular quarry. The seams are few in number, are without definite dip, and in compact much jointed and apparently much disturbed serpentine. The mode of occurrence and distribution is very indefinite, while the seams rarely approach or exceed half an inch in thickness. The crude roughly cobbed fibre lumps were found suitable, after cleaning, etc., as raw material in the manufacture of asbestos in Messrs. Hancock & Co.'s factory at Newtown (Johannesburg).

5. *Northern Transvaal* (Potgietersrust District), Messina.—Some prospecting work was recently carried out on the farm *Doornkraal No.* 149 (formerly No. 1213), some 100 miles north-west of Potgietersrust, in another area of serpentine. The chrysotile here consisted of several cross-fibre seams of promising length and quality, but when the deposits were followed downwards, the seams were found to split up into a series of thin unpayable bands at a depth some 20-30 feet below the surface.

On the farm *Maryland No.* 277, situated six miles due north of *Messina,* on the right bank of the Limpopo River, is an outcrop of serpentine carrying chrysotile, but not of economic grade.

B.—*Chrysotile in the Dolomite Series or in Carbonate Rocks of the Pretoria Series.*

In Chapter IV it was shown that the occurrences of chrysotile in dolomite are invariably associated with basic intrusive sills, which play most probably an indirect but necessary part in the origin of that fibre. Such conditions may be expected to recur wherever the dolomite was invaded by basic igneous rocks; moreover, the mode of origin suggests that the parent rock might be any carbonate formation carrying magnesia, and not necessarily only the Dolomite Series of the Transvaal System. Actually chrysotile deposits with these associations have been recorded at many places more or less all over the Dolomite Series in the Transvaal, but also along certain horizons, where magnesian carbonate rocks lie in the Pretoria Series.

SECTION ACROSS THE CHRYSOTILE HORIZON NEAR GRASKOP (PILGRIMS REST DISTRICT).

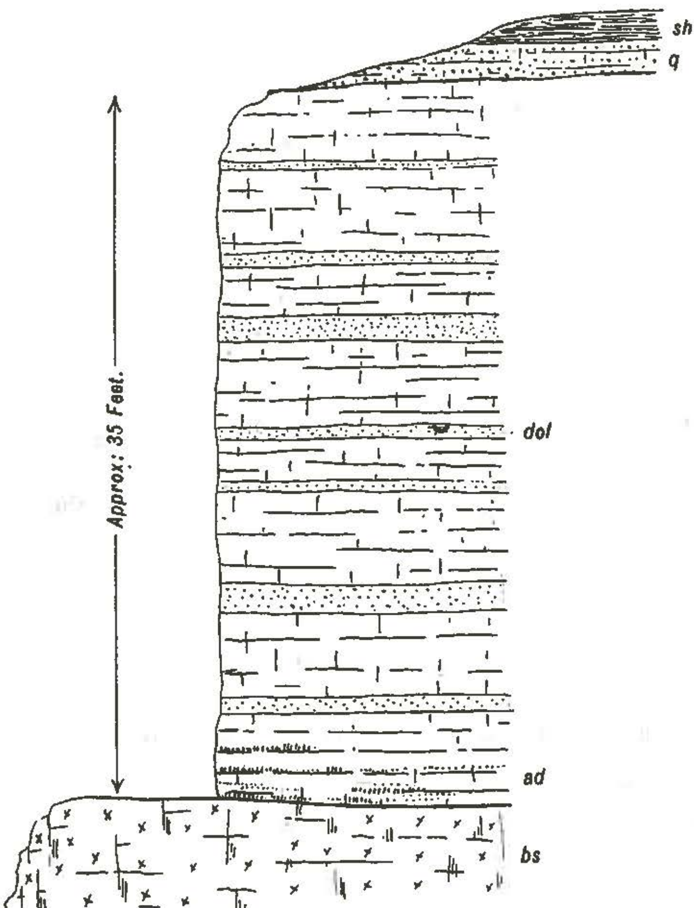


Fig. 41.

bs basic sill; *ad* = altered serpentinized dolomite; *dol* = dolomite with chert; *q* = Blyde River quartzite; *sh* = lower shale group.

1. *Elandshoek, Graskop, and Kaspersnek.*—Passing northwards from the type occurrence of chrysotile in dolomite, e.g. the Diepgezet form of deposit described in Chapter IV, a similar fibre deposit is found on *Elandshoek No.* 139 on the north side of the Delagoa Line.

Further north, in the Pilgrims Rest District, is an instructive chrysotile deposit near *Graskop;* it lies on the south side of the main road leading from Graskop Station to Pilgrims Rest, some 2½ miles from the former, and about 150 yards from the road, at the bottom of a short but very well marked krantz built of dolomite and chert, over which there is a little waterfall. A few feet above the top of this fall is an outcrop of the Blyde River quartzite (overlain by the lower bluish grey shale group of the Dolomite Series), while at the bottom of the krantz—which is some 35 feet high—there is an almost level shelf marking the upper selvedge-contact plane of the basic sill on which the krantz rests. (See Fig. 41.)

The seams of chrysotile are of the usual cross-fibre type, inter-bedded in pale greenish altered (serpentinized) dolomite, and spaced over the lowermost 2 or 3 feet of the dolomite, with a very low westerly dip, along which prospecting operations were carried on. There are several sub-parallel seams, the lowest of which lies almost directly on the top of the basic sill, the wider seams being round ½ to ¾ inch in thickness; the fibre quality is good, but the amount available shows a rapid decline in direction of the dip.

In the *Kaspersnek* area, some 20 miles north of Pilgrims Rest on the farm *Normandale* (which adjoins Kaspersnek No. 1183 on the south) chrysolite seams are found in altered dolomite under geological conditions and at an horizon corresponding almost exactly to those on Diepgezet east of Carolina. (See Fig. 42.)

Underlying the basal shales of the Pretoria Series comes the Rooihoogte Quartzite, which rests on some 4 feet of dolomite, including some chert. The locality is near the head of a densely wooded kloof, round which runs a vertical krantz due to a basic doleritic sill; the dip of the country is low and regularly to the west. In the lowermost beds of the dolomite (see Fig. 42) that rests directly upon the fine-grained selvedge at the upper contact of the sill the formation is altered in the usual manner and shows several parallel seams of cross-fibre chrysolite of fair quality; the thickest seam observed was almost ¾ of an inch, but more usually the width is from ⅛ to ⅓ inch; on the whole, the display of fibre is disappointing.

2. *Pietersburg Asbestos Fields.*—The presence of chrysotile seams in altered dolomite, similarly associated with basic intrusions became known over 10 years ago, when such an occurrence was discovered on the farm *Staanplaats No.* 565, some 2 miles south-east of Chuniespoort. More recent search over the easterly extension of the Dolomite Series has yielded further occurrences on the farms *Steenrots No.* 557, *Gramdoel No.* 481, *Driekop No.* 637, and *Onverwacht No.* 489; these farms lie (see Plate XXXVI) east of the M'Phatlele's River in the strip of dolomite that intervenes between the Black Reef Series on the north

and the base of the Lower Ironstone Band on the south, and it is possible that still further to the east additional occurrences may be found, subject to the condition that the sills also continue in that direction. Chrysotile deposits have also been reported from the farm *Honingkop No.* 605, through which passes the Wonderkop Fault. (See Plate XXXVI.)

3. *Pretoria District.*—West-south-west of the Capital further occurrences of chrysotile, also in the Dolomite Series, are found e.g. on the farm *Roodekrans No.* 203, some 16 miles from Pretoria.

SECTION ACROSS THE CHRYSOTILE HORIZON NEAR KASPERS NEK.

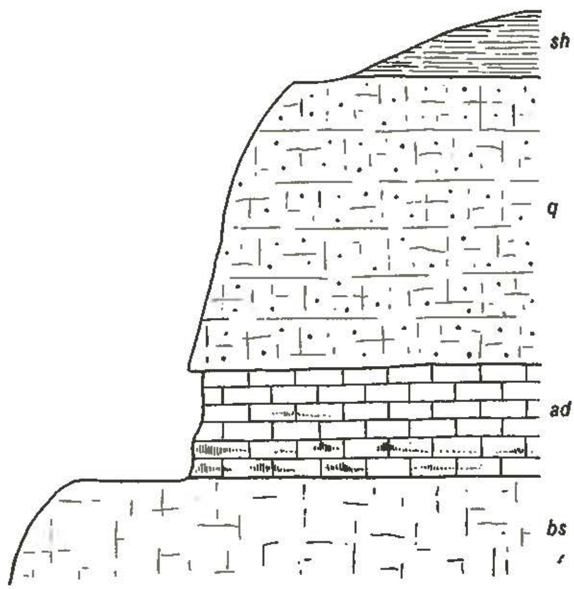


Fig. 42.

bs = basic sill; *ad* = Altered Dolomite with chrysotile; *q* = Rooihoogte Quartzite; *sh* = shales (Pretoria Series).

4. *Carbonate Rocks in the Pretoria Series* carry chrysotile seams near the old Lead Mine on *Edendale,** some 14 miles north-east of Pretoria. Here lies a narrow band of pale greenish compact carbonate formation directly above, or in the uppermost beds of the Magaliesberg Quartzite; this is the same rock which was at one time quarried for ornamental stone south of the Premier Diamond Mine. The chrysotile deposits near *Dullstroom* may probably also be classed with this mode of occurrence.

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* Now *Nooitgedacht No.* 458. See Geological Survey Sheep No. 1, (New Series).

C.—*Amosite.*

Since amosite is restricted to banded ironstone and appears to have originated in the Lydenburg and Pietersburg Fields, as a result of metamorphism to which the ironstones were subjected, the same fibre variety is liable to be found also in other ironstones than those of the Transvaal System, if the condition of their metamorphism is also satisfied.

1. *Marico District.*—On the farm *Rhenosterfontein No.* 50, 12 miles south-south-east of Zeerust, are found cross-fibre seams of an asbestos (probably amosite) interbedded in brownish shale associated with chert and cherty quartzite, altered by contact-metamorphism. Near the centre of the area a cutting showed several seams of fibre up to 1½ inches thick. So far further prospecting has not led to economic developments.**

2. *North-west of Warmbaths* are minor occurrences of amosite in the banded ironstones, not so far of any commercial importance.

3. *Messina.*—Several occurrences of amosite have been found within the Botanical Reserve, situated some 38 miles west of Messina, e.g. round the south-eastern corner beacon of *Dunsappie No.* 732, one of the nine farms which make up the Reserve. All the fibre so far discovered is a very delicate pinkish slip fibre amosite in dark ironstone, some of it several inches long. This deposit is not promising, but it is interesting to find such fibre in an ironstone that must be assigned to the Swaziland System and suggests an origin due to the metamorphism induced by the intrusive Older Granite of that area.

D.—*Anthophyllite.*

The only occurrence of this type of fibre found under commercial conditions within the Union is that of the farm *Korea* * *No.* 663 in the Zoutpansberg District, some 44 miles in a direct line due west of Lilliput Siding on the Messina Line north of the Zoutpansberg; this farm is situated some 117 miles almost due north of Pietersburg and lies 50 miles by road to the west of Waterpoort Siding as the nearest railhead, in nearly level bush-country with a low rainfall—some 2,400 feet above sea level. Some years ago the New Gloria Asbestos Company carried on prospecting and developing operations on these deposits and used the fibre in the preparation of boiler lagging; these operations have since been suspended. The name ". asbetic " has been applied to this fibre variety.

In the prevalent granite-gneiss formation of the surrounding area are certain massive igneous rocks rich in magnesia, which have locally

** The writer is indebted to the late P. A. Wagner for this information.

* (Also spelt " Corea " and known formerly as No. 1304.

developed a fibrous structure under the influence of changes in the zone of weathering; hydration and carbonation are the main processes involved, so the formation of asbestic would seem to depend largely upon proximity to the present surface. This view is supported by the constant association in the many quarries, trenches, and prospecting pits of highly decomposed rocks with abundant secondary calcareous matter, often distributed in a network of irregular veins or in films coating kernels or nests of less altered magnesian rocks—analogous to the distribution of magnesite in olivine-bearing formations, originating under dry conditions in the zone of weathering. It is possible to collect a series of transitional stages, starting with an almost massive magnesian rock, and passing through progressive degrees of fibrous structure to rocks rich in, or composed wholly of, asbestic. Persistence of anthophyllite to any great depth is, therefore, doubtful.

The deposits lie in the south-western corner of the farm, where they cover several acres, but in a vertical direction most of the workings —of which none exceeded 30 feet in depth—show at the bottom a formation not yet sufficiently fibrous to be described as "asbestic"; the "critical" depth may probably be taken as 20 to 25 feet at the maximum.

The identity of this fibre as anthophyllite is based on its optical properties and chemical composition: an analysis is given in Chapter I. The fibrous structure is not so fine, nor the orientation of the fibres so perfect, as in the case, e.g. of chrysotile; the material has a poor tensile strength and is therefore not adapted for textile purposes, while the extent of the deposit is not known in sufficient detail to furnish a reliable estimate of the available resources.

Appendix.

The Chrysotile Deposits on Havelock's Concession in Northern Swaziland.

Though not falling into the Union, the recent discoveries of chrysotile deposits in the extreme north-westerly portion of Swaziland are included in these pages, both on account of their very close proximity to the Transvaal border, and on their association with a geological structure that stretches from Barberton south-eastwards into Swaziland.

Recent prospecting operations on Havelock's Concession have proved the existence of promising deposits of chrysotile within that area, about one mile in a direct line due east of the Transvaal border, and 12 miles south-south-east in a direct line from Barberton: these developments are commonly referred to as the "Havelock Mine." * They lie in very well watered country of tremendous relief, belonging to Moodies Series (Swaziland System) in which the thick resistant quartzites determine very prominent high ridges, separated by deep complex valleys defined by a regular network of perennial streams. (Plate XXXII.) One of the most conspicuous ridges runs along the Emlembe Quartzite and culminates in Emlembe Mountain, the highest point in the whole of the Barberton Mountain Land and some 6,030 feet above sea level; deep down in the floor of a little side valley is the Havelock Mine, over 2,000 feet below the giant Emlembe. The approach to this somewhat inaccesible spot is through some of the wildest scenery to be found anywhere in the Union or Swaziland; at present there is no route for the wheel transport that leads right to the mine. One mode of approach and the more amenable is along the main road from Hectorspruit via Jeppes Concession across the Lomati River to Piggs Peak Police Station.† This point may also be reached from Carolina via Oshoek and Forbes Reef, whence the route descends some 2,500 feet to the Komati River (Pont Ferry) and continues northwards up to Piggs Peak. In either case the last stage has to be taken along the old Piggs Peak-Barberton bridle path to a piece of level ground known as the "Station" (close to the old Devils Reef Gold Mine): this point is some 4-5 miles west-north-west from the Piggs Peak Police post and serves as a provisional delivery point for mine material, etc. There is also a direct route from Barberton across the mountains, via the Devils Bridge.

From the "Station" the Havelock Mine is distant about 3 miles south-west by a path that first descends into the deep valley of the Umkomazaana, then crosses that stream and rises to the divide between that stream and the adjoining river basin: the mine workings extend from the watershed south-westwards over the floor of a little stream known as the "Tutuz."

The Havelock Mine consists of a block of 100 claims that were prospected during 1928 and 1929: at the end of the latter year they were acquired by Messrs. Turner and Newall, so that the question of accessibility will doubtless be effectively dealt with in the near future. The above claims are laid out as a rectangular block approximately 5,000 by 1,200 feet, the long side of the area running more or less north and south across the Tutuz River which divides the mine into a Western Section (on the right side of the Tutuz) and an Eastern Section (on the left bank of the Tutuz) extending in the direction of the "Station" as

* Its situation on the map accompanying Geological Survey Memoir No. 9 is ¾-inch measured 16 degrees east of due south from the north-easterly beacon of Josefsdal No. 35.

† The routes, etc., are shown on the map accompanying Geological Survey Memoir No. 9 (Barberton District).

Composite Section across the Chrysotile Horizon at the Havelock Mine, N. Swaziland.

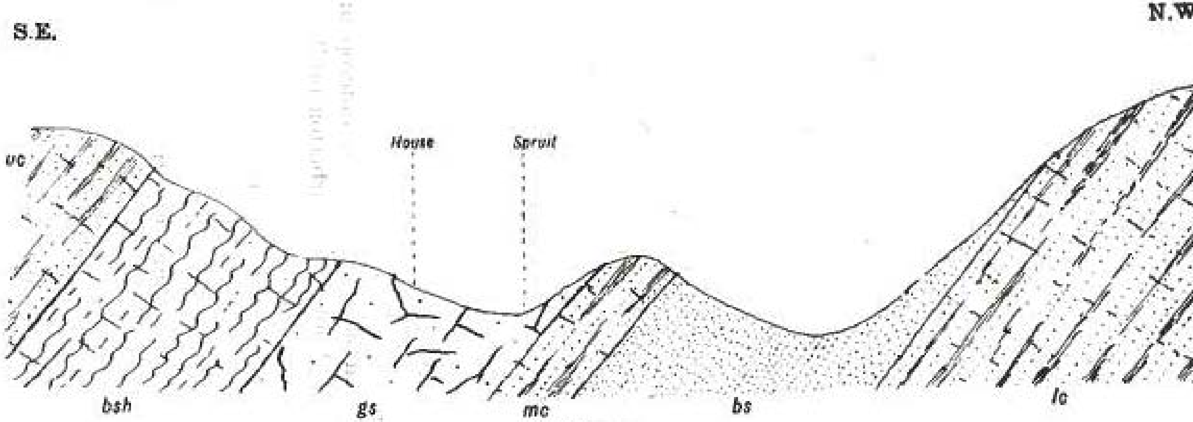

Fig. 43.

uc = Upper Chert Band; *bsh* = black hard barren serpentine (?); *gs* = soft green serpentine, 150' approx. wide, with chrysotile seams; *mc* = middle chert band; *bs* = barren serpentine; *lc* = lower chert band.

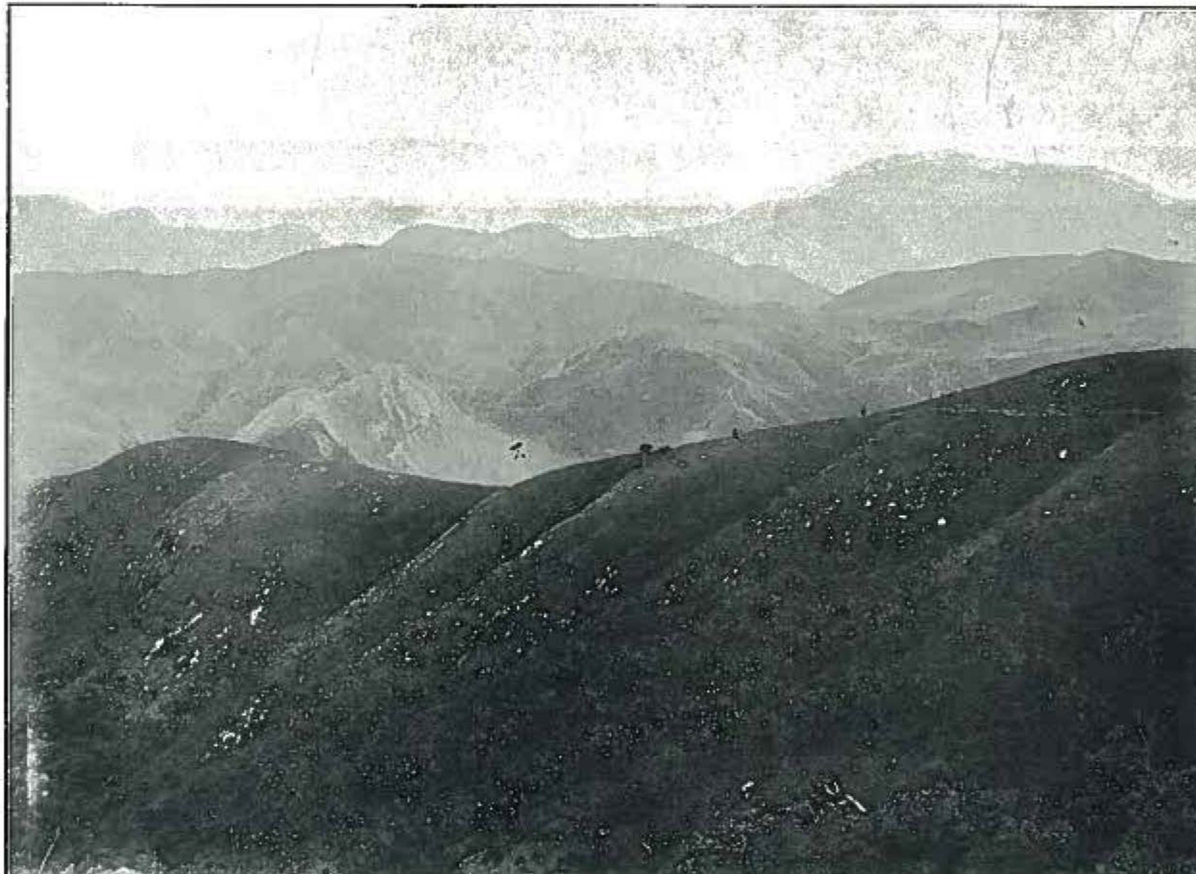

PLATE XXXII.—*View across the Barberton Mountain Land* (Moodies Series) from near the Havelock Asbestos Mine. In the far distance on the right the Emlembe Range.

far as the divide referred to above. Plate XXXIII gives a general view looking from this divide in a south-westerly direction across the Tutuz River, the Eastern Section being in the foreground and the Western Section in the background.

Owing to the excessive rainfall, the formations occurring at the mine are for the most part more or less highly decomposed, so that outcrops are rare and their rocks not very fresh. At the north-eastern end of the mine near the watershed there are definite indications of serpentine with highly pitted dark surfaces of weathering; some of these rocks are crowded with small rounded white spots of magnesite. From this point towards the bottom of the valley and beyond—over the Western Section—the contours are smooth and almost devoid of outcrops, with the exception of three bands of resistant cherty rocks which stand out as more or less continuous ridges. These features are built of very hard siliceous, in part ferruginous, rocks, on the whole not unlike the "Calico" type of rock, but low in iron. Underground work indicates the succession represented in Figure 43, taken across the Eastern Section, over which the Lower, Middle and Upper Chert bands are all three clearly traceable. The dip is regularly to the south-east round 50 to 55 degrees; in the Western Section, however, the middle chert is not seen and probably dies out gradually in passing across the Eastern Section. Between the Lower and Middle Chert (see Fig. 43), is a belt of a hard dark bluish grey formation without fibre (barren serpentine?), while between the middle and upper chert band a somewhat similar rock occurs, without fibre in it, and locally referred to as "Barren Serpentine"; this is underlain by the asbestos-bearing formation—a soft greenish, "granular"-looking serpentine carrying the chrysotile seams. (See Fig. 43.)

Serpentinous formations form a good outcrop at the "Station" referred to (close to the Piggs Peak-Barberton bridle path) whence they probably strike down into the valley of the Umkomazaana River, towards and through the Havelock Mine, to continue further on into Josefsdal; it would appear therefore that the basic intrusions, which subsequently passed into serpentine, occupy a definite horizon in Moodies Series, traceable for several miles along the strike and associated with the equally definite and persistent bands, described above as cherts.

The deposits by the middle of 1930 had been opened up along the asbestos formation by some 6 drives, now up to about 1,000 feet long; some 4,000 feet of continuity along the strike has also been proved for the fibre carrier. At intervals of about 100 feet along the drives are a series of cross cuts in both directions: these indicate the persistence, through some 150 to 170 feet in a horizontal direction, of the fibre-bearing serpentine, until it meets the footwall or hanging wall of barren serpentine. In these workings the barren formation is a very fine-grained rock with a kind of coarsely schistose structure, and more or less highly altered, so that its exact nature is doubtful.

The fibre carrier is a soft green massive serpentine having a horizontal width of some 150 feet. Within it the cross fibre seams of chrysotile are disposed anyhow, more like a stockwork than a lode—some being inclined approximately with the dip, others across it at all sorts of inclinations. At the mouth of No. 2 West Adit a very fine display of fibre was observed, some 6 to 9 seams being counted, several of which as much as 1½ inches thick; fibre continuity is maintained with fluctuating display right to the face of the drive (now some 1,000 feet long). The quality of the fibre is very good.

It is hardly necessary to point out that it is difficult at the present relatively early stage in the development of this interesting deposit to gauge both the correct percentage of fibre to rock and the proportion of textile chrysotile to be expected when the mine is fully developed and producing steadily.

The exceptional width of the fibre-bearing body and the high grade of the chrysotile, together with the present nature of the seam display, are promising factors in this new occurrence, the future developments of which will be watched with much interest.

The exact nature of the barren serpentine and its relationship to the fibre-carrier are not certain, but the geological associations are not unlike those observed, e.g. in some of the chrysotile deposits in the Komati River valley, where one finds alternations of hard dark barren and soft greenish chrysotile-bearing serpentines; at the Havelock Mine the former may likewise prove in the end to represent a serpentinous rock derived from an essentially pyroxenic intrusion, the latter probably originating as a true olivine-bearing rock, chemically well adapted to the formation of chrysotile.

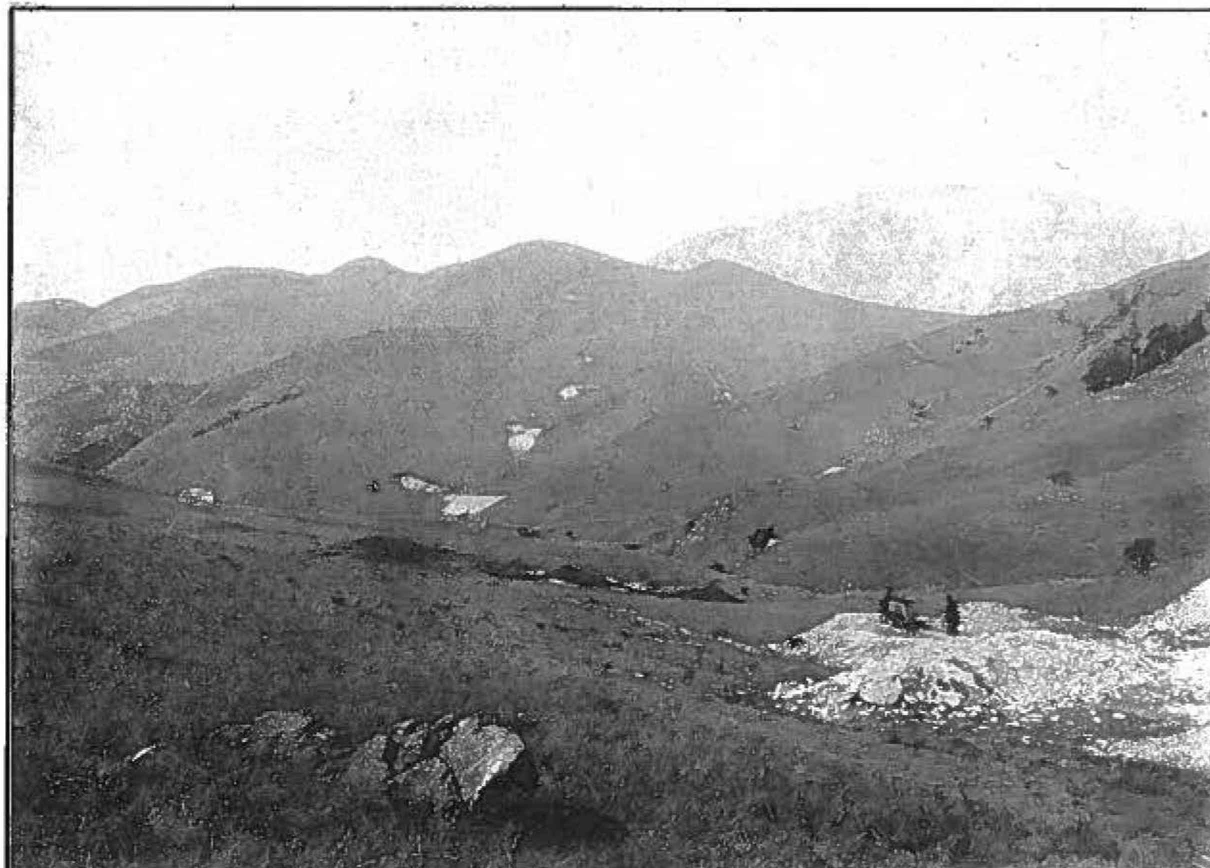

PLATE XXXIII.—*General View over the Havelock Asbestos Mine,* N. Swaziland; chrysotile workings in serpentine associated with Moodies Series; in the far distance the Emlembe Range of the Barberton Mountain Land.

Chapter VIII.

Asbestos in Natal.

Since the publication of the original edition of this volume there have been no important developments in the asbestos resources of the Natal Province, which is known to have occurrences both of chrysotile and tremolite in Zululand. The recent completion by Dr. A. L. du Toit of the survey of the N'Kandhla region has furnished additional information, referred to below. Neither amosite nor crocidolite have been recorded from this province, as far as the writer is aware.

1. *Chrysotile.*

An important occurence 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 Zuluanl 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 parts 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 intrustions 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 1,500 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. 44, 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 in 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 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

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

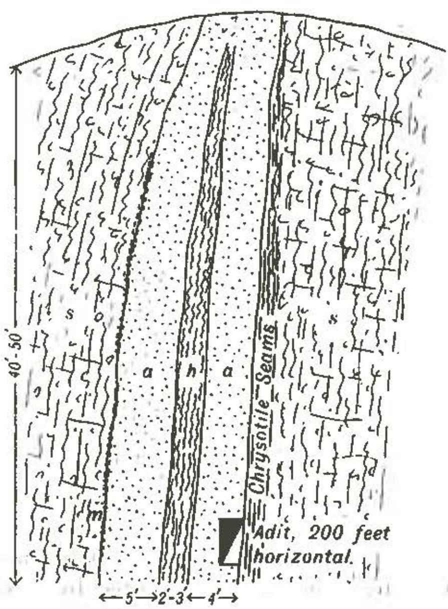

Fig. 44.

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

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. 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 prerequisite condition for the persistence of the former.

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 £1,697. The asbestos was of inferior quality, but found a market for the manufacture of cement slate and for steam-lagging purposes.†

On *Tugela Randt*, 12 miles west of the Middle Drift and 6 miles north of Kranskop are several occurrences of cross fibre chrysotile in serpentine, which were developed at one time by the Buffalo Asbestos Company and Natal Asbestos, Limited; here (as at Sitilo) the fibre deposits are closely associated with narrow intrusions of aplite, on both sides of which lie the chrysotile seams generally ranging between ⅛ and ¾ inch. Du Toit emphasizes the mode of occurrence alongside aplite or microgranite, and concludes that the fibre "owes its genesis to these acid intrusions" (Biblio. No. 74).

Other occurrences have been recorded from *Madegela*, north-west of Sitilo, *Ezingulweni*, north-east of Sitilo, in the Fort Yolland area, etc.

2. *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 and including talcose rocks.

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. The 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.

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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.

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.

Both the talcose rock and the tremolite were formerly recovered and worked up at Dundee into asbestos stove bricks, so-called Buffalo jointing for steam or acid jointing, boiler lagging, steam packing, etc.

A little nearer to Elandskraal an open cast working—made by the African Asbestos Company, showed the same variety of pale greenish talcose rocks, traversed by an irregular seam of similar asbestos up to 8 inches wide, and splitting up into several narrow seams.

Chapter IX.

THE GENETIC PROBLEM.

General Remarks.

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 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 *cross-fibre seams* predominates conspicuously over slip and mass fibre in the case of chrysotile, crocidolite, and amosite; in spite of the very large number of instances examined, not a single case among commercial deposits of the above fibre varieties, found within the Union, has come to the writer's notice of a definitely slip or mass fibre type; only the minor occurrences of tremolite (Natal) and anthophyllite (Korea) show a difference in this respect. Such experience probably depends not only on factors controlling crystalline growth, but also on the geological relationships to surrounding rocks, etc.

By the *Law of Association* is meant the restriction of one fibre variety to the same class of country rock, i.e. chrysotile being found only in serpentinous rocks—whether consolidating directly from igneous fusion (Kaapsche Hoop deposits, Canada, etc.) or originating from the alteration of dolomite rocks (Carolina deposits)—and hornblende asbestos being rigidly confined to banded ironstones (Cape Belt, Lydenburg–Pietersburg Fields).

In this way the genetic problem of asbestos is complex, in that it is partly crystallographic, partly geological; the essential conditions controlling the fibrous growth are probably more or less similar for different varieties of asbestos, but those determining the distribution of each variety in a distinctive formation are different for chrysotile on the one hand and hornblende asbestos (amosite and crocidolite) on the other.

It is therefore convenient to consider the two main elements in the genetic problem separately, though they are obviously intimately bound up with one another.

1. *The Fibrous Structure.*

Though many attempts have been made in finding an explanation for the remarkably pronounced fibrous structure of asbestos, it cannot be said that a complete solution of this difficult problem has yet been reached such as to meet with general acceptance, neither has the writer been able to find during his study of the different asbestos deposits of the Union any definite sign-posts pointing to a solution. It is natural that the problem has been associated almost exclusively with the mode of occurrence of chrysotile, owing to the prominent position which the Canadian deposits have acquired, while the corresponding modes of occurrence of amosite and crocidolite have—with one notable exception* —been more or less neglected from this aspect.

The problem of the genesis of asbestiform structure has been illuminated by some interesting results obtained by *Prof. S. Taber,*† depending upon the use of the experimental method. Owing to the difficulty of reproducing natural conditions, this method can have only a limited application, and its lesson must be extended to natural cases with caution.

Professor *Taber* describes an experiment where a porous cell is partially immersed in a saturated solution of copper sulphate, the latter gradually ascending through minutes 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 copper 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

* *M. A. Peacock.* "The Nature and Origin of the Amphibole Asbestos of South Africa." Amer. Mineralogist, 13, 1928, p. 283.

† *S. Taber.* "The Genesis of Asbestos and Asbestiform Minerals." *Bull. Amer. Inst. Min. Eng.* 1916, *pp.* 1973–1978, and "The Growth of Crystals under External Pressure." *Amer. Jl. Sc.*, 1916, *pp.* 532–556.

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."

The justification of extending results obtained in the laboratory to natural occurrences has been questioned,* attention being called to the nature of the wall rock as an important factor, and to the possibility of the vein spaces representing shrinkage cavities. In his very fine study of the South African amphibole deposits—to which reference has been made above—Peacock† reaches the conclusion that—

> "Taber's general theory of cross-fibre vein formation involving deposition through the walls of the vein from solutions in the wall-rock, and forcible displacement of the walls by growing fibre, is shown to be inapplicable to the South African asbestos"; . . .

further, that—

> "The cross-fibre structure of the asbestos seams is related to the little-understood but undeniable control which bounding surfaces commonly exert on the orientation of the structure of fibrous minerals crystallizing from solutions or gels."

The origin of chrysotile has been discussed, amongst others, by *R. P. D. Graham,**) with reference to the Canadian occurrences, where it is concluded that siliceous magmatic 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).

In a recent‡ contribution, Prof. *Taber* summarizes the many theories of the origin of the fibrous structure and discusses them under the following three heads:—

> "(1) They were deposited in open fissures; (2) They were formed at the expense of the walls by recrystallization *in situ* or by replacement; (3) The veins, in growing, displaced the wall rock."

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* *Bull. Amer. Inst. in. Eng.*, 1917 and *Sc. Progress*, January, 1918.

† *M. A. Peacock*, loc. cit. p. 283.

* (*R. P. D. Graham.*)—"Origin of Massive Serpentine and Chrysotile Asbestos, Black Lake, Thetford Area, Quebec." Econ. Geol. 12, 1917, pp. 154–202.

‡ *S. Taber.*—"The Origin of Veins of Fibrous Minerals." Econ. Geol. 19, 1924, pp. 475–486.

In the course of his discussion the author summarizes his own standpoint as follows:—

> "The peculiar structure of cross-fibre veins has been attributed by me to the mechanical limitation of crystal growth through addition of new material in only one direction, the material for growth being supplied through small, closely spaced openings in the walls, which have been pushed apart by the growing veins. This theory is applicable to all kinds of cross-fibre veins; in veins of the asbestiform minerals the fibrous structure is accentuated by a normal prismatic habit, and cleavage. . . ."

The view that asbestos seams were deposited in open fissures through the agency of circulating solutions is hardly any longer advocated seriously, though it attracted early attention and appeared a simple conception. The emplacement of large masses of ultrabasic intrusions and their final consolidation from igneous fusion, ultimate cooling, contraction, later serpentinization, or subsequent movement, render volume changes very probable, so that shrinkage spaces are conceivable. The possibility of the formation of open spaces offers many difficulties from a mechanical point of view. Thus in Southern Quebec** the chrysotile seams 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 thus, but an exclusive or even predominant mode of origin of this kind would be almost impossible to conceive. On the theory of open spaces, the great 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 (often very wide in case of amosite) in sedimentary rocks—a condition altogether too artificial.

The writer is inclined to look upon the formation of cross-fibre seams as the result—not of the introduction of material through circulating solution—but rather of the rearrangement of material already available in the rock encasing the seams, without any addition excepting most probably water in the case of chrysotile, or of magnesia in case of some of the amphibole asbestos. The fundamental distinction between olivine-asbestos and amphibole-asbestos as regards their restriction—in the former case to serpentine (igneous) and in the latter to banded iron-

** J. *A. Dresser*.—"Preliminary Report on the Serpentine and Associated Rocks of Southern Quebec." Geol. Survey of Canada, Memoir No. 22, 1913.

stones (sedimentary)—makes it highly probable that the transformation of these country rocks into asbestos would not follow along strictly parallel lines.

When considering chrysotile-asbestos, it can hardly be questioned, that the change from, e.g. an olivine-peridotite into serpentine (which always carries a high percentage of water of constitution) is associated with an increase in volume, a result likely to give rise to strains; these do not necessarily lead to the establishment of open fissures, nor are they even likely to do so, but they probably tend to produce a system of potential fractures. In case of a larger mass of serpentinized olivine rock, this system would show no regular disposition and seams of asbestos, subsequently developed along such potential fractures would assume the characters of an irregular network of fibre veins (stockwork type of occurrence, e.g. the Havelock Mine). Where, on the other hand, there is some structural feature associated with the serpentine, e.g. a definite contact with some foreign formation, it is conceivable that the potential fractures may be more regular, i.e. disposed more or less in the same sense as the structural feature: the later development, of fibre seams would accordingly be also more regular, thus leading to a fibre channel (lode type of occurrence) rather than to a stockwork.

The prominent structural contrast between thoroughly oriented chrysotile fibres and its surrounding apparently massive serpentine becomes less striking when the latter is examined in thin sections, which also reveal a fibrous structure but no orientation. Since chrysotile asbestos is essentially nothing more than very finely fibrous (oriented) serpentine, the fact that this rock already has a certain fibrous structure, though no cross fibre asbestos seams are as yet developed in it, suggests that the massive serpentine is a kind of mass-fibre chrysotile, only differing from true asbestos in structural degree. But the potential fractures are probably bound up with unequal strain, and this may affect orientation, so that molecular rearrangement of serpentinous matter (or the growth of already fibrous serpentine) tends to follow the line 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, would become elongated, while those lying more or less across this direction will have their solubility increased, so as to be redeposited along the direction of ultimate fibrous structure. The last mentioned effect presumes the validity of Riecke's principle as applied to asbestos fibre growth, but there seems no valid reason why this principle should not apply in this case, when it appears to do so in the growth of other minerals with fibrous habit. Continued long enough, the above actions would finally lead to cross fibre seams, yet there is clearly a limit to this, which seems to depend upon adjustments determined by increase of volume in relation to the weight of superincumbent material, so that long fibre seams might be expected to be gradually replaced in depth by shorter fibre seams. This experience is often actually the case, as far as the writer's observations in the asbestos deposits of the Union go (see below).

In considering the fibrous structure of the amphibole-asbestos varieties—which are restricted to sediments—it will be shown later on that there are good grounds in support of the line of thought developed above, viz., that the formation of asbestos does not depend on solutions circulating along the open spaces, but essentially on a rearrangement of material *in situ*, i.e., supplied by the sediments themselves. In particular, there are definite indications that both amosite and crocidolite originated as mass fibre, so that some form of antecedent mass-fibre condition would seem to exist in the initial stages of asbestos genesis for all three fibre varieties. Peacock's (Bibl. No. 58, p. 283) conclusion on the process of fibre growth has been quoted above.

2. *The Law of Association.*

(*a*) *Chrysotile.*

As already explained above the origin of asbestos contains the Law of Association as the second leading factor, meaning, in short, the restriction of a given fibre variety to a certain type of formation, i.e. in the case of chrysotile its occurrence in serpentine. One may allow this statement to cover also those fibre deposits that have been described from the dolomite formation (Carolina), since the seams actually lie in serpentinized carbonate rocks, and not in true dolomite; hence the existence of serpentine is an indispensable prerequisite condition for the occurrence of chrysotile. The form which the law takes for such fibre follows naturally from the fact, that this mineral is nothing more than fibrous serpentine, i.e. fibrous hydrated olivine, in turn derived from an original basic rock rich in magnesia, e.g. olivine peridotite. Thus the phylogeny of olivine-asbestos lies along the following probably successive stages :—Peridotite-Serpentine-Chrysotile. They involve the two transformations :—Peridotite into Serpentine, and Serpentine into Chrysotile.

Serpentization.—Much has been written on the problem of the serpentization of peridotite and allied magnesian igneous rocks, and it may be recalled that the original view of this process as essentially one of weathering is now no longer accepted as widely as formerly; *Weinschenk* may be mentioned as an example of a prominent earlier advocate in emphasizing * a derivation of serpentine through changes that do not belong characteristically to the zone of weathering, but

* *E. Weinschenk.*—" Allgemeine Gesteinskunde " Second Edition, 1906, Chapter VIII ; and " Ueber die Peridotite und die aus ihnen hervorgegangenen Serpentingesteine." Abh. K. Bayer. Akad. Wiss. 18, 1894. See also *W. N. Benson*, " The Origin of Serpentine." Amer. Jl. Sc. 46, 1918.

depend on post-volcanic processes. It is beyond the scope of these pages to include a discussion of the problem of serpentization, specially in view of the recent detailed review of the subject given by Dr. Keep in his admirable memoir,† based on an exhaustive study of the important Shabani chrysotile deposits, to which the reader's attention is specially drawn. Dr. Keep comes to the following conclusion (loc. cit. p. 82) :—

> " that the serpentinization of the ultra-basic rocks of the asbestos deposits at Shabani was due to the action of the magmatic waters accompanying the intrusion of the granite bathylith of the Lundi Native Reserve."

In the Union the most important chrysotile formation is the broad and extensive belt of serpentine north of Kaapsche Hoop, described in Chapter III. It is in contact along its northern and southern edges with the Crocodolie Poort and De Kaap Valley granites, the intrusive nature of which is very clearly established by the widespread and intense metamorphism of the sediments, that are in places very intimately associated with the serpentine. (Bibl. No. 28A, Chapter VI.) It seems quite possible that the serpentinization of the original olivine rocks—predominant in the western section of this belt—may also be due to the intrusion of the granite. Tempting as it is extend the scope of this cause also the formation of chrysotile seams, a detailed study of the Kaapsche Hoop fibre deposits and of many others within the Union, does not support such a mode of origin. (See below.)

The Question of Acid Intrusion.

In considering the second stage in the formation of chrysotile, i.e. the development of serpentine into cross fibre seams, it is natural to turn to the influence of igneous intrusions as an incentive; where the mode of occurrence (i.e. distribution and disposition) of the seams show a close relationship to that of the intrusion, the argument of direct genetic association would be strengthened in case of *acid*, in comparison with a basic intrusions, since the former are commonly richer in mineralizing agents than the latter: this would apply specially to water, which in some way seams to play a significant part in chrysotile genesis and would—in case of igneous intrusions—be magmatic and not meteoric.

Chapter VIII gives an account of the Natal chrysotile deposits, which are repeatedly found associated with granitic or related *acid* intrusions, e.g. at the Sitilo Mine (Fig. 44) so that in these cases the formation of such fibre seams, as a result of igneous intrusion of the above type, would appear justified.

On the other hand, in the great serpentine belt of the Jamestown Series in the Barberton District no indications were found either in the

† *F. E. Keep*.—" The Geology of the Shabani Mineral Belt, Belingwe District." Geol. Survey S. Rhodesia, Bull. No. 12, Salisbury, 1929, pp. 78–95.

extensive developments of the New Amianthus Mine or in the Munnik-Myburgh Mine, of the presence of any acid intrusion, nor does the distribution of the asbestos (which is found in the heart of the serpentine belt—Griffin and Munnik-Myburgh lines) show any relationship to the granite margins. Then again, the rich Amianthus Reef (Ribbon Line) strikes nearly north and south, i.e. more or less directly across the alignment of the serpentine belt. Furthermore, the fibre display reveals a very marked decline as the belt is traced to the east, and in spite of the fact that serpentine bands identically persist along their eastward strike and are associated with highly altered sediments in the same contact belt, one finds stretches of serpentine without any seams at all; where they do occur, their display is very feeble, and their distribution likewise not related to the line of contact.

The same experience of the want of acid intrusive also holds good for all the other chrysotile occurrences of the Transvaal Province described in the preceding chapters. Apart from the Carolina type of deposit—which is associated with dolomite metamorphosed by a basic sill and therefore obviously not concerned with any acid intrusive—all these additional occurrences show fibre-bearing serpentine masses not far from a granite; those specially impressed with the genetic functions of acid intrusion might point to these granites as supplying the required incentive of such intrusion. A mode of origin which connects these types of igneous rocks with the formation of chrysotile in a relationship of cause and effect must be admitted as pointing to deep-seated conditions, analogous to the sense in which, for example, the metamorphism of a slate by the intrusion of a mass of granite is deep-seated, and therefore naturally to be expected, and actually observed, to continue in depth. It is an undoubted fact, however, observed in the great majority of those chrysotile occurrences, that the deposits do not persist in depth and in several instances rapidly decrease—sometimes almost vanishing within a vertical distance of a few feet or a fewyards.

For these reasons the writer finds it impossible to resist the conclusion that a causal connection between *acid* intrusions and chrysotile formation does not hold good in any of this type of fibre deposit that have come under his notice—comparable to associations displayed in the Sitilo type of occurrence, for which a genetic significance possibly, or even probably, holds good.

This conclusion leads naturally to the consideration of the possible influence of *basic* intrusions.

The Question of Basic Intrusions.

In the Carolina type of deposit (Chapter IV) the seams are exclusively distributed (and disposed) with reference to an intrusive basic sill, which is directly overlain by altered (serpentinized) dolomite. The asbestos never lies in the sill itself, but is confined to a zone of altered dolomite up to some three or sometimes five feet wide above the margin of the sill; further away from the latter, where the dolomite is not altered, there is no fibre, while the seams are disposed with the bedding planes of the dolomite, becoming more numerous and more definite in proportion to the more pronounced alteration of the country rock. These features would seem to point conclusively to a metamorphic origin of the chrysotile due to a basic intrusion. It is very improbable, however, that the asbestos is a direct product of contact metamorphism. The first effect of the emplacement of the sill was the formation of metamorphic minerals, e.g. olivine—characteristic of carbonate rocks; for this change the necessary magnesia and silica exist in the dolomite. In this rock silica is not distributed throughout—like in a peridotite as silicates—but only along certain layers, generally trending with the bedding, so that the distribution of the fibre in interbedded seams readily follows. The second step is the change of the metamorphic magnesian silicates into serpentine which requires the addition of water and is accompanied by an increase of volume; the source of the water may have been magmatic or meteoric, probably the former as suggested by the tendency of the serpentine to persist in the direction of dip after the asbestos has more or less wholly given out. The conclusion, that the effect of the basic sill is limited to the formation of olivine, etc., and its subsequent serpentization, but does not cover the formation of chrysotile, is based on the following line of thought:—The intrusion of the sill and its metamorphic effects are in the nature of the case deep-seated, so that contact minerals should persist for as far as the sill does, and the same should hold good for the asbestos, if this be also regarded as directly due to the intrusion, i.e. the successive changes (emplacement of sill—production of metamorphic olivine—its serpentinization *and* formation of fibre) should be independent of the present surface. As a matter of repeated observation, there is a very marked tendency for the asbestos to die out comparatively rapidly, as the fibre channel is followed in the direction of dip, though serpentinized dolomite is maintained. This conclusive result applies in variable extent to all the Carolina deposits as well as to the similar minor occurrences referred to in Chapter VII. The formation of this type of chrysotile occurrence is therefore not believed to be the direct, but only indirect, result of the emplacement of a basic sill and its consequent metamorphism.

The genetic problem of the chrysotile type of deposit in dolomite is probably (1) analogous to that of the serpentine of Mountville, described by Merrill,* where a massive dolomite with siliceous layers contains veins and nodules of partly fibrous serpentine, derived from

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

diopside with considerable increase of volume, and (2) to that described by *Noble* and *Diller* from the Grand Cañon, Arizona.†

In the Algonkian succession of Asbestos Cañon is a sill of biabase with crystalline limestone 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.

The negative conclusion reached for the dolomitic type of chrysotile occurrences raises the question, what evidence the other deposits that are not found in dolomite afford from the point of view of basic intrusions.

The outstanding example of this type is the Ribbon Line of the New Amianthus Mine near Kaapsche Hoop (Chapter III), which was shown to follow the base of a group of sediments; the distribution of the seams—which is described above—keeps strictly to a structural plane that is formed sometimes by a quartzite, sometimes by what appears to correspond to the selvedge of a doleritic sill. Though the relationships are for the most part not clearly seen underground, and the basic sill is not well defined at the surface, the restriction of the fibre channel to a more or less constant horizon leaves the impression that a genetic connection between the former and a basic sill is possible, although a contact zone several yards wide is not easy to realize in case of a sill only a few feet or yards thick. In several other localities, i.e. along the Griffin Line, the Munnik–Myburgh Mine, Sterkspruit, Kalkkloof, and perhaps also at the Havelock Mine, the fibre channels ar found in a soft green serpentine along their contacts with a hard dark serpentinous rock, generally referred to as " barren " serpentine, since it is nearly always free from fibre. If one could prove that the dark serpentine originated as a later intrusion into the green serpentine, the antecedent condition of a basic sill would be satisfied. Such a view is, however, not satisfactory, since the so-called " barren " serpentine, though very commonly free from fibre, does occasionally itself carry chrysotile seams.

† *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.

In several other occurrences (Krugersdorp, Doornkraal, Kajaleri Kop, etc.), there is no suggestion whatever of the presence of a basic sill.

In the case of non-dolomitic serpentine the general conclusion therefore is that in several instances the field relationships appear to point to a *basic* intrusion as a genetic factor, though the evidence in favour of this is not very satisfactory. In other instances, there is no trace of any such intrusion.

Origin of Chrysotile in the Zone of Weathering.—A study of the distribution of the chrysotile occurrences in the Transvaal reveals some interesting features which suggest the question whether possibly the mode of fibre origin may—apart from igneous intrusion—not sometimes be dependent on changes falling within the zone of weathering and thus in some way connected with proximity to the present surface. These features are concerned with these two aspects (*a*) the *situation* of the deposits and (*b*) their *persistence in depth.*

(*a*) The most important Transvaal chrysotile occurrences are found in areas of very high precipitation, i.e. the New Amianthus Mine, directly below the edge of the Great Eastern Escarpment, the Havelock Mine at the eastern foot of the very high and prominent Emlembe Ridge, or the Kalkkloof Mine in the south-westerly extension of the Drakensberg, east of Carolina; all these areas are well known to be associated with high rainfall. The chrysotile occurrences found in regions of moderate or low precipitation show only a minor or poor display of fibre, e.g. Malelane, Doornkraal, Kajaleri Kop, Messina, etc. In following the serpentine belt, in which the Kaapsche Hoop Asbestos Fields lie, eastwards, one observes a general decline in the intensity of the fibre development, which is at its maximum at the foot of the Drakensberg, becomes less a few miles to the east—where the Munnik–Myburgh Mine is situated—becomes still less round Kaapmuiden, until it is feeble near the eastern end of the serpentine belt round about Malelane; this progressive decrease conforms more or less to a similar decrease in the precipitation from west to east. If the chrysotile deposits described in Chapters III, IV, and VII are arranged in a descending order of importance (display-intensity), the order will be fairly closely one of decreasing precipitation. The relationship is not quite so rigid in detail, as the above remarks imply, and it is not difficult to find one or other deposit that does not fall accurately into line (chemical unsuitability of some serpentine varieties), but, taking the distribution of the fibre localities as a whole, the parallelism is very striking, and in the writer's opinion, holds good closely enough to be hardly accidental. The above conclusion—whatever its rationale may be—is a matter of observation.

(*b*) Attention has already been called to the fact that the majority of the Transvaal chrysotile deposits, after showing almost invariably a more or less promising appearance at the surface, become sooner or later disappointing, when followed in depth. Here the term "depth" requires careful consideration. One mine may not be sufficiently developed to afford any definite indication of its economic persistence in depth, another shows fibre continuity down to a depth that assures a "life-expectation" to be counted in years, while other occurrences pass rapidly downwards into a non-payable condition within distances to be measured in yards. In almost every case one observes some measure of decline in the intensity of the display further underground, and the instances, where this condition is more or less rapidly established, form the majority of the observed deposits; the writer finds some difficulty in concluding that the frequent association of such a decline with regions of moderate or low rainfall is merely an accident, and has therefore tried to find some explanation.

With the possibility in mind that the change from serpentine into asbestos is accompanied with an increase in volume, the specific gravities were determined for a series of fibre samples taken from different occurrences, and compared with those of the corresponding serpentine in which each fibre deposit lies. The results* are given in Table No. 33; they show a specific gravity consistently higher for fibre than for serpentine, with one exception [determination (*g*)], which is accounted for by the fact that some iron-ore was mixed up with the fibre.

TABLE NO. 33.—*Specific Gravities of Chrysotile and Associated Serpentine.*

Locality.	*Chrysotile.*	*Serpentine.*
(*a*) New Amianthus Mine	2·452	2·524
(*b*) Munnik-Myburgh Mine	2·512	2·552
(*c*) Kalkkloof Mine	2·481	2·511
(*d*) Havelock Mine	2·537	2·573
(*e*) Sterkspruit	2·07	2·88
(*f*) North of Krugersdorp	2·39	2·57
(*g*) Althorpe Siding	2·66	2·59

The question of hydration was also examined from the point of view whether the change from serpentine into chrysotile might involve an addition of water; for this purpose the loss on ignition was determined for a series of fibre samples from various chrysotile occurrences, together with their associated serpentine, in the Government Chemical

* In view of the results obtained by R. P. D. Graham (referred to in Chapter I) both fibre and serpentine were boiled for a period of not less than two hours under identical conditions; this treatment was found necessary to secure a constant specific gravity. The writer is greatly indebted to Mr. F. C. Partridge, Mineralogist to the Geological Survey, for these determinations.

Laboratories, Johannesburg; two determinations [(*b*) and (*c*) in the accompanying Table No. 34] were made*) in the laboratory of the Geological Survey from different points in the Amianthus Mine. Dr. J. McCrae kindly supplied the following details :—

> " For the examination only the fibrous portion of the asbestos was used and in the case of the rock specimens all fibrous portions were excluded. Each sample was heated at 105° C to 110° C until of constant weight : the loss is recorded as moisture. The sample, after this thorough drying, was then placed in an electric muffle—furnace (temperature 900° to 1000° C) and heated for about an hour. It was established that further heating at this temperature gave rise to no further loss. The column headed " Loss on Ignition — " gives the actual loss calculated on the original weight used ; the column headed " Loss on Ignition : — in dried sample " is the loss sustained by the dried material. . . . ."

TABLE No. 34.—*Water of Constitution in Chrysotile, Compared with Associated Serpentine.*

Locality.	Asbestos or Serpentine.	Moisture.	Loss on Ignition.	
		Per cent.	Per cent.	Per cent. on dried sample.
(*a*) New Amianthus Mine..........	Asbestos	1·84	13·91	14·17 }
	Serpentine	1·00	13·58	13·72 }
(*b*) Amianthus Mine..............	Asbestos	3·96	13·97 }	—
	Serpentine	2·55	13·05 }	
(*c*) Amianthus Mine..............	Asbestos	3·96	13·97 }	—
	Serpentine	1·80	13·05 }	
(*d*) Munnik-Myburgh Mine.........	Asbestos	0·91	13·15	13·27
	Serpentine	0·79	13·55	13·61
(*e*) Kalkkloof Mine..............	Asbestos	1·19	13·62	13·79
	Serpentine	1·07	14·31	14·47
(*f*) Havelock Mine...............	Asbestos	0·90	13·20	13·32
	Serpentine	0·52	14·57	14·65
(*g*) Sterkspruit.................	Asbestos	1·60	12·74	12·95 }
	Serpentine	0·72	7·54	7·60 }
(*h*) North of Krugersdorp.........	Asbestos	1·85	13·05	13·30 }
	Serpentine	0·25	12·07	12·10 }
(*k*) Althorpe Siding..............	Asbestos	0·97	12·64	12·76 }
	Serpentine	0·68	11·50	11·58 }

The results given in Table No. 34 show that in all cases the fibre has a higher percentage of moisture than the serpentine in which it occurs: the same result holds good in the majority of cases also for the percentage of water of constitution, but not for all cases, so that the conclusion for greater hydration in respect of the fibre does not hold

*) The writer is indebted to Mr. C. C. Gardthausen, former Assistant Curator, Geological Survey, for these determinations.

good every time; it is considered that the available evidence is sufficient to show that the fibre seams occupy a volume greater than that of the serpentine from which they are derived, and that the passage from serpentine into fibre generally, even if not in all cases, involves the addition of water.

The nature of these changes, the special prominence of the fibre display in areas of high precipitation, the markedly reduced display in fibre deposits situated in regions of moderate or low rainfall, and lastly the general experience of a lack of economic persistence in depth (more marked in areas of low than of high precipitation) when taken together, suggest features more or less characteristic of the zone of weathering, as if the formation of chrysotile were somehow connected with the present surface. Where a transformation involves an increase in volume, it is reasonable to suppose that the increasing weight of superincumbent material must sooner or later set a limit to fibre formation. Hence the formation of chrysotile would not be continued indefinitely in depth, but be more prominent nearer the surface—as is actually observable. Hydration requires water and in the zone of weathering, it is much more likely to have been of meteoric than of magmatic origin. Such a process should lead to an irregular distribution of the seams, and this can be observed in several instances. Where, in other cases, an occurrence of fibre has more the characters of a lode, there is the possibility that a definite structural element, e.g. contact between two different formations, may represent a more or less effective water parting, with the result that conditions of fibre formation might be more favourable along such planes than elsewhere. The views here developed imply that the origin of chrysotile is not necessarily always a deep-seated phenomenon, but perhaps one of comparatively recent date, in the sense that the derivation of magnesite from ultrabasic rocks is also not a deep-seated change, with the natural difference that the latter case is one of carbonation under relatively dry climatic conditions. It is interesting to note how in the great serpentine belt of the Jamestown Series, the intensity display of magnesite varies in a manner opposite to that of asbestos, i.e. in going from the richly watered Drakensberg end of the serpentine (with its strong asbestos development) towards the eastern portions with only a moderate or low rainfall, chrysotile deposits become much less prominent, while magnesite is almost unknown at the New Amianthus Mine, but very much in evidence round Kaapmuiden and further to the east (Malelane). Like chrysotile, magnesite does not "go down" indefinitely. Also, the constant association of abundant stichtite (a hydrated oxy-carbonate mineral) with chrysotile, which is a very marked feature at the surface in the upper levels of the New Amianthus Mine, no longer holds good for the lower levels, until in the deepest workings stichtite becomes exceptional.

It is realized that the above views, in which the possibility is discussed of the Law of Association being genetically involved with changes characteristic of the Zone of Weathering, will probably appear novel and startling to those who look upon the origin of chrysotile as conditioned by acid intrusions. The writer has, however, been much impressed with the aspects of situation and lack of persistence in depth, referred to above, and has found great difficulty in reconciling these with the generally accepted mode of origin that is based on igneous and therefore deep-seated causes, requiring independence of the zone of weathering and unlimited persistence in depth.

2. *Crocidolite and Amosite.*

Essential Identity of Origin.—Since (*a*) amosite as well as crocidolite are very closely related chemically as iron silicates carrying a high percentage of iron oxides (ferrous and ferric) together with some magnesia, and in case of crocidolite also soda as an essential constituent; (*b*) they are restricted exclusively to banded ironstones (sediments), which term also covers the ferruginous shales; (*c*) they show identical mode of occurrence as interbedded cross-fibre seams throughout their extensive distribution; (*d*) they occur in the same geological horizon—it must be concluded that they have a community of origin in all essential respects.

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.

Similarity in Composition of Amphibole Asbestos and Country Rock.—Apart from the soda and magnesia content (referred to below) the composition of crocidolite and amosite with its large percentage of iron might be expected to be more or less reflected in the bulk analyses of their country rocks. A comparison of Table 8 with the analyses of hornblende asbestos in Tables 2, 3 and 5 shows an essential similarity, allowance being made for the fact in the composition of a banded ironstone—free from fibre—magnesia and soda cannot be expected to feature in the analysis. This general correspondence, and the rigid restriction of the fibre to one and the same type of rock, already furnish some a priori grounds for the probability, that the genesis of this asbestos would depend not on the introduction of foreign material by solutions and deposition of material along open spaces, but on a kind of rearrangement of essential constituents, already more or less wholly available in the strata themselves, i.e. some form of growth *in situ*. The sharp restriction of crocidolite and amosite to ferruginous siliceous sediments, but thus be a natural result of the mode of fibre origin.

Lateral Variations along the Same Horizon.—Compared with the great attention that has been devoted to the subject of chrysotile genesis in the Canadian fields, where derivation through the influence of igneous intrusions has been emphasized, the origin of amphibole fibre varieties has been very little studied, and in the scanty literature dealing with this genesis the recent paper by M. A. Peacock is the only outstanding contribution, since the earlier edition of this volume first called attention to the possibility of asbestos originating from sediments without the direct action of igneous intrusions. Probably, therefore, such a mode of origin is at first sight somewhat startling and difficult to realize.

The strata containing crocidolite and amosite are certainly of great age and may have on that account suffered more profound changes, which is very likely the case to some extent at any rate, notably perhaps in the amount of subsequent silicification. It appears worth while, therefore, to examine to what degree lateral variations of identical horizons in the Pretoria Series show changes of facies that provide material chemically adapted to the formation of amphibole asbestos, and what is the interrelation between the Series as it is found in the Transvaal and Cape Province respectively.

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 group of the Transvaal System shows:—The *Pretoria Facies* with predominant shales and quartzites to the virtual exclusion of banded ironstones. 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.

A Preliminary Conclusion.—It follows from what has been so far said, that before crocidolite and amosite can be formed, the future country rock must consist of material of essentially the same composition as the fibre, as regards iron and silica. Clearly, however, the genetic problem is not covered by the above, since there remain the difficulties of soda and magnesia, the question why amphibole asbestos does not occur in other ironstones, e.g. the Ironstone Band below the Daspoort Quartzite, while lastly one requires some ultimate general agency that would initiate and maintain the change from ironstone into asbestos.

The Source of the Soda.—All crocidolite analyses show soda, which rises to a maximum of 7.71 per cent. (see Tables Nos. 2 and 3); most probably this is therefore an indispensable factor in the chemistry of that asbestos. Amosite contains a variable and much lower amount of soda, sometimes none at all. The source of this soda is an extremely difficult question, to which no answer has so far been found, satisfactory in every respect. In the first edition preference was given to the view that the soda is original and dependent upon special conditions of deposition, and no evidence has since been obtained to modify this postulate of soda-rich layers in the ironstones, which appears to the writer to offer least objection. Peacock points out* the three following possibilities:—

> . . . "soda may have been a foreign constituent introduced by travelling solutions, or the crocidolite may occupy the place of pre-existing soda rich bands; or soda may have been uniformly distributed through the ironstones and subsequently concentrated in certain bands."

and after an illuminating discussion reaches a conclusion in favour of the same postulate, to which reference is made above.*)

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* M. A. Peacock (Bibl. No. 58), p. 271.

*) *loc. cit.* p. 272.

The Source of the Magnesia and the Association of Dolomite.—The second requirement is magnesia, which is distinctly more abundant in the amphibole asbestos than in the banded ironstones; these only contain up to ·42 per cent. of this constituent (Table No. 8) compared with amounts ranging from 1·37 to 4·55 per cent. (Tables Nos. 2 and 3) in case of crocidolite, and from ·74 to 8·50 per cent. in amosite (Table No. 5).

Reference is made in earlier chapters to the close proximity of the fibre seams to the underlying dolomite as a constant experience in the Lydenburg and Pietersburg Fields; it is also indicated by the Zeerust occurrence. This association is too constant to be purely accidental and becomes specially marked, where in a great succession of banded ironstones the amosite seams tend to keep to the base of the series (Malips River Section); 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 apparant, 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 reptition of the same set of fibre horizons due to the synclinal structure. An examination of these parts of the Cape Asbestos Fields leaves a strong impression of the crocidolite display being more prominent nearer the base (Wonderwerk, Klipvley, Hurley, Warrendale, Oudeplaats, etc.) than further to the west (Crawley). These considerations, coupled with the well-marked tendency of the amosite to lie near the dolomite (both at Penge and in the Pietersburg Fields) render the association genetic and not accidental. Probably the absence of any records of crocidolite from the Upper Griqua Town Series is not without significance in this respect. The influence of the underlying dolomite on the basal portion of the Lower Griqua Town beds, owing to partial removal of carbonate matter in solution, is also on record (e.g. Blink Klip Breccia), so that the wider circulation of magnesian waters through a greater thickness of ironstone would amount to a difference in degree only.

In discussing this aspect, Peacock* points out that crocidolite contains about four times as much magnesia as is found in the ironstones, and comes to the following conclusion :—

> " . . . the postulate of rising solutions transgressing the bedding offers som difficulties ; and since a simple concentration of the magnesia in belts four times as wide as the respective crocidolite seams would be adequate—and the ironstones in the neighbourhood of the asbestos seams commonly exhibit

* *loc. cit.* p. 271.

> a leached appearance—the writer is inclined to explain magnesia in crocidolite to local concentration, and to refer the greater abundance of crocidolite seams in the lower reaches of the ironstone formation to the higher temperatures which probably obtained at the lower horizons."

This leads up to the question whether—after all the material present in the fibre has been made available—the effects of igneous intrusion (whether direct or indirect) are the agency through which the incidence of actual transformation of ironstone into fibre eventuates.

The Question of Metamorphism.—Here it will conduce to greater clarity, if this question is considered separately for (*a*) amosite and (*b*) crocidolite.

(*a*) In the North-eastern *Transvaal* the possibility of the formation of amosite being a metamorphic phenomenon is suggested by the fact that the emplacement of the great Igneous Complex of the Bushveld has brought the asbestos horizons into the outer contact zone of the former, but before a genetic connection can be established, it has to be shown that this intrusion is of an appropriate magnitude, that the asbestos-bearing country is definitely within the aureole, and that the nature of the mineralological changes is in agreement with the effects such an agent may be expected to produce.

The first point is now definitely established, and detailed information will be found in a series of publications, e.g. Bibl. Nos. 23-25. Independently of any inference based on the distribution of amosite, it has been shown that over the Lydenburg and Pietersburg Fields the Pretoria Series is profundly 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 (as it does also south of Zeerust). In the Lydenburg Fields the beds resting on the above-mentioned quartzite form a great succession of chiastolite and staurolite slates, and it cannot be supposed that the effect of the Bushveld intrusion was arrested at this quartzite; that it extends some way below the latter is indicated by further altered slates (alluded to in Chapter V).

With regard to the second point, it has also been shown that the ferruginous slate described in Chapters V and VI as " amosite slate " with its scattered tufts of hornblende occurs in direct association with the principal amosite horizon at Penge, Streatham, etc., and is also met with more or less all over the Pietersburg Fields. This rock shows a very striking metamorphic habit comparable e.g. to that of chiastolite slate. Thus there are good grounds for concluding that the fibre belt falls within the aureole of the Bushveld; on this view one would expect now and then to find traces of metamorphism in the dolomite itself, since the latter is nowhere far from the amosite horizons. This feature was observed at the Montana Mine and near the South African Consolidated Asbestos Mine, where altered dolomite charged with conspicuous crystals of actinolite occur (Chapter VI) in typically metamorphic habit.

As far as the third point is concerned, it is well known that the kind of metamorphic mineral formed is not in general dependent upon actual transference of foreign substance, but conditioned by the nature of the original sediment. Where a siliceous ferruginous rock falls into an outer belt of thermal metamorphism, the formation of a ferrous silicate (amosite slate) is just as normal as that of aluminium silicate in argillaceous rocks (chiastolite slate). The conclusion that the amosite slate is a true metamorphic rock is supported by the further experience that its horizon—traced into the true shale facies—freely develops typical chiastolite slate under the influence of the same intrusion (Zeerust), and that in the altered dolomites, referred to above, the metamorphic hornblende is not amosite, but actinolite (low in iron and rich in lime), once more illustrating the close relationship between the nature of the new mineral to that of its parent sediment.

The preceding discussion shows that the three requirements for a genetic connection between the Bushveld in trusion and the formation of amosite are satisfied.

(*b*) In the *Cape* crocidolite belt no evidence has so far been observed of an igneous intrusion on a scale and with effects comparable to the Bushveld Complex, yet the associated formations are so closely similar to those of the Transvaal amosite belts, that the conclusion of identical genetic conditions, or at any rate, a community in one or other of such conditions, is impossible to resist. If there is a concealed igneous agent, its possible existence is not supplied by the geological history of that area; signs of such an agent are nowhere traceable. Anything comparable to the characteristically metamorphic " amosite-slate " of the Transvaal Fields are almost unknown in the Cape Belt; the only possibly comparable phases are the very exceptional occurrences referred to as " needle-crocidolite," e.g. from Enkelde Wilgeboom, described in Chapter II (and also found in the Pietersburg Fields east of the Malips River). Possibly the so-called " potential crocidolite " (mass fibre crocidolite) falls into line here.

Thus it would appear that metamorphism (in the stricter sense) is not an agency in the production of amphibole asbestos that can be applied to *both* the Transvaal amosite *and* the Cape Crocidolite Belt.

Necessary and Sufficient Genetic Conditions.—The writer would regard the conditions necessary and sufficient for the formation of the two varieties of amphibole asbestos under their modes of occurrences in the Union to be the following three :—(*a*) The presence of sediments with ferruginous and siliceous characters containing along certain layers soda as a pre-existing constituent; (*b*) their association with rocks capable of supplying magnesia; (*c*) some geological process constituting an agency in the transformation of sediment into fibre.

The *first two conditions* are satisfied by the banded ironstones and their underlying dolomitic rocks, found wherever crocidolite or amosite occur.

With regard to the *third condition* (Cape Belt), it is very probable that metamorphism (i.e. due to igneous intrusion) as a possible agency must be ruled out in the Cape Belt, yet it cannot be supposed that the existence of the two first conditions should—by themselves—suffice to bring about the formation of crocidolite in that area; some other agency has thus to be searched for.

Whatever may have been the exact conditions under which crocidolite was formed, there can be little doubt that the process must have been a slow one, requiring a considerable stretch of geological time, and involving an increase of temperature and pressure. A high temperature arises not solely through the agency of some regional intrusion, but probably also through burial under an appropriate thickness of succession, while increased pressure accompanies such a result by virtue of the weight of superincumbent strata. It seems therefore not excluded that a kind of "load metamorphism" may provide the agency for crocidolite formation in the Cape Belt. Peacock (Bibl. No. 58, pp. 274-275 and 283) starting with the conditions under which the synthesis of amphibole has been accomplished, develops this aspect of the origin of crocidolite in a most ingenious discussion, and arrives at the following conclusion:—

> "Crocidolization is thus conceived as a mild, static, non-additive, metamorphic process, resulting in the chemical union, along soda-rich bedding planes, of the necessary constituents *in situ*. The process is described as a "sweating" action, facilitated by interstitial rock moisture, and induced by a moderate rise of temperature and pressure such as would result from simple burial of the ironstones to moderate depths."

Doubtless the above conception of load metamorphism contains some speculative element, but it represents in the writer's opinion the nearest approach to an intelligent working hypothesis that seems possible in the present state of our knowledge. Seeing that for reasons already given, one cannot set up one genetic theory of fibre formation for the Cape Belt, and a separate different one for the Transvaal amosite belt, specially as crocidolite seams occur in the latter fields also, the hypothesis in question must be admitted as *one* factor in the genetic problem of the Transvaal amphibole asbestos fields as well.

This, then, constitutes the common link in the genetic problem of *both* fields.

With regard to the *third condition* (Transvaal Belt), there are good grounds for the belief that in the case of the *Lydenburg and Pietersburg Fields* the necessary conditions for increased temperature and pressure were also supplied through the metamorphic agency of great Bushveld intrusion, and in this conclusion the writer finds himself in agreement with Peacock's results (loc. cit., p. 282); thus in the *Transvaal* amphibole asbestos belt thermal metamorphism becomes the second factor in the agency condition of the genetic problem, additional to the common factor of load-metamorphism (reflected in the occurrence of crocidolite seams in the Pietersburg fields also). The extraordinary display of amosite and its frequent phenomenal fibre length tempt one strongly to the suggestion that this feature—so striking in the Transvaal and unknown in the Cape Belt—may be due to the co-operation of both factors.*

The First Stage towards Fibre Formation.—Turning now to the fibre itself, it must be clear that the interbedded nature of the seams 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 veins of magnesite sometimes met with, as mentioned in preceding chapters. Such veins are more prominent in the Transvaal amphibole asbestos belt than in the Cape belt, seeing that magnesia through the abundance of amosite, plays a special feature in the former area. The first stage in the formation of an interbedded cross-fibre seam will therefore be the growth of non-oriented crystals of iron-amphibole; this leads—in the Transvaal fields to amosite-slate having its crystals either scattered, or concentrated in thin layers due to uneven distribution of regional chemical

* This conclusion raises the possibility of amosite being found in banded ironstones other than those of the Transvaal System, provided the necessary genetic conditions are satisfied; these put the formation of amphibole asbestos within narrow limits, not likely to be found often. In Moodies Series of the Swaziland System banded ironstones are a prominent feature, and since the Older Granite has an intrusive relationship to this system, there may conceivably be localities, where the other genetic restrictions are also satisfied. It appears to the writer of special significance, that in the banded ironstones near Messina (referred to in Chapter VII), which belong to Moodies Series and are associated with Older Granite, amosite has also been recorded, its country rock showing a metamorphic habit strongly recalling the grunerite-slate described in Chapter V from the deep levels of the Penge in the Lydenburg District.

composition of the parent rock—in the Cape to "potential" ("incipient") mass fibre crocidolite, locally passing further to the "needle" crocidolite condition. The tendency towards well developed amosite crystals in the former area most likely reflects the higher temperature due to the added influence of the Bushveld intrusion. In both fields, however, the development of some form of mass fibre asbestos precedes that of oriented asbestos; many localities can be observed where such mass fibre occurs.

The Second Stage towards Fibre Formation.—Supplementary to the discussion of the growth of fibrous structure given earlier in this chapter, it may be argued that in a mineral like amphibole with its inherent tendency to develop a prismatic habit, 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 may be expected to exert a certain amount of pressure against the containing walls, since it seems well established that crystals can exert a considerable pressure during growth. It is possible to suggest other physical conditions that might aid oriented growth, but such suggestions are very speculative; our definite knowledge of the conditions determining fibrous growth in crystals is certainly far from complete.

Intermediate stages are found in the Cape Belt (Westerberg, Hurley, etc.), but are rather more common in the Transvaal amphibole asbestos fields, being specially noticeable round Penge, in the Malips Valley, etc.; an instructive example from the Egnep (Malips Drift) Mine is illustrated by Fig. 35. A comparison of a large number of instances shows connecting links from thin yellowish brown layers having scattered elongated crystals or crystalline tufts of amosite without orientation through others with irregular stringers or patches of rudely oriented fibrous growths, which do not as yet show the perfectly oriented structure of the final seam, but clearly display—though at times in a more shadowy manner—a distinct tendency to orientation. Between these intermediate amosite stages and the heavy dark blue very coarsely (in places almost faintly) fibrous layers—e.g. in the Westerberg Mine—there is no essential distinction in structural principle.

In the *third and last stage* of asbestos formation, no doubt through the accentuation of the processes of fibrous growth over a long period, the tendency to alignment becomes fully effective, and results in a well-defined seam, exhibiting that perfection of delicately fibrous structure which is the marvel, but remains the riddle of asbestos. Peacock's final conclusion on the origin of cross-fibre structure has been given above.

Cone and Corrugated Structure.

Closely bound up with the origin of amphibole asbestos is the problem of the so-called "Cone and Corrugated Structure," referred to in previous chapters, and illustrated in figures 4 to 7 and Plate XVII.

From an examination of a very large number of instances, showing a wide range in detailed variations, the following points emerge as the leading features (applicable to both types of amphibole asbestos) of this peculiar and most puzzling structure :—(*a*) The undulating nature of the bounding surface of a seam (more often the lower than both surfaces) reflected along the drives by wavy lines; (*b*) a more or less cone-shaped prolongation of the country rock into the seam, often from above downwards, but also in the reverse direction; (*c*) the development of ridge-like corrugations in the bounding wall of a seam, probably representing a lateral extension of the cone-principle. With regard to (*b*) and (*c*) the material of which the cones and ridges are built is in the great majority of cases non-fibrous country rock, but now and then it is fibrous in alignment with structure of the asbestos. A satisfactory explanation for this structure has not been found; one might think of an unequal rate of growth, as suggested by the fibre starting one one side of the seam over an almost level plane, while terminating at their other end in a locus corresponding to the undulating plane, or to an effect of folding—to which Peacock (*loc. cit.*, p. 249) objects. Throughout the Cape Belt and Transvaal amphibole asbestos fields the beds are much folded, and the seams share in this structure (e.g. Plate XXVII). At first sight, therefore, the date of folding appears later than that of asbestos formation, and where a cone is fibrous in conformity with the structure of the seam, the common orientation points most probably to an identical time-incident. Yet it seems conceivable that the folding was not a much later event, but occurred while potential passed into actual fibre; some most instructive examples have been studied, where a very marked increased fibre length is conspicuous in one and the same seam of amosite, as it is traced under the arched up country rock, as if the gathering up of the strata under lateral pressure had provided a potential relief, favourable to continued growth. Such discussions, though perhaps justifiable as based on field observations extending through many years, do not, however, lead to any definite conceptions, and it must be admitted that as yet no explanation of " cone and corrugated " structure has been found, likely to command general acceptance.

Summary of the Genetic Aspects.

The mode of origin of asbestos is in some degree at any rate, still in the controversial stage, and the writer is well aware that the prevailing discussions can claim nothing more than forming a contribution for the study of asbestos formation—as a problem by no means fully understood in all its phases.

If these pages achieve no more than lead to further critical examination of the questions that remain unanswered, one of the writer's main objects will have been attained.

Chrysotile.

1. Chrysotile (olivine-asbestos) is restricted to serpentine, whether originating through the serpentinization of (*a*) ultrabasic intrusions, or (*b*) of magnesian silicates arising in dolomitic rocks as the result of igneous intrusion (basic sills).

2. Serpentinization, though often regarded as the result of weathering, may also be brought about by igneous intrusion—preferably acid; it is not held that the agents of serpentinization are necessarily also those of the subsequent transformation of serpentine into cross fibre seams.

3. Based on their close association with acid intrusions, the origin of cross fibre chrysotile seams due to the agency of such intrusion is admissible for the Natal deposits of the Sitilo Type.

4. In all the Transvaal chrysotile deposits the agency of acid intrusions is ruled out; a genetic connection with basic intrusions is possible, but the evidence for such a conclusion is not satisfactory.

5. The origin of "dolomitic" chrysotile cannot be ascribed to the direct agency of basic intrusions, but only indirectly through the intermediate stage of metamorphic magnesian silicates, subsequently transformed into asbestos—independently of such intrusions.

6. The observed facts of diminished fibre display in depth raise the question of chrysotile formation being a change—not of a deep-seated character—but one belonging to the zone of weathering.

Crocidolite and Amosite.

7. Owing to their very close analogies in distribution, mode of occurrence chemical composition, etc., the genetic problem is in most respects identical for both varieties.

8. Crocidolite and amosite originate from (and are restricted to) sediments having pronounced ferruginous and siliceous characters, three major attendant conditions being all satisfied.

9. The first condition is the presence of soda; the second is a source of magnesia; the third is an agency to induce the transformation of adequate rock into fibre.

10. The first two conditions are satisfied by the banded ironstones in the lower part of the Pretoria Series (Transvaal System) in case of the Transvaal, or in the Lower Griqua Town Series, as the corresponding group in the Cape Province—pre-existing soda-rich layers being postulated and association with underlying dolomite being observed, in both regions.

11. In the Cape Fibre Belt the third (or agency) condition is held to be provided by increased temperature and pressure arising through something analogous to Load-Metamorphism. No evidence of such favourable conditions being traceable to thermal metamorphism, based on igneous intrusion on an appropriate scale, has been found.

12. In the Transvaal amosite (and crocidolite) Fields the agency of load metamorphism is also held to apply; thus one phase in the third condition is common to both fibre belts.

13. Since the Lydenburg and Pietersburg Fields fall within the (outer) contact aureole of the Bushveld Complex (amosite-slate; grunerite-slate, etc.) thermal metamorphism establishes another phase of the agency condition, the co-operation of which suggests the striking amosite display (unknown in the Cape Belt) as a kind of reinforced effect.

14. Amphibole asbestos thus becomes the result—not of solutions circulating in open fissures—but of recrystallization of material for the greater part already present in the ironstone, and can be described as a growth *in situ*.

15. In this transformation the first stage (Cape Belt) is "potential" (or "incipient") mass fibre crocidolite, or "amosite-slate" (Transvaal Belt).

Persistence in Depth.

The question how far asbestos deposits persist in depth, or may be expected to continue in depth, is obviously one that might now and then have an important bearing on the economic outlook. During the past 12 years some of the mines that have survived the test of that period have made substantial progress in their development, while a very large number of new localities have been added to the record of asbestos occurrences in the Union, so that a review of the present position of the question of underground persistence is necessary; it can hardly be discussed with profit, unless the possible modes of fibre origin are kept in view.

Chrysotile.—In his great classic on the Canadian chrysotile deposits, Cirkel* refers to the 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. Serpentization is, by the same author, regarded as a deep-seated process, not depending on the action of the atmosphere. In describing the Tasmanian occurrences, Twelvetrees‡ also inclines to the opinion that chrysotile persists in depth, a conclusion also reached by Keep for the Shabani deposit in Southern Rhodesia (Bibl. No. 40, p. 123).

As pointed out in the description of the Transvaal chrysotile occurrences given in Chapters III, IV, and VII, the observed facts point to the conclusion that these fibre deposits are liable actually to fail, or may be expected not to persist, in depth. The rate of decline in the display varies within wide limits, but is rapid in the majority of cases, though it is arguable now and then, whether development has gone far enough to afford clear evidence of decline. This does not necessarily always imply an unsatisfactory lease of economic life, nor the total disappearance of fibre in depth, but the possibility of the fibre display eventually passing in depth below the workable limit, can hardly be ignored, when estimating the chances of continued profitable exploitation, as far as the present knowledge of the behaviour of such deposits goes under the modes of occurrence observable in the Transvaal Province.

* Bibl. No. 9, pp. 100–102.

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

‡ Bibl. No. 76, p. 25.

In the *Crocodolite* Fields of the Cape, the majority of the workings only extend to a very moderate depth below the surface, and are therefore too shallow to throw any light on persistence in depth.

On the other hand, several mines have been in active existence for a good many years and in a more advanced stage as regards develop-In the Westerberg, Carn Brea (Keikamspoort) and Blackridge workings deeper development on the dip of the fibre channels has had to be stopped, because the seams failed to persist under workable conditions. In the Westerberg Mine (probably the oldest asbestos mine in the Cape Province and under development certainly for not less than 30 years) the workable fibre horizon continues for 320 feet in the direction of dip; at this depth the display began to dwindle, but sinking was continued for another 60 feet on the dip, when a cross-cut (showing pools of ground water) was made through some 90 feet to explore a possible channel horizon laterally; sinking was finally resumed for another 35 feet, but the seams continued unworkable; all further development on the dip was then stopped; the position of the cross-cut referred to is 210 feet vertically below the surface. At the Carn Brea (Keikamspoort) Mine, which has now been under development for some 12 years at least, good " reef " has been found persisting for some 280 feet on a dip of about 60°, but within a few feet the display suddenly dwindled, and though sinking was maintained for a further 60 feet, there was no asbestos. At the Blackridge Mine sinking on a dip averaging 45° revealed workable fibre for some 320 feet; at the bottom the display declined, the country rock became harder, and signs of dampness were observed. Sinking was maintained for a further 30 to 40 feet, but the crocidolite seams became still poorer, so that development on the dip has been stopped. Information kindly given by Mr. Rundle Olds, whose knowledge of the Cape Belt is unique, shows the following remarkable experience. On Naauwpoort tunnelling operations on the " flat " reef were carried through an ironstone ridge from one side to the other: the total length driven amounted to 2,100 feet, and on both sides good reef was met with at the surface and maintained as a workable seam through some 300 feet into the ridge. Then the reef became poor and practically failed altogether in the centre, where a 40-foot exploratory cross-cut gave no seams at all.

It seems very unlikely that experience like the above should depend upon the gradual disappearance of soda, and it seems impossible to escape the conclusion, that in considering the question of persistence in depth, it may eventually be found that some connection between fibre display and the present surface has to be taken into account.

In the Transvaal *Amosite* Fields, no mine is so far developed to any depth great enough to furnish any decisive evidence; this holds good for the Penge deposits. In the most advanced working in the Pietersburg Fields—the Egnep, Ltd. (Malips Drift Mine)—there is a tendency, observable the deeper ones goes, for the seams—after tapering off—to be succeeded by increasingly longer stretches of country free from amosite; when continuity is re-established, it becomes decreasingly less.

Future developments will be watched with great interest from the point of view of persistence in depth; if the amphibole asbestos deposits were eventually to reveal this as a definite feature, such a conclusion might call for a further consideration of their genesis, as summarized above. Since, in the case of amosite, for example, the agency of thermal metamorphism is in the nature of the case deep-seated, its effects must be expected to continue underground for as far as the ironstones keep within the aureole of the Bushveld intrusion, so that no grounds exist for the formation of amosite-slate to have any connection with the present surface. If the undoubted prerequisite condition, that this metamorphic rock (or potential crocidolite) precedes the formation of asbestos, is to remain valid, which appears almost certain, then it may turn out that the further step of transforming "amosite-slate" into cross-fibre seams may not depend upon deep-seated conditions at all, but upon factors within the zone of weathering. Should it be possible eventually to establish this, the genesis of amphibole asbestos would fall more in line with that of chrysotile (deep-seated causes of serpentinization preceding cross-fibre formation near the surface), than is the case—as far as present knowledge goes.

The above shows once more, how little has so far been achieved in laying bare the whole riddle of asbestos.

Chapter X.

INDUSTRIAL ASPECTS, AND USES, OF ASBESTOS.

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 capacities.
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.

Marketable fibre is disposed of according to grades, the specification of which varies with different producers, as shown in previous chapters. By some producers the grades are grouped into two major classes denoted as (*a*) *Cobbing fibre, and* (*b*) *Milling fibre;* the former embraces all grades (sometimes referred to as " Crude ") that are prepared by hand cobbing, and the latter covers the grades that are milled. Another classification is much in use depending upon textile qualities and it distinguishes between (*a*) *Spinning Fibre,* i.e. material of adequate length for spinning purposes, and (*b*) *Non-spinning fibre.* The dividing line is variously drawn, but probably ⅜ of an inch is the extreme lower limit of spinnability, though fibre of such length may require a certain admixture of some other material to produce yarn. Full details on the technology of the manufacture of asbestos goods cannot be considered here, and are for obvious reasons difficult to obtain for general information.

The most important source of *supply of asbestos* is *Canada*, which comes easily first and in 1928 furnished 70 per cent. of the world output. (See Table No. 36 in Chapter XI.) Next come Rhodesia, where the value of the 1928 output was only exceeded by that of its gold production; then follow Russia, and the Union of South Africa. (See Table No. 36.) The United States, though the largest consumer of fibre, only contribute a very small fraction of the world production. (Table No. 36.)

The *Canadian asbestos deposits* are specially interesting, in view of the above position they hold in that country, owing to their enormous extent, fully developed conditions, advanced methods of mining, etc., and—perhaps most important of all—close proximity to the United States, as the leading asbestos manufacturing country. Some years ago Canada's share in the world amounted to something like 80 per cent., and even to-day, where this figure is near 70 per cent., it easily retains the lead. Table No. 35 reflects the Canadian situation during 1928, and shows the relative proportions of the various grades and their average value :—

TABLE No. 35.—*Production of Asbestos in Canada (Quebec) for 1928.* *(Short Tons.)*

Grade.	*Total Output.* *Tons.*	*Percentage.*		*Average Value per Ton. In Dollars.*
(*a*) Crude No. 1..............	706	·30	6·65	534·87
(*b*) Crude No. 2..............	2,784	1·02		296·65
(*c*) Crude Run of Mine........	507	·19		127·65
(*d*) Spinning Fibre............	14,051	5·14		148·71
(*e*) Shingle Fibre.............	41,975	15·30	93·35	73·80
(*f*) Mill Board and Paper Fibres	71,141	26·04		38·73
(*g*) Fillers, floats, and other short Fibres..............	142,071	51·01		15·79
	273,235	100·00		

Rock mined in 1928: 5,159,247 tons.
Rock milled in 1928: 4,109,823 tons.

On the basis of actual shipments and sales the average value per short ton was 41.16 dollars during 1928.

The position is different in the case of spinning fibre, which is always superior in value, so as to make its disposal at more distant sources economically more satisfactory than is the case of the less valuable milling grades. Formerly Canada held the lead in spinning fibre, but in 1928 produced only approximately one quarter of the world supply of such grade. Fibre of textile length—and this obviously applies specially to chrysotile—is therefore always a highly prized feature in those deposits. If the grades (*a*) to (*d*) of Table No. 35 be taken as being all textile, then the ratio between spinning and non-spinning fibre works out as 6.65 to 93.35 per cent. for the Canadian mines, which is closely comparable to the position in the Union. (Table No. 23A.)

For many years *chrysotile* has now enjoyed a leading position in the international asbestos market, whether from the point of view of quality, quantity or value. This is due to the extensive and highly developed Canadian resources and their favourable situation near the United States; it is also due to the superior quality of chrysotile, with its extremely fine fibrous structure, infusibility, etc. Yet in some of its physical properties this fibre is below the standard of crocidolite or amosite (e.g. sea-water resisting power, fibre length, etc.).

For many years the production of asbestos in the Union was confined to crocidolite, and, leaving out of consideration the very small output from the dolomitic deposits of the Carolina Fields, chrysotile only began to appear since the Kaapsche Hoop occurrences began to produce some 12 years ago. The contribution of chrysotile from the Union to-day is shown in Table No. 38 in the next chapter, and though it is only a very modest amount, it is an important element when judged from the aspect of the development of an industrially young country.

Crocidolite is, in respect of some of its physical properties, superior to chrysotile, e.g. its use is specially insisted upon for certain applications in the navies of some countries. Comparatively speaking, crocidolite is a new comer in the international market, and in view of the large, long well known, and regulated output from the extensive Canadian deposits, in contrast with the relatively small production from crocidolite, it required much effort before this variety secured a footing in the market (as commonly the case with a new base-metal source). The same remark applies even more forcibly to amosite.

In the exploitation of crocidolite the Union of South Africa has a practical monopoly, and the very large supplies available in the Cape Province have been referred to. (Chapter II.) The Cape Asbestos Company, 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 work-workings. Thus only a proportion of the combined yield from the Cape fibre area has so far entered into competition in the open market. It is very satisfactory to find that Messrs. Turner and Newall, Ltd., the world's largest firm engaged in the manufacture of asbestos goods, is now also established in the Cape Crocidolite fields—through the Dominion Blue Asbestos Mines (Pty), Ltd.

While in the Southern Section of the above fields the predominance of the mines under the Cape Asbestos Company, with their long experience of the exact requirements of their factories, had led to well-established methods of development, e.g. as regards market preparation and grades, the Northern Section round Daniels Kuil and Kuruman, where the resources were opened up by smaller companies and syndicates, was at first not always equally far advanced in its methods of development, etc. This result has been due in part to the fact that the seams are—in general—not sufficiently persistent to admit of more systematic underground mining, so that the pecularities of the contract system of labour had greater play, in part also to less thorough deficient market preparation; the danger of shipment not coming up to sample is to the detriment, not merely to the producer concerned, but to the entire fields, a result specially deplorable in a young industry competing on the international market. The advent of a strong concern like Messrs. Turner and Newall, will doubtless lead to the extension of better and more definite methods of exploitation, while offering improved circumstances of local marketing.

Greater fibre length is an important aspect of the Cape (and Transvaal, crocidolite deposits. The comparatively low proportion of spinnable fibre in the case of chrysotile has been pointed out; taking ¾ of an inch as the limit of spinnable length, some 13 per cent. of the crocidolite output (for 1929) would represent spinnable fibre, so that in this respect the Cape (and the Pietersburg) crocidolite deposits have a distinct advantage over chrysotile. Thus, in spite of the commanding position of chrysotile in the world's markets, crocidolite should secure an increasing share in the manufacture of asbestos goods.

Amosite, the new iron amphibole asbestos of the Eastern and North-eastern Transvaal, is the latest addition to the fibre family, and great difficulty was found in bringing it on to its feet. Though known at least as far back as 1907, amosite remained more or less a curiosity for some time, since its chemical composition differs markedly from chrysotile, and its ash-grey or pale brownish appearance recalls neither "white" or "blue" fibre. It proved also difficult to convince the international market that the extraordinary fibre length, coupled with the enormous supplies available in concentrated form—in which respects the Penge deposits are unique among the world's resources—was not an exceptional but a characteristic feature of the new fibre. A long struggle followed, until amosite is now finally established in the market, though it cannot be expected to supplant textile chrysotile. In its fibre length amosite is without a rival, values from 3 to 6 inches being maintained over long distances in the Lydenburg Fields, while lengths between 1 and 2 inches are very common in the Pietersburg Fields, as explained more fully in Chapters V and VI.

The superior fibre length maintained for the bulk of the output, combined with the more regular mode of occurrence along fairly definite horizons traceable for comparatively long distances, allow of the amosite deposits to be developed on more systematic lines, an obvious advantage in regulating a steady supply. Although not as good as chrysotile from the point of view of spinnability, and therefore lower in value, this factor of great fibre length places amosite in a strong position, provided other essential properties are satisfied; in the South African asbestos industry, this fibre has been for some years successfully applied to the manufacture of asbestos sheeting, roofing material, etc., and it is also being employed in some of the overseas asbestos manufacturing concerns. The expectation is therefore justified that its use will increase though it may take time before amosite comes fully into its own.

In the industry asbestos *is used* in ever greater varieties of manufactured articles, too numerous for enumeration. Spinning fibre is mainly used, e.g. in the motor industry as brake-band linings and clutch facings, also for a variety of fire-proof articles, e.g. curtains, suits, gloves, and so on. The largest consumption is for the building trade,* often with an admixture of cement; here belong asbestos sheeting, corrugated roofing, tiles, and slates, boiler coverings, etc. Heat insulation requirements call for steam packing, stove linings, etc., while asbestos fire-proof mats, asbestos millboard, asbestos paper illustrate further extensive uses. Bowles (Bibl. No. 4) calls special attention to several recent industrial developments: Moulded brake linings, estimated to have been in service on 800,000 cars in the United States during 1928—by far the largest use of spinning fibre; asbestos plaster to improve the acoustic qualities of meeting halls, etc. Reference is also made to hat-making, where asbestos cloth has replaced other fabrics for severe service.

The manufacture of asbestos goods from crocidolite of the Union is carried on 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 superior sea-water resisting capacity of crocidolite and its heat-insulating power have a great practical application in navies and mercantile marines as flexible boiler and steam-pipe coverings, so much so that its exclusive use is enforced in some countries. A very great 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.†

The *manufacture of asbestos articles* in which the fibre constituent comes *from Union resources,* has now been successfully carried on by

* Already in 1910 it was estimated (Cirkel Bibl. No. 9) that in the near future fully 75 per cent. of all asbestos produced in the world would 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 industry led to an increasing number of factories all over the world, requiring large quantities of cement, so that some manufacturers established their own cement works.

*) See also *P. A. Wagner* (Bibl. No. 77).

† *Cirkel,* Bibl. No. 9, p. 255.

one or another factory, for more than 12 years, in Durban, Johannesburg, and Meyerton.

At *Durban,* the asbestos section of the Iron, Concrete and Asbestos Manufacturing Company was taken over in 1918 as the *Asbestos Cement Manufacturing Company, Ltd.* (a subsidiary concern of Messrs. J. S. Hancock & Co. in Johannesburg). The difficulty met with in the disposal of asbestos goods at inland centres—largely owing to cost of transport—led in 1925 to the establishment of a factory in *Johannesburg* (Newtown) as *Asbestos Products, Ltd.* (also subsidiary to Messrs. J. S. Hancock & Co.).

The raw material used at both factories consists of South African Portland cement and asbestos; the latter comprises: (*a*) Chrysotile, obtained from Southern Rhodesia and from an occurrence near Malelane in the Barberton District (Althorpe), but was until recently also derived from north of Krugersdorp (see Chapter VII); (*b*) amosite, which comes from the deposit worked by Chunies, Limited, in the Pietersburg Asbestos Fields. Where necessary, the crude fibre lumps are crushed and cleaned, etc., at the factory. The natural colour of the finished article is grey, but if required coloured, this is done by staining afterwards. The proportion of the mixture is from 15 to 12 per cent. by weight of fibre and from 85 to 88 per cent. by weight of cement.

The crude asbestos-bearing ore passes through a Chilean mill, which eliminates rock-waste, whence the fibre passes over shaking tables, while a suction fan allows dust to escape; the clean fibre, together with the requisite proportion of cement, then passes to the mixer, from which the mixture and water are discharged on to the surface of a horizontal cylinder of wire-gauze. Most of the water passes on, but the mixture of fibre and cement is retained as a thin and matted layer. A canvas belt passes this layer to another cylinder, and since the process is continuous, the latter cylinder becomes covered with a gradually incresing layer built up from many superimposed films. Since the fibres are disposed anyhow, the final structure is somewhat like that of mass fibre material, where the fibre lies criss-cross, thus giving special strength. This is the so-called Hatschek principle of manufacture.*

In the articles turned out, a blende of amosite and chrysotile is used, but the superior tensile strength of the latter is taken advantage of, wherever extra special strength is essential, i.e. in corrugated roofing material. Hitherto the manufacture has been confined to building material and to articles of use in the agricultural and other industries, i.e. not involving the spinning of fibre. The largest proportion of the manufactured products is represented by flat sheets and corrugated

* Cirkel (Bibl. No. 9, p. 246).

sheets, the former turned out up to 12 feet long; the following list illustrate the wide range of products available:—

Flat Sheets,	Millboard,
Corrugated Sheets,	Fluming,
Guttering,	Circular Water-tanks,
Roof Ridging,	Fencing Posts,
Tiles,	Cattle Troughs,
Roofing Tiles,	Native Beds,
Boiler Lagging,	Etc.

The annual output of the Durban and Johannesburg factories together now averages over 6,000 tons of asbestos goods, in the manufacture of which some 900 tons of fibre are consumed. Corrugated asbestos roofing now forms a very considerable portion of the output, and is used, e.g. by the Railway Administration for covering fruit-sheds, in locomotive sheds, etc.

At *Meyerton* is the factory of *Wilsons Meyerton, Limited;* this was originally established by Messrs. J. Wilson & Son at Doornfontein as the pioneer inland manufacturing concern of asbestos goods for the building trade, over 12 years ago, where roofing tiles, etc., were turned out from cement and crocidolite from the Cape Belt or amosite from the Lydenburg District.

At Meyerton—some 30 miles south of Johannesburg in the Klip River Valley—the raw material consists of South African Portland cement and amosite from the Penge Mine in the Lydenburg District; these constituents are mixed in the approximate proportion of about 14 parts of fibre to 60 parts of cement, the fibre being first cleaned and suitably prepared. The bulk of the manufacture consists of flat sheets up to 8 by 4 feet in size and from $^3/_{16}$ of an inch upwards in thickness, sometimes reinforced with wire-netting; ridging material and some corrugated roof-sheeting are also made. The average monthly ouput corresponds to round 11 tons of amosite which represents approximately 70,000 superficial feet of asbestos goods.

Though the local asbestos manufacturing industry based on domestic fibre resources is now well established and expanding, the asbestos products do not appear to be as widely used as they deserve to be, specially under the climatic conditions of South Africa, where material having great durability under extreme variations of temperature, and low heat conductivity (high heat insulating capacity) is of special importance, e.g. as material for farm buildings, etc. Attempts to establish local industries have sometimes to contend with prejudice, for reasons that need not be discussed here. Possibly the fact that imported asbestos products, by cracking or otherwise, have at times failed to come up to expectations, has increased the difficulties at first met with in placing the domestic article successfully on the market. On the other hand, the use of locally made asbestos products shows a distinct increase, as shown by the large number of South African concerns that are consumers of such products to-day, so that in the inland centres the competition with the imported articles has become much less severe.

The extraordinary strength of asbestos cement material, only exceeded by metallic sheeting, is well illustrated by experiments carried out by the David Kirkaldy Testing Works at Southwark, London, where a pipe 4 feet long, 6 inches in internal diameter, and 1⅛ inches thick was tested to destruction; this point was reached under a pressure of 1,045 lb. per square inch. Similarly a corrugated asbestos sheet 7 feet by 3 feet 3 inches and a ¼ of an inch thick remained unbroken under a load of 1,012 lb. placed on an area of one foot square. The complaint sometimes made that sheets are brittle, is therefore without foundation; the strength appears to depend largely upon the thickness, and the Hatschek principle of manufacture allows a wide range for this factor.

Though, judged by international standards, the domestic market for asbestos goods is likely to remain moderate, the high proportion of spinnable fibre available in the Union, suggests the possibility of increasing local consumption by extended uses rather than by supplanting chrysotile in established applications. This remark applies to crocidolite, and even more strongly to the best quality amosite. As regards fibre length the Union deposits are in a strong position, for the known deposits of long spinnable fibre have through recent discoveries been greatly extended; this important factor, combined with quantity, points to possible fields of utility, not contemplated, so long as the world's resources of spinnable fibre (chrysotile) remained strictly limited. Referring to the demand for textile goods, Cirkel stated that this had never yet been met for certain purposes, due in part to the anticipated difficulty of obtaining regular supplies of long fibre chrysotile to secure a continued output, e.g. of asbestos cloth.* Since then, additional sources of chrysotile have become available, but there has also been an enormous increase in the application (in extent and variety) of asbestos in many industries, and it does not appear that to-day the proportion of spinnable chrysotile has been materially raised, so as to approach the strong position of crocidolite and amosite with their high proportions of superior fibre length. Assuming that such fibre satisfies technical tests of spinnable quality, there should be a good opening for amphibole asbestos in the manufacture of many articles adapted to the open-air conditions of life in South Africa, as substitutes for cotton, linen and hemp, these being liable to rapid decay on prolonged exposure.

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* Bibl. No. 9, p. 251.

Chapter XI.

STATISTICAL INFORMATION.

In the following Table No. 35 the world production of asbestos is shown, as well as the share of the various producing countries in the total; this information is based on Mineral Industry for 1928 (Bibl. No. 4) and place the Union's contributions in its correct international perspective. The small amount of 94 tons derived from Australia is not included in this table.

Table No. 36.—*World Production of Asbestos in* 1928.

Country.	Short Tons.	Percentage.
Canada	273,235	70·33
Rhodesia	39,960	10·30
Russia (1927–1928)	27,000	6·95
Union of South Africa	23,584	6·10
Cyprus	18,242	4·70
Italy	3,968	1·02
United States of America	2,239	0·60
Totals	388,228	100·00

The production of asbestos in the Union of South Africa is shown in Table No. 37 compiled from the official records of the Government Mining Engineer. The writer is greatly indebted to the Statistical Branch of the Department of Mines and Industries for this information. " Production " in Table No. 37 means " Shipments and Sales "; the Annual Reports of the Government Mining Engineer make distinction—since 1917—between the above and " Actual Production " which may be less or greater than " Shipments and Sales," according to trade fluctuations, etc. The difference is small, so that Union totals shown in Table No. 37 may be taken as representing " Actual Production " sufficiently closely for present purposes :—

TABLE No. 37.—*Actual Production in the Union of South Africa. (Short Tons.)*

Year.	Cape.		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	1253·5	20,765	—	—	13	74	1266·5	20,839
1912	1217·3	18,822	—	—	3	60	1220·3	18,882
1913	937·5	15,599	—	—	24·2	429	961·7	16,028
1914	1160·4	18,657	30·1	1,430	—	—	1190·5	20,087
1915	2082·9	33,166	55·5	2,733	—	—	2138·4	35,899
1916	4227·8	74,293	407·3	8,490	20·6	287	4655·7	83,070
1917	2999	49,445	3192·5	37,486	28	393	6219·5	87,324
1918	2738·613	44,148	930·44	9,829	5	60	3674·053	54,037
1919	3203·507	57,578	630·67	7,699	97·9	1,149	3932·077	66,426
1920	3525·771	71,875	3541·49	41,183	45	1,137	7112·261	114,195
1921	3467·366	74,489	1592·897	27,546	62·175	1,032	5122·438	103,067
1922	2990·718	55,290	1392·336	25,896	5·5	44	4388·554	81,230
1923	4317·356	55,063	4075·576	66,390	—	—	8392·932	121,453
1924	3001·246	38,370	4239·45	71,705	—	—	7240·696	110,075
1925	2540·236	42,108	7627·45	110,007	—	—	10167·686	152,115
1926	3993·375	80,656	10103·5	135,810	—	—	14096·875	216,466
1927	4827·1	106,446	17313·3	236,855	—	—	22140·4	343,301
1928	5077·5	113,400	18976·5	286,150	—	—	24054	399,550
1929	6030	150,995	26984	346,058	23	340	33037	497,393

* Last Seven months.

Prior to 1926 no official statistics were available of the asbestos production according to varieties. Table No. 38 gives the data for the period 1926 to 1929; for this information the writer is also indebted to the Statistical Branch of the Government Mining Engineer :—

TABLE No. 38.—*Asbestos Production in the Union of South Africa—According to Varieties. (Short Tons.)*

Year.	Province.	Amosite.		Chrysotile.		Crocidolite.		TOTAL.	
		Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.
			£		£		£		£
1926......	Transvaal......	2940	28,755	7133	105,876	30·5	1,179	10103·5	135,810
	Cape..........	—	—	—	—	3993·375	80,656	3993·375	80,656
	Natal.........	—	—	—	—	—	—	—	—
1927......	Transvaal......	5093·3	50,319	12173·5	184,897	46·5	1,639	17313·3	236,855
	Cape..........	—	—	—	—	4827·1	106,446	4827·1	106,446
	Natal.........	—	—	—	—	—	—	—	—
1928......	Transvaal......	6748·313	69,039	12162·262	214,866	66	2,245	18976·575	286,150
	Cape..........	—	—	—	—	5077·5	113,400	5077·5	113,400
	Natal.........	—	—	—	—	—	—	—	—
1929......	Transvaal......	9260	98,241	17724	247,817	—	—	26984	346,058
	Cape..........	—	—	—	—	6030	150,995	6030	150,995
	Natal.........	—	—	23	340	—	—	23	340

The total value of the asbestos produced in the Union from the earliest date of existing records down to the end of 1929 amounts to:—

£2,675,342.

For purposes of comparison, the production of chrysotile in Southern Rhodesia (From "Mineral Industry") is added—Table No. 39:—

TABLE No. 39.—*Production * of Asbestos in Rhodesia (Short Tons.)*

Year.	*Tons.*	*Value* £
1914	487	8,612
1915	2,010	32,190
1916	6,157	99,059
1917	9,562	189,890
1918	8,574	158,684
1919	9,798	425,240
1920	18,823	459,572
1921	19,528	795,698
1922	14,249	577,699
1923	20,364	626,898
1924	26,141	603,423
1925	34,349	765,926
1926	33,344	726,835
1927	33,176	794,211
1928	39,960	970,327
1929	42,634	1,186,627
TOTAL	319,156	8,420,891

* For 1914 to 1928, data are taken from "Mineral Industry" for 1928.

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 following *fibre varieties* occur in the Union, enumerated in the approximate order of abundance :—

(*a*) Amosite, an ash-grey silicate of iron (Transvaal).

(*b*) Crocidolite or Cape "Blue," a lavender blue silicate of iron (Cape and Transvaal).

(*c*) Chrysotile or "white" asbestos, a hydrated silicate of magnesia (Transvaal and Natal).

(*d*) Anthophyllite or "Asbestic," a mass fibre variety of anthophyllite (Transvaal).

(*e*) Tremolite, a silicate of lime and magnesia (Natal).

The Free State has not so far produced any deposits of asbestos.

3. *Crocidolite or Cape "Blue"* is the longest developed variety in the Union, 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 or 1/2 inch up to 1 inch in length.

Crocidolite in this belt occurs at a very large number of localities, and two section are commonly recognized: A southern section, extending from the southern end (south of Prieska) across the Orange River northwards to about Griquatown, and including the majority of the mines owned by the Cape Asbestos Company; the most important centres are Keikamspoort, Prieska Town Lands, Koegas, Westerberg, Elandsfontein, Blackridge, Nauga, etc. The northern section reaches from near Daniels Kuil northwards through Kuruman to the Mashowing River; since about 1910 many deposits have been opened up in this portion mostly by smaller producers. The recent establishment in this area of the Dominion Blue Asbestos Mines (Pty.), Ltd.—subsidiary to Messrs. Turner & Newall, Ltd.—has led to the erection of a complete mill at Kuruman.

Mining usually proceeds by open-cast workings, at times extending into underground developments, as e.g. at Westerberg, Klipvley, or Hurley.

The oldest and most important producer is the Cape Asbestos Company, the headquarters of which are at Koegas, some 35 miles north-west of Prieska. This company obtains fibre from a number of farms, the principal source being Westerberg; they are also manufacturers of asbestos goods in Europe.

The methods of market preparation are simple; the only more elaborate treatment plant is that of the Dominion Blue Asbestos Mines at Kuruman.

In the *Transvaal*, crocidolite is restricted to the north-eastern parts of the Province, situated east of Chuniespoort and covering portions of the Haenertsburg Goldfields, at an average distance of some 60 miles from Pietersburg, the nearest railhead. The seams occur interbedded in the basal part of the Pretoria Series, in banded ironstones similar to those of the Cape Belt, and consists of the same lavender blue fibre, though the quality is not as good as in the Cape Fields. Though known since 1905, the deposits have only been in course of (intermittent) exploitation during the last 10 years or so.

4. *Amosite* is a new fibre variety, which has so far been definitely found in the Transvaal only, whence it was first recorded in 1907 in Eastern Sekukuniland at what is now the rich Egnep Mine (on the farm Penge); this area forms the Lydenburg Asbestos Fields, but pass northwards without a break into the Pietersburg Asbestos Fields.

Amosite is found over some 60 miles of strike at many localities along both banks of the Olifants River from the junction of that stream and the Steelpoort River, generally northwards to Malips Drift in the Haenertsburg Goldfields. The deposit forms cross-fibre seams interbedded in banded ironstones, which most probably correspond to the same horizon in which the crocidolite of the Cape Asbestos Fields occurs.

In the Lydenburg District both crocidolite and amosite may occur in the same mine, but amosite has hitherto not been found outside the Transvaal. The chief centres of activity are Penge, some sixty miles north of Lydenburg, and Malips Drift, about forty-five miles south-east of Pietersburg. The exploitation of the Penge section has been to some extent hampered by transport difficulties, but the new railway line from Lydenburg has reduced road transport to eighteen miles.

The Egnep and Amosa Mines, now owned by the Cape Asbestos Co., are the chief producers, and show enormous quantities of fibre still available. Their most extraordinary features are their great regularity in distribution, which has enabled a regular system of drives and levels to be made out, and the phenomenal fibre length, in which respect this field is unique. Unlike other varieties of fibre, amosite maintains its great length over long stretches in the principal horizon. The maximum length observed is 11 inches, but in the great majority of cases the fibre is between 4 inches and 5 inches long.

The quality of amosite is different from that of any other asbestos. In texture, the mineral, though very delicately fibrous, tensile, and readily fiberized, is harsher to the touch than Cape " blue " or chrysotile, but the fibres are quite as strong and to a certain extent elastic. Difficulty was at first experienced in marketing amosite, but it has now been taken up both in America and Europe. Since it can be put on the market at a much lower price than other classes of spinnable fibre and also occurs in very large quantities, it should eventually take a prominent position in the markets.

In the Pietersburg Fields, amosite has also been found at many points under conditions generally similar to the Penge mode of occurrence, but the length is not so striking as in the Lydenburg Fields. Here belong the many developments described in Chapter VI.

5. *Chrysotile* is found both in the Transvaal and in Natal, but at present only exploited in the former Province.

Here the principal occurrences are :—

(*a*) In the Carolina District, where chrysotile is associated with altered dolomite;

(*b*) in the Barberton District (Kaapsche Hoop), where chrysotile is in its normal association with serpentine; and

(*c*) in the Komati River Valley (eastern Carolina District), where the fibre is also found in serpentine;

(*d*) in Swaziland.

(*a*) In the *Carolina* District, some twenty-five miles from the railway, chrysotile of excellent quality has been recovered at intervals on a modest scale since about 1906. The deposits are in the form of a series of sub-parallel cross-fibre seams lying in gently inclined serpentinized dolomite directly above an intrusive sheet of basic igneous rocks. The fibre length ranges from the very rare maximum of 7 inches down to microscopic dimensions, but the average run of mine is in the neighbourhood of one-quarter to half an inch.

These deposits are traceable for several miles, always under the same geological conditions, but the output has so far been small and intermittent.

(*b*) In the *Barberton* District are the most productive chrysotile deposits so far found in the Union—within a wide and extensive belt of serpentine, along which fibre has been proved to extend for several miles. Here belongs the very important New Amianthus Mine, one of the richest chrysotile occurrences known from anywhere in the world, with the very high recovery of nearly 20 per cent., based on a lode-type of fibre channel, several feet wide, and yielding chrysotile of very superior quality; the mine is fully developed and equipped with an elaborate treatment plant. A little to the east lies the Munnik–Myburgh Mine in the same belt of serpentine.

(*c*) Within the basin of the *Komati River,* several deposits of chrysotile lie in another development of serpentine; the best of these occurrences are at Kalkkloof Mine.

(*d*) Recently a promising deposit has been opened up in Northern *Swaziland*—known as the Havelock Mine, close to the Transvaal boundary, some 11 miles south of Barberton.

6. *Anthophlitte* ("asbestic") is found on Korea north of the Zoutpansberg, and has been used in the local manufacture of boiler-lagging.

7. *Tremolite* was formerly exploited in Natal, as a slip-fibre deposit.

In *estimating the economic outlook* of the Union's asbestos industry it is essential not only to think internationally, but also to view the present situation in its historical perspective.

The basis of such an estimate is twofold, and may be formulated in these terms:—

(*a*) Great reserves of asbestos coupled with a complete range of varieties, and

(*b*) a great increase in production.

The first conclusion should be sufficiently clear from a perusal of preceding chapters; it secures that reliable geological foundation of continuity, without which all industrial superstructure must collapse. The second conclusion reinforces the solidity of the first, in showing a young industry raising its output from 7,000 to 33,000 tons in the space of 10 years; this is perhaps not a sensational result, measured on the scale of other and long-established base-metal industries, but it is a good beginning. It is difficult to believe that a new industry resting on such a basis should fail to advance to manhood.

One is apt, in estimating mineral industries, to have in mind, consciously or perhaps unconsciously, the outstanding importance of precious metals and to overlook the fundamental difference between gold, for example, and base metals. This great economic distinction is not always sufficiently appreciated by those who are not in close touch with the many difficulties to be overcome in marketing a competitive mineral; gold with its universal and growing demand, and diminishing resources, commands an instantaneous and world-wide market, while base metals meet with severe competition and cannot be disposed of at all, until the producer succeeds in finding a customer. The final success—after years of struggle—in obtaining for some of the Union's fibre varieties a permanent footing in the international market says much for the perseverance of the early discoverers, as well as for the quality of their ware; this result tends to increase one's confidence in the vigour of our asbestos industry and its expansion, notwithstanding those adverse market fluctuations that seem inevitably to dog for a time the progress of one or other field.

No doubt the pessimist thinking internationally, will be impressed by the very strong position held by the Canadian Chrysotile Fields, or perhaps view with concern the great advance made in the Rhodesian fibre exploitation; he may point out, how our unique command of almost unlimited resources of amosite and crocidolite concerns, after all, something less valuable than chrysotile. Then again, he will no doubt think of the Pietersburg Fields as they appeared in 1927 and contemplate the solitude that now reigns over much of the area that was dotted with a string of active mining camps only some two or three years ago. Failing to think historically, he will forget that there was a time, not so very long ago, when no asbestos at all was produced in any of the provinces, except one variety in a small portion of the Cape, now proved the most extensive asbestos field in the world; that there was also a time when the chrysotile deposits of the normal type were unknown in the Union, whereas to-day there is the solid asset of the New Amianthus Mine; similarly the entirely new and at first quite unsaleable amosite variety has to its credit to-day a fully developed and rich mine in the Lydenburg District, as well as additional resources, since proved over many miles.

On the other hand, the optimist also thinking internationally, and admitting the commanding position of Canada, will realize the significance of these facts:—That the spinnable proportion of fibre from that source only amounts to a fraction of the market requirements; that the control both of the great Rhodesian assets and of the largest chrysotile resources in the Union (and Swaziland) have now passed into the hands of the greatest asbestos manufacturing concern in the whole world, and that consequently the best chrysotile assets of the Union can and do enjoy exploitation on a scale not otherwise possible—to the obvious benefit of our rising fibre industry; that the solid footing now acquired by the same company also in the Cape Fields, may be expected to supply a powerful stimulus to the marketing of our crocidolite resources. The optimist likewise appreciates that amphibole has less value than olivine—asbestos, but does not forget, e.g. that linen has some definite market value, even though it is not as precious as silk. Turning also to the Pietersburg Fields, he will naturally regret their present shrinkage, yet remember that their exploitation has not come to a standstill, but only remains greatly restricted, owing almost solely to adverse market conditions, more likely of a transitory than a permanent nature, due to an economic situation of world-wide extent. He may perhaps also wonder whether, possibly, the recent somewhat feverish activity throughout these fields was not here and there unhealthy, and think of those features that are not unknown in the mining history of some other countries—over capitalization, unwarranted optimism with regard to quantity and quality in this or that portion of the fields, neglect of the best methods of development or market preparation, trying to lean on the reputation acquired by one or other deposit, etc. Thinking historically, the optimist will review the progress of the industry in its proper perspective and realize how much has already been accomplished to-day in competing successfully with the market of the world, while weighing the future prospects on the basis of the resources definitely known to be available. He will regard the varying fortunes of the Union's asbestos industry as features specially peculiar to a highly competitive base metal industry, and look upon the difficulties under which some of our fields at present labour as a passing chapter in the history of the industry.

It must be admitted that, in a young country, the attempt to establish local industries, based on domestic raw material, is liable to meet with great difficulties, not the least of which arises from the restricted home market, due in the end to our relatively small white population. As in some other industrial fields, it took a long time before asbestos goods manufactured in the Union figured in our domestic market, but this initial difficulty has been successfully overcome, and an increasing demand in favour of the home article is noticeable, e.g. in the requirements of building material. Thus the outlook for the South African asbestos manufacturing industry is encouraging. Under the general climatic conditions that prevail in our country, one may anticipate an eventual more extended use of asbestos goods, in which low heat conductivity is an outstanding feature.

Without, therefore, indulging in undue optimism, one may base the *general favourable economic outlook of the Union's asbestos industry* on the following summary factors, viz., that:—

(1) There are large reserves available of all the three principal fibre varieties, of commercial grade.

(2) Production shows a steady increase, and though not as yet very great, when viewed internationally, is a substantial contribution, when viewed domestically, towards the industrial development of a young country.

(3) The present reduced activity in certain fields is most probably a temporary phase in the economic situation, not caused by the resources being inadequate in quantity or grade, but mainly by international market fluctuations.

(4) The utilization of domestic supplies in the local manufacture of asbestos goods is now well established.

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APPENDIX I.

For the benefit of those interested in the surface features associated with the asbestos fields, the following list of heights for a few of the principal points is given; it includes several railway station levels and one Trigonometrical Survey Level (Iron Crown); the remainder are based on aneroid readings and therefore only approximate.

LIST OF HEIGHTS.

(Feet above sea level.)

Barberton Station	2,717
Burgersfort Station	2,440
Carolina Station	5,476
Chee, South of Kuruman	5,800
Chuniespoort	3,250
Corea	2,400
Cork (highest workings)	4,150
Devils Kantoor	5,520
Dublin (Schechter's Camp)	2,920
Emlembe Mountain	6,030
Forbes Reef Store	4,750
Fort Burger	2,250
Gakarusa, N. of Daniels Kuil	6,070
Gamohaan, W. of Kuruman	5,277
Gamopedi, N.W. of Kuruman	4,264
Godwan River Station	3,049
Graskop Station	4,721
Havelock Asbestos Mine	4,100
Iron Crown	6,964
Josefsdal Workings	4,250
Kaapsche Hoop Post Office	5,280
Kaapmuiden Station	1,182
Kaspers Nek	4,000
Korea	2,400
Kranskop	3,791
Kuruman	4,500
Komati River Bridge (Hlom Hlom)	3,160
Komati River Ferry (Swaziland)	2,150
Koegas	2,900
Lydenburg Station	4,660
Malips Drift Post Office	2,800
Messina Station	1,788
Molapatsi Drift	3,000
M'Thlapitsi Drift	3,030
Montana Camp	3,800
Montana Mine	5,300
Munnik-Myburgh Mine Office	3,800
New Amianthus Mine Office	4,200
Penge Mine	2,500
Oshoek Post Office	4,650
Pietersburg Station	4,109
Piggs Peak Police Post	3,350
Pilgrims Rest	4,500
Prieska Station	3,082
Sitilo Peak	2,450
Tugela Middle Drift	600
Tugela Randt	1,950

APPENDIX 2.

List of Asbestos Mining Concerns, 1929.

The following list of concerns engaged in asbestos prospecting, mining, or production (or otherwise interested in asbestos occurrences) is included for convenient reference. The writer is indebted to the Statistical Division of the Government Mining Engineer's Branch of the Department of Mines and Industries for this information.

A.—Cape Province.

Name.	Situation.	District.	Name of Chairman, Owner, Lessee, or Tributor.	Address.
* African Asbestos Co.	Amy's Hope, England	Kuruman	C. Ochse	P.O. Box. 3, Barkly West.
‡ Bechuanaland Asbestos Mines, Ltd.	Gathlose Native Reserve	Kuruman	G. A. E. Becker	P.O. Box 3185, Johannesburg.
* Blaauwputs Prospecting Syndicate	Blaauwputs	Prieska	E. G. Bryant	P.O. Box 11, Prieska.
* E. G. Bryant	Stoffbakkies	Prieska	E. G. Bryant	P.O. Box. 11, Prieska.
* Cape Asbestos Co., Ltd	Various	Hay, Prieska, and Vryburg	L. Breitmeyer	P.O. Box 40, Kimberley, C.P.
* Crown Land Mines	Khosis Native Reserve	Kuruman	C. Dyason	P.O. Khosis.
* De Hart, I. J	Middlewater	Prieska	I. J. de Hart	P.O. Box 17, Prieska.
* De Kroon Platinums, Ltd. (in liquidation)	Naauwgekueld	Prieska	J. W. H. Warren	P.O. Prieska.
* Dominion Blue Asbestos Mines (Prop.), Ltd.	Various	Kuruman	F. E. Roberts	P.O. Box 2536, Johannesburg.
* Edelstein, S., and Co.	Fonteinje	Prieska	S. Edelstein	P.O. Box 2, Prieska.
* Emslie, A. G.	Oudeplaats No. 61	Barkly West.	A. G. Emslie	P.O. Danielskuil.
* Fairport Asbestos Mines (Prop.), Ltd. (in liquidation)	Oudeplaats No. 61	Barkly West.	M. Cohn	P.O. Box 958, Johannesburg.
* Griqualand Exploration and Finance Co., Ltd.	Elandsfontein No. 395	Hay	C. O. Hager	P.O. Box 31, Griquatown.

* Producing during 1929. ‡ Not working in 1929.

Name.	Situation.	District.	Name of Chairman, Owner, Lessee, or Tributor.	Address.
‡ Groenwater Asbestos, Ltd........	Groenwater Native Reserve	Hay.........	C. A. Lagesen..........	P.O. Box 3692, Johannesburg.
* Hay Asbestos Syndicate.........	Lelijkstad No. 320........	Hay.........	F. J. de Klerk.........	P.O. Koegas.
* Hirschfield & Son..............	Brakpoort "A" and Rooidam	Prieska......	E. L. Hirschfield.......	P.O. Box 43, Prieska.
* Hopefield Asbestos Works........	Hopefield................	Hay.........	C. Edelstein...........	P.O. Griquatown.
* Kuruman Asbestos Co., Ltd.....	Mansfield and others......	Kuruman....	G. A. Chalkley.........	P.O. Box 5591, Johannesburg.
* Lovedale Asbestos Prospect......	Lovedale.................	Prieska......	H. R. Jefferson........	P.O. Prieska.
* Naauwpoort Asbestos Mines......	Naauwpoort and Kaffirkrantz	Hay.........	W. Corbett............	P.O. Niekerkshope.
* Nauga Asbestos Co., Ltd........	Kalkgat and Nauga......	Prieska......	A. G. Owen...........	P.O. Box 2213, Johannesburg.
* Northern Asbestos Syndicate....	Various..................	Hay, Kuruman	S. Weingarten..........	P.O. Box 625, Kimberley, C.P.
‡ Orange River Asbestos Mines, Ltd.	Stoffbakkies..............	Prieska......	H. J. Sexton..........	33–36 Goschen Buildings, London, W.C. 2.
* Orcadia Asbestos Co.............	Gamopedi Native Reserve.	Kuruman....	—	P.O. Box 3, Kuruman, C.P.
† Prieska Lands and Minerals (Prop.), Ltd.	Zoetvlei.................	Prieska......	A. Mathewson..........	P.O. Box 1607, Capetown.
* Riverside Asbestos Co..........	Riverside................	Prieska......	Oosthuizen and Opperman	P.O. Naauwpoort.
* Star Asbestos Syndicate.........	Gathlose Native Reserve..	Kuruman....	W. E. Page...........	P.O. Khosis.
‡ Union Asbestos Corporation, Ltd.	Government Ground......	Barkly West.	D. Christopherson......	P.O. Box 1167, Johannesburg.
* Van der Merwe, P. J. A........	Roodepan No. 389 and Kwakwas No. 318	Hay.........	P. J. A. van der Merwe	P.O. Koegas.
* Werbeloff, L...................	Blaauwboschkuil..........	Hay.........	L. Werbeloff...........	P.O. Niekerkshope.
* Werbeloff, L. B................	Klein Kaffirkrantz........	Hay.........	L. B. Werbeloff........	P.O. Prieska.
* Zeekoeneus Asbestos (Prop.), Ltd.	Zeekoeneus No. 357......	Hay.........	S. P. Lee..............	P.O. Box 3047, Johannesburg.

* Producing during 1929. † Worked in 1929, but did not produce. ‡ Not working in 1929.

B.—Transvaal Province.

Name.	Situation.	District.	Name of Chairman, Owner, Lessee, or Tributor.	Address.
* African Asbestos Trust, Ltd.....	Kalkkloof No. 250........	Carolina.....	J. Neilson.............	P.O. Box 619, Johannesburg.
* Amosa, Ltd....................	Streatham No. 251 and others	Lydenburg...	H. Eckstein............	P.O. Box 1676, Capetown.
* Central Asbestos Mines of S.A., Ltd.	Holkloof No. 1581 and others	Pietersburg..	J. C. Bitcon...........	P.O. Box 3053, Johannesburg.
* Christiane, C. F................	Klipfontein No. 4........	Johannesburg	C. F. Christiane........	P.O. Fontainebleau.
* Chunies Asbestos, Ltd...........	Koedoeskloof No. 608 and others	Pietersburg..	J. S. Hancock.........	P.O. Box 1920, Johannesburg.
† Cowlhan and Whiteley..........	Joubertsdal No. 99.......	Barberton....	Cowlhan & Whiteley....	P.O. Kaapsche Hoop.
† De Kaap Valley Asbestos Co. (Prop.), Ltd.	Government Ground......	Barberton....	S. P. Blackmore........	P.O. Box 66, Barberton.
* Dominion Blue Asbestos Mines (Prop.), Ltd.	Government Ground......	Pietersburg..	F. E. Roberts..........	P.O. Box 2536, Johannesburg.
‡ Doyershoek Asbestos Properties..	Doyershoek No. 145...... Groenvaly No. 204....... Belvue No. 82	Carolina..... Barberton....	S.A. Townships, M. & F. Corp., Ltd.	P.O. Box 311, Johannesburg.
* Egnep, Ltd....................	Penge No. 304........... Uitval No. 1791 and others	Lydenburg... Pietersburg	H. Eckstein............	P.O. Box 1676, Capetown.
† Fibratus (Prop), Ltd...........	Sterkspruit No. 239.......	Carolina.....	Sir J. v. Boeschoten....	P.O. Box 738, Pretoria.
* Graskop Asbestos Mine..........	Graskop No. 27..........	Pilgrims Rest	R. Wham..............	P.O. Graskop.
† Greenstone Asbestos Syndicate...	Dolton No. 261..........	Barberton....	E. Budd..............	P.O. Kaapmuiden.
* Hancock's Asbestos Co..........	Koodoo No. 332......... Zilverkop No. 31......... Driefontein No. 81....... Government Ground......	Barberton.... Carolina Krugersdorp Pietersburg	J. S. Hancock.........	P.O. Box 1920, Johannesburg.

* Producing during 1929. † Worked in 1929, but did not produce. ‡ Not working in 1929.

Name.	Situation.	District.	Name of Chairman, Owner, Lessee, or Tributor.	Address.
† Island Asbestos Co.	Government Ground	Pietersburg	H. Norris & F. W. Fell	P.O. Box 1798, Johannesburg.
‡ Joubertsdal Asbestos Co., Ltd.	Joubertsdal No. 99	Barberton	G. S. Persse	P.O. Box. 989, Johannesburg.
‡ Kaapsche Hoop Asbestos (Prop.), Ltd.	Berlin No. 119	Barberton	F. Bennetts	P.O. Kaapsche Hoop.
* Kalkkrans Asbestos, Ltd	Rietfontein No. 70 and others	Carolina	W. A. Harper	P.O. Box 6656, Johannesburg.
* Klipfontein Asbestos Mine	Klipfontein No. 4	Johannesburg	C. F. Chritiane	P.O. Fontainebleau.
* Montana Asbestos Mine	Government Ground	Pietersburg	M. Haskel	P.O. Malipsdrift.
* Munnik-Myburgh Asbestos (Kaapsche Hoop), Ltd.	Joubertsdal No. 99	Barberton	W. K. Baxter	P.O. Box 989, Johannesburg.
* New Amianthus Mines, Ltd	Joubertsdal No. 99 and others	Barberton	F. E. Roberts	Kaapsche Hoop, E. Transvaal.
* Northern Asbestos Mines (Prop.), Ltd.	Kranskloof No. 1786 and others	Pietersburg	L. Kramer	P.O. Box 7505, Johannesburg.
† Pietersburg Asbestos, Ltd.	Government Ground	Pietersburg	G. V. Leather	P.O. Box 152, Pietersburg.
† P.O.D.S. Consolidated Dev. Syndicate, Ltd.	Government Ground	Barberton	A. de Klerk	P.O. Box 775, Johannesburg.
‡ Sebato Mineral Exploration (Prop.), Ltd.	Diepgezet No. 37 and others	Barberton	E. Jacobson	P.O. Box 6933, Johannesburg
* Seelig Asbestos Mines, Ltd.	Middelrand No. 480 and others	Pietersburg	J. Donaldson	P.O. Box 3308, Johannesburg.
* South African Consolidated Asbestos, Ltd.	Government Ground	Pietersburg	H. Nielsen	P.O. Box 1244, Joh nnesburg.
† Southern Amianthus Development Co., Ltd.	Uitkyk No. 165	Barberton	S. Morel	P.O. Box 6940, Johannesburg.

* Producing during 1929. † Worked in 1929, but did not produce. ‡ Not working in 1929.

Name.	Situation.	District.	Name of Chairman, Owner, Lessee or Tributor.	Address.
† Standard Asbestos Co., Ltd......	Eton No. 510 and others.	Letaba......	A. Pratt...............	P.O. Box 5281, Johannesburg.
† Transvaal Alluvial Metals Syndicate (Prop.), Ltd.	Fochabers No. 459 and others	Lydenburg...	G. Giannopoulos........	P.O. Box 6716, Johannesburg.
	Magdalena No. 216.......	Letaba		
† Union Asbestos Corporation, Ltd.	Government Ground......	Pietersburg..	E. D. Richardson......	P.O. Box 1167, Johannesburg.
† Union Minerals Exploration Syndicate, Ltd. (in liquidation)	Sterkspruit No. 239.......	Carolina.....	G. A. E. Becker.......	P.O. Box 3185, Johannesburg.

C.—Natal Province.

* Brightside Asbestos Syndicate.....	Native Reserve...........	Alfred.......	S. W. Brewer..........	498A West Street, Durban.
† Zululand Asbestos Syndicate.....	Native Reserve No. 19....	N'Kandhla...	J. Pullar..............	P.O. Box 1146, Durban

* Producing during 1929. † Worked in 1929, but did not produce.

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

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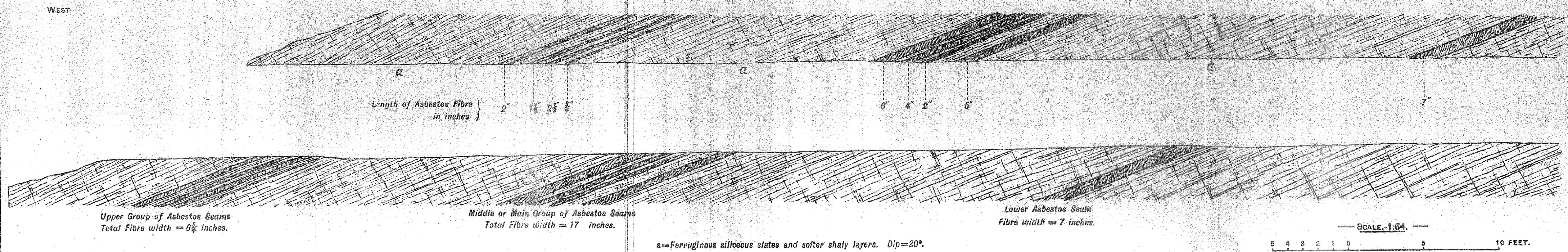
UNION OF SOUTH AFRICA. DEPARTMENT OF MINES AND INDUSTRIES,—GEOLOGICAL SURVEY.

Memoir No. 12, Second Edition, PLATE XXXIV

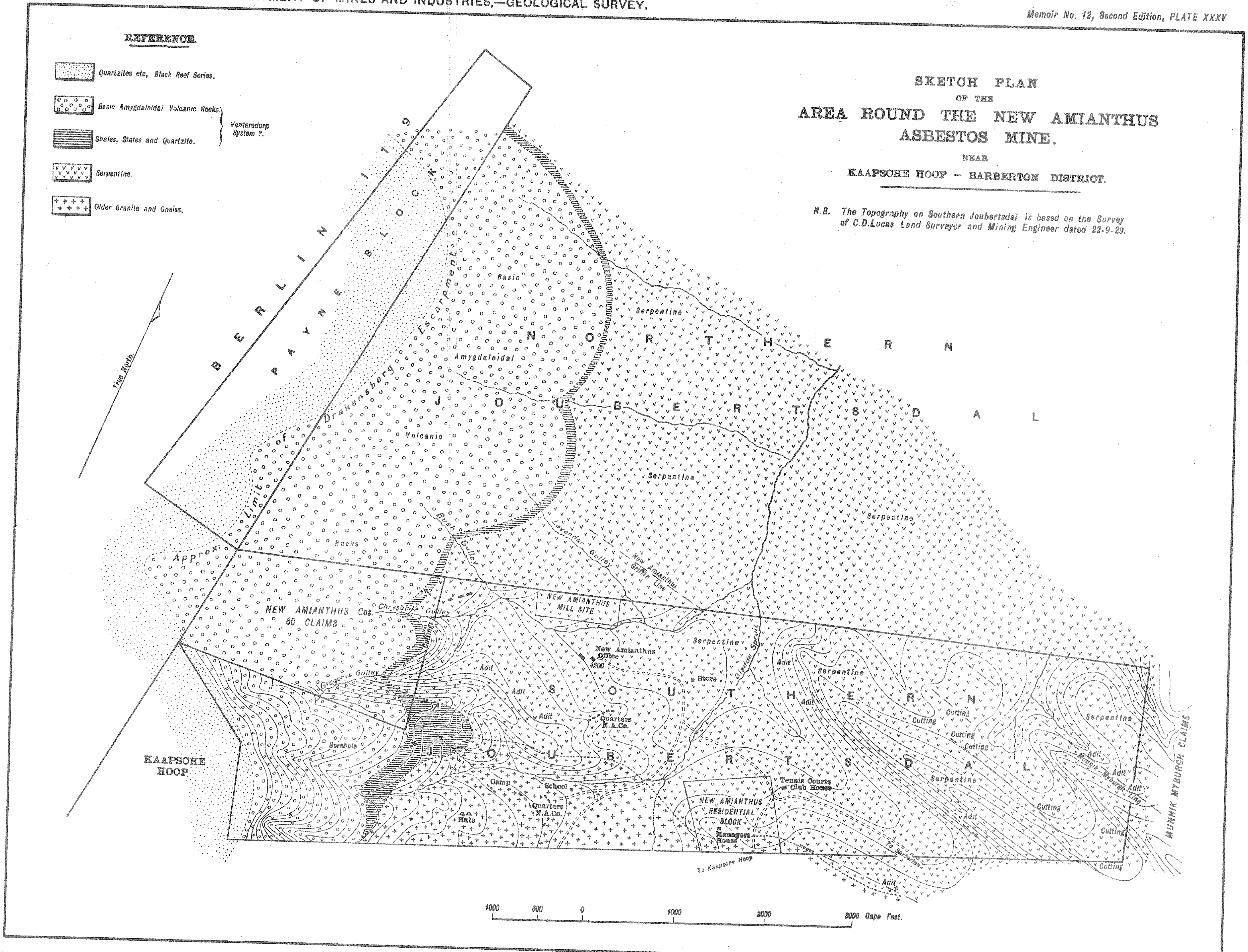
SECTION ALONG FIRST LEVEL, "B" SECTION, PENGE—SHOWING THE DISTRIBUTION OF THE AMOSITE SEAMS.

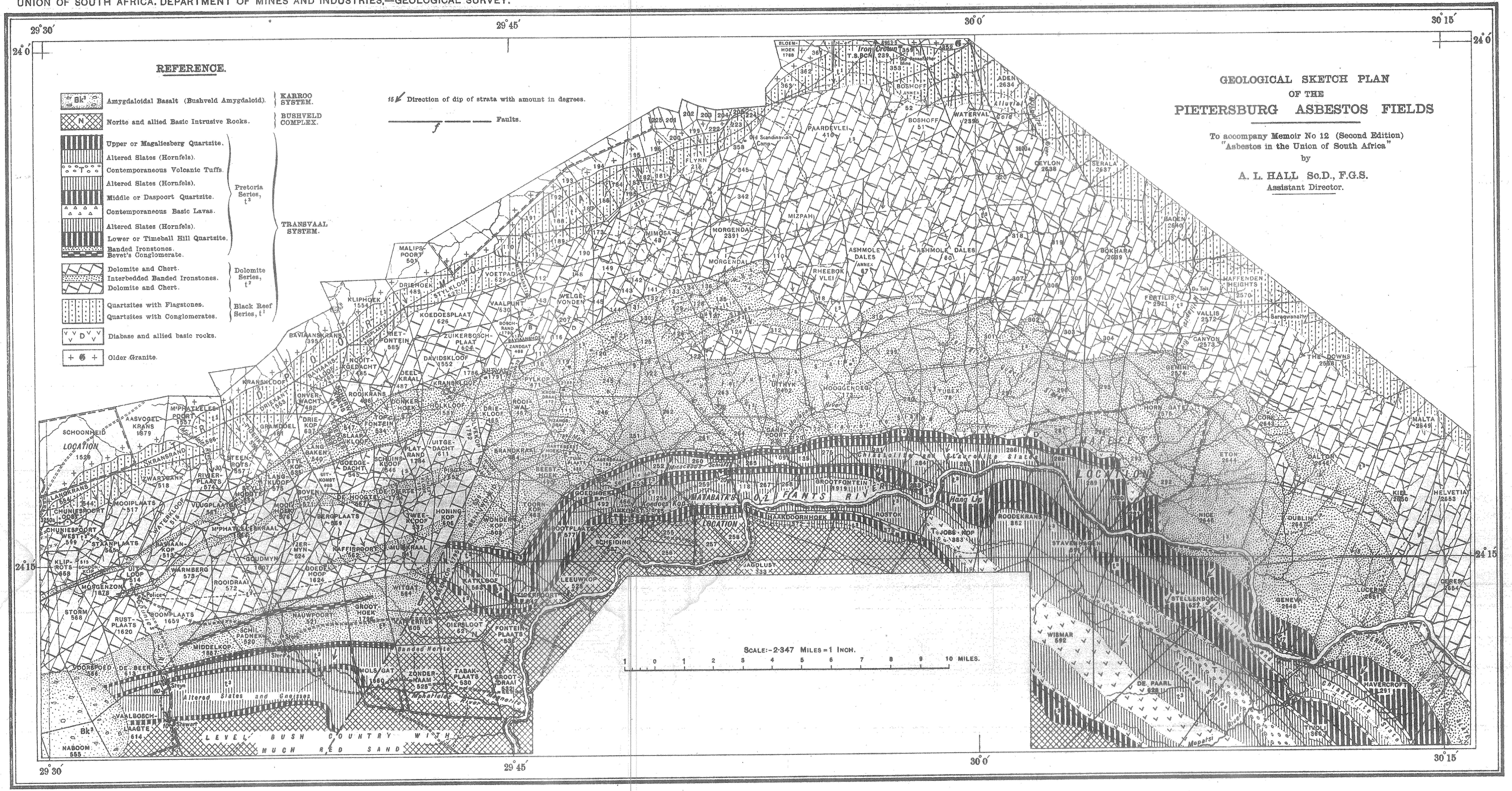


a=Ferruginous siliceous slates and softer shaly layers. Dip=20°.

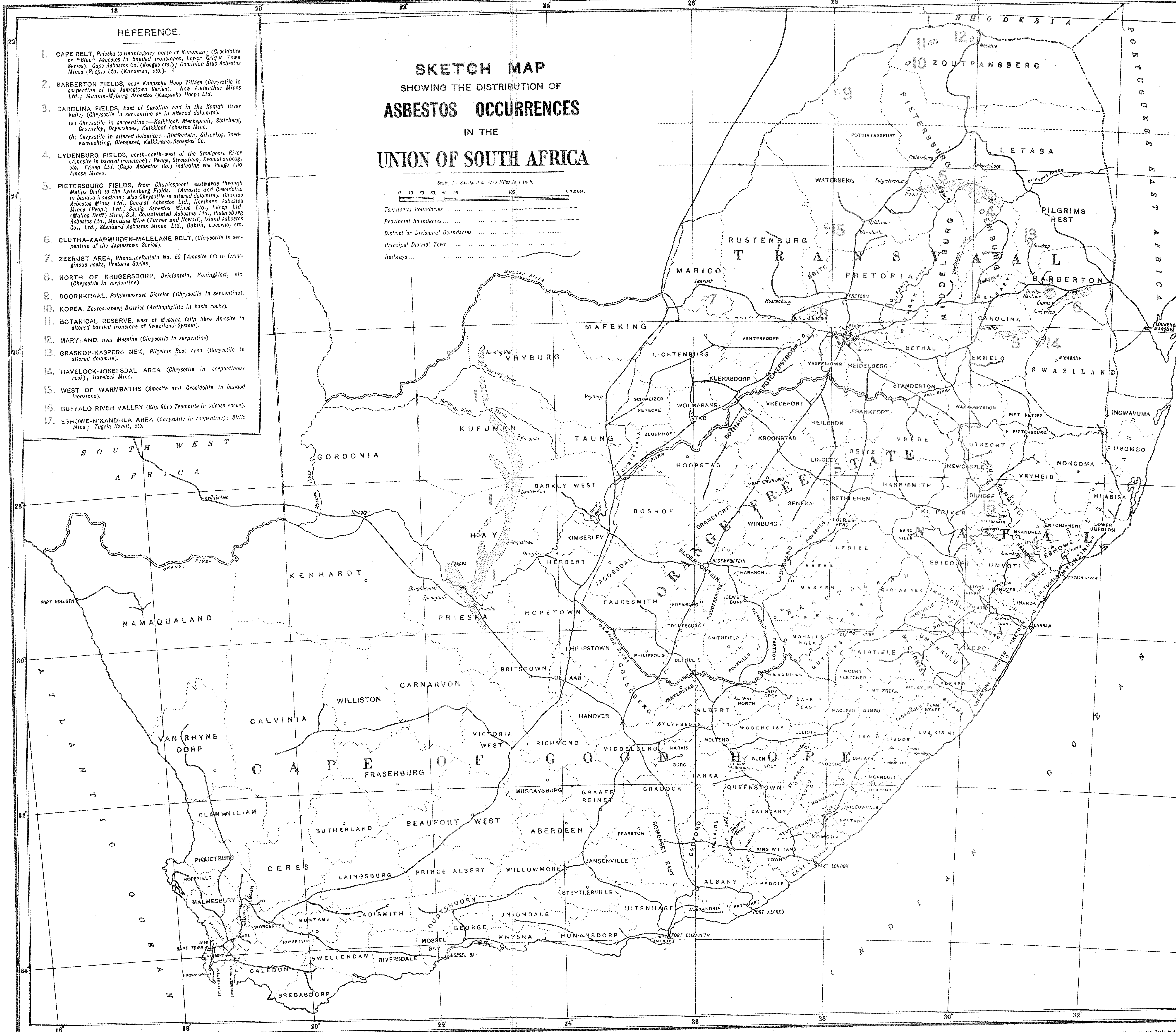
SKETCH PLAN OF THE AREA ROUND THE NEW AMIANTHUS ASBESTOS MINE. NEAR KAAPSCHE HOOP – BARBERTON DISTRICT.

N.B. The Topography on Southern Joubertsdal is based on the Survey of C.D.Lucas Land Surveyor and Mining Engineer dated 22-9-29.





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



Drawn in the Geological Survey Office.
Helio-zincographed at the Government Printing Works, Pretoria.

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