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PART I.

THE BLUE ASBESTOS BEARING BANDED IRON FORMATIONS OF THE HAMERSLEY RANGES, WESTERN AUSTRALIA,

BY

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AND

PART II.

THE BLUE ASBESTOS DEPOSITS OF THE HAMERSLEY RANGE AND THEIR ECONOMIC IMPORTANCE,

BY

J. S. FOXALL, B.E. (Syd.), M.I.E. Aust.
ASSISTANT STATE MINING ENGINEER.

WITH TWO APPENDICES.

1. The Yampire Gorge Crocidolite Deposits (1937), F. G. Forman.
2. Report on the Hamersley Range Blue Asbestos (1938), J. S. Foxall.

Issued under the authority of the Hon. A. H. Panton, Minister for Mines.

WITH TWO PLATES AND TEN FIGURES.



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PREFATORY NOTE.

Increasing interest during recent years in the blue asbestos deposits of the Hamersley Ranges led to the decision to publish the available information as Bulletin No. 100 of the Geological Survey. This Bulletin comprises two parts which are complementary.

In Part 1 written by Mr. Keith R. Miles of the Geological Survey, the crocidolite asbestos deposits and the associated rocks of the Hamersley Ranges are described from the point of view of the petrology of the rocks and the mineralogy and microscopic characters of the crocidolite itself. A comparison is made between these deposits and the blue asbestos-bearing banded iron stones of the Cape Province in the Union of South Africa.

Part 2 of the Bulletin written by Mr. J. S. Foxall, Assistant State Mining Engineer, describes the deposits from the practical mining point of view and lays particular stress on the extent and economic importance of recent discoveries at Marramamba.

Two earlier reports dealing with blue asbestos deposits in various parts of the Hamersley Ranges are attached as appendices to Part 2 in order to complete the record of our knowledge of these deposits.

F. G. FORMAN,
Government Geologist.

Geological Survey Office,
Perth, 8th October, 1941.

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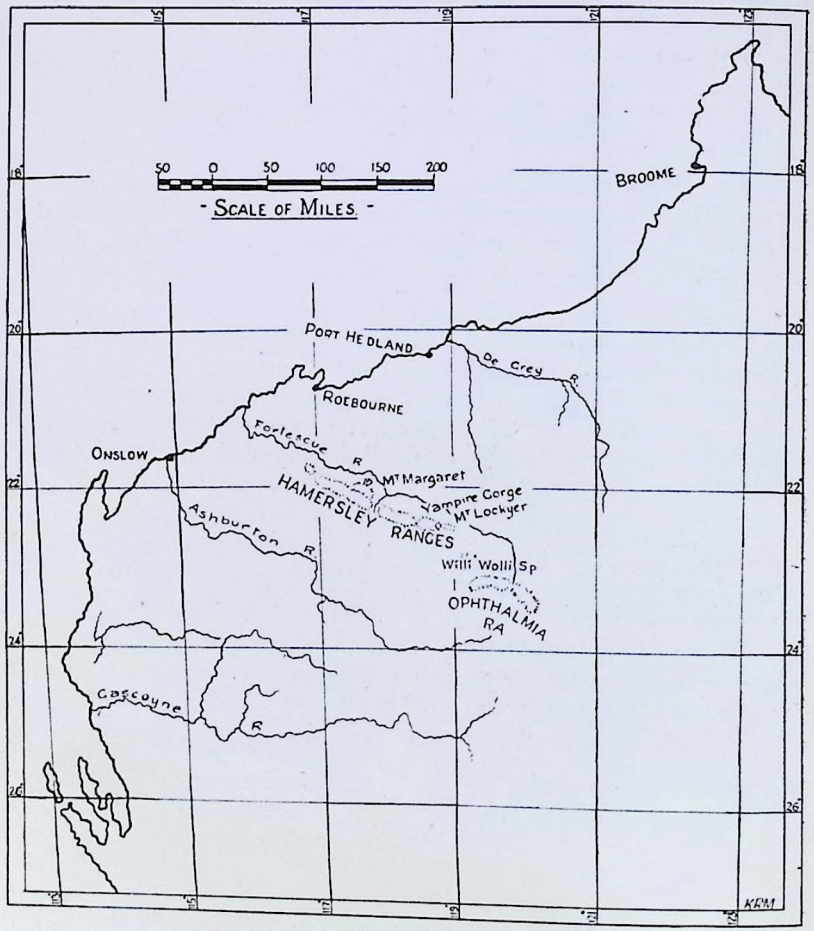


Figure 1.
Locality Map, showing the position of the Hamersley Ranges in the North-West of Western Australia.

PART I.

THE BLUE ASBESTOS BEARING BANDED IRON FORMATIONS OF THE HAMERSLEY RANGES, WESTERN AUSTRALIA,*

BY

KEITH R. MILES. B.Sc. (HONS.).

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*This work represents portion of a thesis submitted in part fulfilment of the requirements for the degree of Doctor of Science in the University of Western Australia.

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INTRODUCTION.

First reports of the occurrence of blue amphibole asbestos, crocidolite, in the rocks of Nullagine age in the Hamersley Ranges, North-West Division of Western Australia, reached official circles many years ago. It was not, however, until 1929 that any credence was attached to them.

In that year E. S. Simpson published a brief account of the mineralogy of some crocidolite specimens from Mt. Margaret and Willi Wolli Springs (1). He indicated that specimens of cross fibre from both localities were enclosed in a form of banded siliceous ironstone, but beyond that little was known of the geological associations and field occurrence of this mineral. In the following years, reports of a demand for blue asbestos resulted in a considerable amount of prospecting in the search for commercial quantities of long fibre material and a number of deposits were located and opened up. These were examined and briefly reported on by F. G. Forman in 1937 (2) and by J. S. Foxall in 1938 (3)*, and later were the subject of a fairly comprehensive report by K. J. Finucane of the Northern Australia Survey (4). More detailed descriptions of the mining and of the general economic importance and extent of these deposits are contained in the report by J. S. Foxall, Assistant State Mining Engineer, published as Part II. of this Bulletin.

The reports by Messrs. Forman and Finucane both dealt primarily with the general field geology and mining of the blue asbestos deposits in this area, whilst the latter writer also included very brief descriptions of several interesting specimens and gave a short statement of his opinions regarding the origin of the cross fibre in these deposits.

The present paper is intended to be more or less complementary to the abovementioned reports and deals principally with the petrology of the rocks with which the crocidolite asbestos is associated, and also with the mineralogy and microscopic characters of the crocidolite itself. A fairly detailed comparison of these rocks with the crocidolite and blue asbestos-bearing banded ironstones of the Cape Province in the Union of South Africa has also been made.

*Extracts of these reports are published as appendices to Part II. of this Bulletin. See pp. 54, 55, et. seq.



Figure 2.

Contorted banded ferruginous chert from the Nullagine Formation, in cliff face at Coondinna Gorge, Hamersley Range. The dark rock on the left is laterite.
[Photo H. W. B. Talbot, G.S.W.A. Neg. 1270.]

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FIELD OCCURRENCE.

It may be of interest here to enumerate briefly the chief features of the geology of the known blue asbestos deposits in the Hamersley Range. This "Range" in reality represents a dissected high land plateau which extends east-southeastwards from about lat. 21° 30′ S., long 117° E., to the vicinity of lat. 23° 30′ S., long. 120° E., where it merges into the Ophthalmia Range (Fig. 1). These ranges consist principally of banded ironstones or ferruginous cherts, quartzites, shales and thin bedded dolomite, forming part of the Nullagine Series. The beds are horizontal or show limited amounts of warping, the maximum dip recorded by Finucane being eight degrees. More intensely folded portions of these beds—not necessarily asbestos-bearing, do however occur. (See Fig. 2.)

The crocidolite occurs as comformable seams enclosed in the banded ironstones which are frequently interbedded with thin bands of dolomite or of bluish amorphous "riebeckite rock." It should be noted here that, as far as is known, these banded ironstones of *Nullagine Age* form the *sole* host rocks for crocidolite asbestos seams in Western Australia. Finucane reports that no igneous rocks either in the form of dykes or sills were discovered in the immediate vicinity of those localities in which blue asbestos has been mined. Dolerite sills enclosed in potential asbestos-bearing banded ferruginous cherts have been recorded by H. W. B. Talbot (5) in the eastern portions of the Hamersley-Opthalmia Plateau, e.g., near Willi Wolli Springs. (See Fig. 3).

The asbestos bearing beds are exposed in the deep gorges and cliff faces carved out by the action of intermittent streams, mostly tributaries of the Fortescue River.

This type of country is to be found throughout the length and breadth of the Hamersley and Opthalmia Ranges over a total area of probably more than 7,000 square miles (4, Plate I.). Since the banded ironstones, etc., of the Nullagine Series appear to be substantially continuous over this area, it is probable that cross fibre seams of crocidolite also extend continuously throughout the series and the very small amounts now exposed represent only a minute fraction of the vast quantities of asbestos which must exist in these beds.

As regards the quantity and quality of blue asbestos known to be available in the Hamersley Ranges, Finucane (4, p. 20) concludes that although at the present time it is quite impossible to form any estimate of the total quantity of fibre available there is no doubt that it is considerable. He considers that the known deposits compare very favourably with those of the South African Cape Belt and that there is a probability of the Western Australian deposits containing a much greater proportion of long fibre ($> 1\frac{1}{2}$ in.).



Figure 3.

Cliff face near Willi Wolli Springs, showing folded and contorted banded ferruginous cherts bent into an arch by the intrusion of a dolerite sill.
[Photo H. W. B. Talbot, G.S.W.A. Neg. 1273.]

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PETROLOGY.

The rocks forming the banded iron formations (jaspers) within which the blue asbestos deposits have been found are in general finely banded, dense and fine grained and range in colour from greys and whites to dark reds, yellows and browns. The writer has had the opportunity of examining a fairly representative set of specimens of these rocks, and though some of them show serial characters they can be divided petrographically into the following main groups:—

1. Banded cherty carbonate rocks.
2. Banded ferruginous cherty carbonate rocks.
3. Banded ferruginous cherts and quartzites.
4. Riebeckite and crocidolite bearing rocks.

The first two types differ essentially in the quantity of iron oxide present. The third group includes rocks which have been found actually interbedded with riebeckite and crocidolite bearing beds, but which themselves contain no amphiboles. The mineralogy of the different forms of riebeckite and the petrography of the rocks which enclose them are described in the last group.

1. Banded Cherty Carbonate Rocks:

A typical specimen of this rock type (13973D)* is a fine grained, well banded yellowish grey rock consisting of alternating layers of dense grey flinty material, and lighter coloured yellowish, fine granular quartzite. Individual layers average about 1.5 to 2 mm. in thickness but some attain thicknesses of 12 mm. or more.

In section the rock consists of irregular wavy greyish-brown bands rather streaky and lenticular in habit running through a dense, pale greenish microcrystalline ground mass of cherty quartz.

The streaky grey bands consist of minute dusty granular aggregates reddish brown in reflected light—which appear to be slightly altered fine granular siderite. Scattered through these granular bands are strings of minute black opaque rhombohedral crystals of hematite and also scattered strings of coarser grains of hematite rimmed by limonite, and occasional dusty rhombs of carbonate (siderite) altered in more or less degree to dark granular limonite.

This rock is a siliceous type of banded sideritic chert in which some of the primary granular iron carbonate has been altered to oxide and later to the hydrated ferric oxide (as a result of surface weathering).

*All numbers in parenthesis refer to specimens registered in the Collection of the Geological Survey of W.A.

2. Banded Ferruginous Cherty Carbonate Rocks:

These are usually darker in colour than those of group 1 and are often, though not always, sharply and evenly banded. Specimens are made up essentially of alternate layers of well crystallised magnetite or hematite often rimmed by thin bands of brownish limonite, and set in a ground mass of dense dark green to brown cherty material.

Thin sections are usually characterised by the presence of layers of well crystallised porphyroblasts of hematite associated with bands rich in dark red rhombs—limonite and hematite pseudomorphs after original siderite. Occasionally bands almost free of iron ore and consisting essentially of granular greyish rhombic carbonate (siderite) with only a few scattered skeleton grains of hematite, are seen.

One very typical specimen of this type (13969D) consists in hand-specimen of amorphous looking blue-black bands of iron ore set in a dark brown matrix. Microscopic examination shows that these apparently massive ore bands consist of numerous distinct laminae of closely packed hematite granules, set between zones of irregularly but densely scattered crystals of hematite and some rather amorphous granular limonite (very rarely showing rhombic outlines) in a clear cherty quartzite base. The iron rich bands are minutely crinkled. Running through the ferruginous chert zones are several broken strings of coarser, well crystallised magnetite octahedra. These strings are often wholly or in part enclosed by a "pressure fringe" of clear fibrous quartz. This porphyroblastic magnetite and its associated quartz were the latest minerals to develop—they probably formed under some pressure—possibly during the period in which the whole rock was becoming minutely puckered and contorted.

3. Banded Ferruginous Cherts and Quartzites:

The rocks of this type differ chiefly from those of the previous group in that iron ore is predominant over the carbonate which is usually present only in secondary amounts or altogether absent. This may be due to a change in the conditions of original deposition, or the absence of iron carbonates may be wholly due to the fact that they have been converted under mild metamorphic conditions, to the oxides hematite or magnetite.

It has been found possible to distinguish two main types in this group, viz.:—

(a) Red banded (hematitic) fine grained cherts.

(b) Brown and white banded magnetite-hematite cherts and quartzites.

(a) Specimens of the first variety are (13969A) and (13969B & C) all of which come from the vicinity of Mt. Newman in the Opthalmia Range.

The former is rather more brown and yellow than red coloured but it is included here because of its close field association with the others and because of certain peculiarities of composition which it shares with them. It will be described first. The rock is finely banded, individual layers ranging from .05—1 mm. thick, and appears to have been somewhat silicified at the surface. The dark bands consist of compact, almost amorphous layers of finely divided granular iron ore, which judging from a translucent reddish marginal stain is predominantly hematite, set in between light grey to white bands. The light coloured bands are composed of layers of greyish semi-opaque granular material alternating with layers of clear colourless microcrystalline chert.

The greyish opaque material is white in reflected light. Blunt, rounded needles and irregular curved cylindrical, worm-like rods of this material project outward from the margins of the grey bands into the adjoining clear quartz-rich layers. These rods frequently have blunt or rounded terminations and numerous cross-fractures. They appear to be hollow. They are apparently isotropic and have a refractive index greater than quartz. Occasionally they are stained brown by limonite along the margins but are more frequently clear. It was at first thought that they might represent a granular form of calcium carbonate, but a portion of the rock on crushing and treatment with hot HCl gave no reaction for carbonate.

This peculiar material was noted and described by Farquharson (5, p. 181), but he also was unable to reach any conclusions as to its identity.

There is an occasional sprinkling of hematite crystals throughout these grey opaque bands. Goethite occurs in the rock as tiny yellowish acicular needles scattered through some layers richer in iron ore.

(13969B & C.) These are finely laminated dark red and black rocks consisting of alternate layers of dense bright red jasper (chert) and of dark coloured glistening, finely divided hematite. The bands appear minutely crinkled in some specimens.

In thin section the jasper layers are microcrystalline almost opaque and bright red under reflected light due to the presence of fine earthy hematite dust. The interstitial iron rich layers usually consist of a granular mosaic of euhedral hematite interlocked with clear quartz, and some red-brown limonite. Some parts of the specimen show a more sharply banded structure but in others the banding is ill-defined and the section appears almost opaque from the presence of closely packed layers of hematite crystal aggregates. Intercalated between the iron rich layers are lenses of red jasper and clear cherty quartz mosaics in which are scattered numerous greyish yellow to colourless isotropic jointed rods identical with those described above. Under high powers tufts of minute colourless to pale bluish acicular fibres may be seen

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sprinkled through the clear chert lenses. These fibres probably represent an incipient growth of fibrous riebeckitic amphibole similar to that described below.

(b) Specimen (2/1479), a banded magnetite-hematite chert or quartzite is a typical example of the second variety. It is a sample of the normal host rock for the crocidolite deposits of Yampire Gorge in the Hamersley Range.

This is a dark greyish fine-grained well banded rock consisting of a dark grey-brown chert base flecked with abundant minute glistening, silvery metallic-lustred crystals of iron ore, and also traversed by parallel bands of massive blue-black metallic iron ore ranging from paper thickness up to 2.5 mms. thick. These bands often trace out a rather crinkly undulating line, and here and there they split and swell out to surround almond shaped lenses of some dense light red-brown coloured material.

The iron ore of both the scattered individual crystals and the massive bands is intensely magnetic and on crushing yields a dark brown to black strongly magnetic powder. Thus it is predominantly magnetite.

In thin section the iron ore is seen to consist almost entirely of magnetite in equigranular, well crystallised cubic, octahedral and dodecahedral forms. These occur coalesced into bands parallel to the bedding, and also in scattered individuals. Occasionally adjoining bands of iron ore are linked by strings of magnetite crystals running across the bedding.

Where the bands are contorted, crushed or broken the magnetite is usually edged on one side by a clear zone of fibrous quartz, marking the areas from which pressure has been relieved by movement of the band. Intergrown with this fibrous quartz at the margins of the iron ore are occasional flakes of a pale greenish brown birefringent mineral which has the appearance of a mica.

The fine grained chert matrix enclosing the iron ore bands is itself banded and consists of alternate layers of fairly clear pale greenish material and bands dusted with abundant minute black specks, too small to be identified, some granules of clear carbonate, and cloudy reddish-yellow flakes of goethite.

One of the reddish brown almond shaped lenses enclosed in a band of magnetite was sectioned. It consists of a cryptocrystalline aggregate of almost opaque reddish scales and tiny roundish granules of limonite. This is probably the altered product of an original lens of granular iron carbonate. Here and there in the clear chert matrix clustered aggregates of red granular or amorphous limonite and opaline silica are developed. These occasionally have a general rhomb shaped outline and probably represent the remains of original siderite. No trace of

recognisable riebeckite was found in this rock though it is possible that a little of the yellowish acicular fibres of goethite present in the cloudy bands of the chert matrix may represent pseudomorphs after such an amphibole. The general grouping of the fibres is similar to the radiating bunches of incipient crocidolite to be described below.

An analysis of a specimen of host rock from Yampire Gorge probably identical with that described above was made in the Government Chemical Laboratory Laboratory in 1938 and is quoted below (Table 4, No. 4). A noticeable feature of this analysis is the predominance of iron in the ferric state indicating that a great deal of the magnetite has been oxidised to hematite, i.e., is martite. The low Na_2O content and absence of CO_2 reflects the absence of riebeckite and of existing siderite. Combined water is also low showing that limonite is an inconspicuous constituent. This analysis also indicates the presence of a small quantity of pyrite in the rock.

The close mineralogical and chemical similarity between this rock and the barren banded ironstone hosts of the South African crocidolite is shown by comparison with an analysis (Table 4, No. 5) of a typical rock from Prieska Kopje, Cape Province. This will be referred to later when dealing with the genesis of these rocks.

4. The Riebeckite and Crocidolite-bearing Rocks:

These rocks vary considerably in outward appearance depending upon the form taken by the riebeckite. For the most part these rocks are directly associated with and enclose the known deposits of blue asbestos seams, but some forms of riebeckite bearing rocks have been found in localities where no seams of crocidolite cross fibre are known.

During 1912-14 H. W. B. Talbot collected a suite of specimens including two (13973A and 13973B) which will be described later, from a gorge in the Hamersley Ranges some 2-3 miles east of Mt. Lockyer (5, pp. 105 and 178). The first was obtained from a cliff face interbedded with a horizontal bedded series of banded carbonated chert and banded hematite-magnetite chert. (13973B) came from a creek-bed at the bottom of the cliff. No asbestos seams are reported from this area. It may be noted here that Talbot (5, p. 104) states that in the vicinity of these rocks "there is an entire absence of the dolerite sills so common to the eastward."

A. *The Riebeckite-Crocidolite.—Optical Properties*:

The riebeckite in these banded iron formations of the Hamersley Range occurs in three distinct forms:—1, needle riebeckite; 2, mass fibre riebeckite or "potential crocidolite"; and 3, cross fibre riebeckite, or crocidolite proper (blue asbestos).

(i) *Needle riebeckite.*—This form is not common and has only been seen in one or two specimens. As it is the form, however, in which the optical properties of this interesting mineral may be most easily determined, it will be described first.

The best examples of needle riebeckite examined came from specimen (13973A) the locality of which has already been described. This rock is a banded magnetite-riebeckite-siderite chert.

In handspecimen it is a dense fine grained indistinctly but finely banded rock of dark brown colour containing numerous soft dull lustred dark blue-black bands with occasional layers of hard black metallic-lustred iron ore. On slightly weathered surfaces the fine brown cherty matrix enclosing these bands is pitted with tiny yellowish brown specks. Fragments of the iron ore bands on crushing yielded a black, intensely magnetic powder, indicating original magnetite.

Under the microscope riebeckite in the form of well crystallised individual needles can be seen scattered in random orientation throughout the rock but there is also a second generation of riebeckite present in clustered groups of very minute radiating fibres (mass fibre form—see below). (See Fig. 4A.)

The longest needles reach a total length of over 1 mm., the terminations of individual needles often passing into an aggregate of slender curved fibres giving them a feather-like appearance. Occasional basal sections are also to be seen. These are usually diamond shaped and show the (110) cleavages intersecting at almost 56° and 124°. The diamonds sometimes are shortened by the presence of the prism faces (010).

Individual needles are intensely pleochroic in the following colours:—

> X = deep (Prussian) blue, Y = indigo blue, Z = yellowish green; Absorption X slightly > Y > Z. The absorption colours are very strong and usually mask the interference colours. Refractive index is moderate, $\beta = 1.695$ approximately. Birefringence is weak.

The needles are length fast. Extinction $X \wedge c = 2 - 3°$ or less; Y = b. Dispersion is fairly strong—sections cut approximately normal to the axial plane (010) giving incomplete extinction.

Interference figures were masked by absorption, and consequently the optical sign and axial angle were not determinable.

Needles of this mineral can often be seen developing on rhombic crystals of iron carbonate or moulded against the margins of hematite and magnetite grains. It obviously represents one of the last formed minerals in the rock. In one section taken from a slightly weathered surface this riebeckite was occasionally seen to be altered to reddish brown hydrated iron oxide.

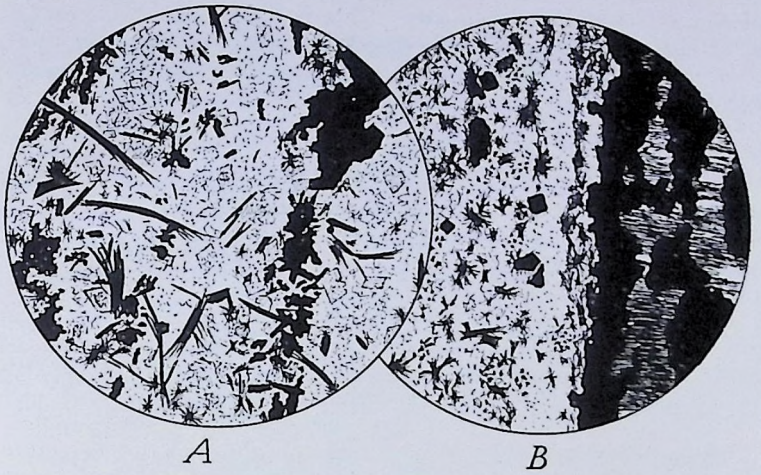


Figure 4A. (13973A.)

Banded ferruginous riebeckite-siderite chert from 10 miles S.S.W. by S. from Survey Station V28. Shows both "needle" riebeckite and "asteriated" or "mass fibre riebeckite (potential crocidolite) in a cloudy cryptocrystalline chert matrix containing numerous rhombs of siderite. Iron ore is present in two forms—massive coalesced octahedral magnetite, and granular masses and skeleton crystals of hematite.

Figure 4B (2/1474.)

Banded crocidolite-magnetite chert from Yampire Gorge. Showing portion of a typical cross fibre seam of crocidolite proper, associated with a magnetite-rich layer. The adjacent microcrystalline chert layer contains groups of asteriated mass fibre riebeckite, scattered magnetite crystals, and aggregates of red opaque granules representing the altered relicts of original siderite.

The recognisable optical properties of this mineral compare very closely with those of "needle" riebeckite and crocidolite from South Africa and Greenland, of babubudanite from Mysore, India, (6) and of rhodusite from Siberia.

The optics of the South African crocidolite were investigated in 1928 by M. A. Peacock (7) who gives for the "needle" form:—

> $\alpha = 1.698$; $\beta = 1.699$; $\gamma = 1.706$. Pleochroism strong, X = indigo; Y = yellow; Z = indigo. $X \wedge c = 0$; Z = b; X and Y may possibly be interchanged. A single basal section gave the angle of intersection of the prismatic cleavage as 54°. Due to the strong absorption and weak birefringence no optical figure could be obtained.

An interesting point arising from Peacock's close optical study of South African crocidolite is that the extinction angle is zero. This is not in accord with previously published data which usually give the

extinction as anything up to 20°. This is comparable with optical data of riebeckite and crocidolite from Greenland published by S. G. Gordon in 1927 (8) and is now generally accepted. Gordon gives for crocidolite from Narsarsuk, Greenland:—

$\beta = 1.701$; $\gamma - \alpha = 0.005$; X = methyl blue, Y = straw yellow ; Z = pale medici blue ; $X \wedge c = 0$; Z = b.

and for riebeckite from Narsarsuk, Greenland :—

$\beta = 1.071$; $\gamma - \alpha = 0.005$; X = greyish blue ; Y = yellow ; Z = dark grey ; $X \wedge c = 5°$; Z = b.

The optical orientation for both crocidolite and riebeckite given above differs from that obtained from the needle riebeckite of (13973A). Both Peacock and Gordon give Z parallel to the b-axis but in the Hamersley Range mineral the writer has always found Y = b.

The minerals bababudanite and rhodusite appear to represent an isomorphous series with riebeckite-crocidolite through the replacement of a considerable amount of the ferrous iron by magnesium and a little calcium (6). (See Table 1.)

The optical characters of bababudanite as given by W. F. Smeeth (6, p. 92) are:—

> Colour = black; angle between prismatic cleavage 56°; elongation is — ve; extinction $X \wedge c = 7\text{-}9°$; b = Y; pleochroism very strong; X = Prussian blue; Y = purple to violet; Z = yellow (with a tinge of green). Absorption = Y > X > Z; dispersion strong. The optical sign and axial angle are not known, because of the strong absorption and the difficulty of obtaining an interference figure.

As regards rhodusite the principal distinction from bababudanite appears to lie in the extinction angle which for the latter is $X \wedge c = 2 - 3°$.

(ii) *Mass fibre riebeckite or "potential crocidolite."*—The mineral in this form sometimes occurs in association with needle riebeckite (as in (13973A) described above). Where better developed, however, it forms a dense, fine-grained heavy, dark blue-black coloured rock. It may or may not show traces of a laminated structure, due to the presence of fine parallel layers of paper thickness of hard dark brown coloured chert running through the softer blue coloured amorphous mass of the rock. Exposed surfaces usually weather to a dark chocolate-brown colour.

A thin slice of a typical fresh, finely laminated specimen (13973B) shows that the soft blue material consists almost wholly of minute

fibres of riebeckite in fine grained mass aggregates and interlocking rudely asteriated or radiating groups. The banded structure is not very distinct but is nevertheless visible as masses of closely packed weakly birefringent fibres pleochroic from very dark blue to pale violet, which are usually partially separated only by thin layers of brownish cloudy microcrystalline chert. So densely packed are the bands, indeed, that the whole rock slice is almost opaque, and no other optical properties could be determined. A few altered grains of black iron-ore (magnetite) can be seen occasionally scattered through the rock but these usually appear to be in course of replacement by the amphibole.

This is the form referred to by Finucane and Forman (4) (2) as "amorphous riebeckite rock" and appears to be identical with the "Potential Crocidolite" in South Africa described by Hall (9, p. 61) and Peacock (7) (see below).

The analysis made in the Government Chemical Laboratory of this "potential crocidolite" rock is quoted below (Table 4, No. 2). Comparison of this with the Hamersley Range crocidolite proper (Table 4, No. 1) and with the South African potential crocidolite (No. 3) indicates an almost identical composition of these three types. Probably the higher water content in No. 2 is due to the presence of the weathering product limonite.

(iii) *Cross fibre riebeckite or "crocidolite proper."*—This is the form in which commercial blue asbestos fibre is obtained. The material occurs as seams of closely packed parallel fibres running transverse (usually about normal) to the borders of the seam and to the bedding of the rock. The writer has examined numerous specimens of crocidolite cross fibre seams from the Hamersley Ranges, and some of these display interesting features which are illustrated below. Fibre from individual seams in different specimens range in length from less than 1 mm. to about 2 inches (50 mm.). Following is a complete description of a specimen (2/1474) of banded crocidolite-magnetite chert from Yampire Gorge, Hamersley Range.

It is a dark brownish fine grained banded rock. One half of the handspecimen contains well crystallised bands of black metallic strongly magnetic iron ore traversed by narrow layers of dark blue fibrous riebeckite having a maximum thickness of about 1 mm. The fibres are arranged at right angles to the walls of the layers, i.e., the bedding planes of the rock. In between these magnetite-riebeckite bands are layers of clear brown aphanitic chert. In the other half of the handspecimen well marked bands of iron-ore are missing. Minute glistening metallic lustred crystals appear to be distributed fairly evenly through a dark brown faintly banded chert matrix, which contains abundant minute, parallel oriented streaks of soft yellowish-brown limonitic material.

In the banded portion of the rock riebeckite occurs in two forms. It is in parallel cross-fibred veinlets running through bands of crystalline magnetite and it also occurs in groups of very fine asteriated fibres in the adjacent cherty layers (See Fig. 4B). This latter form is identical with that described already in 13973 (A and B). No individual needles were found in this rock however. The radiating fibres have commonly developed about a central core consisting of a minute grain of iron ore (magnetite or hematite) or of siderite, in each case now more or less completely altered to limonite.

The cross-fibres of riebeckite occur in parallel intergrowth with clear quartz. The fibres are usually terminated at each end by magnetite crystals but occasionally they may be seen linked to magnetite at one end only, the other end being enclosed by quartz.

The mineral has colour and pleochroism identical with the riebeckite of (13973A) with:—

X = deep (prussian) blue; Y = slightly lighter indigo blue; Z = yellow-green; and the absorption is X > Y > Z.

Maximum extinction angle (X ∧ c) is probably less than 5°, and often apparently zero. Absorption colour was so intense as to mask most other optical properties. The cross fibres were all seen to have the same parallel optical orientation, the fibres of individual seams all showing a similar range of pleochroic colours (usually deep blue to indigo blue).

In a few places radiating riebeckite fibres can be seen altering to reddish opaque hydrated iron oxide, probably limonite.

The matrix enclosing the crocidolite-magnetite bands and also the asteriated riebeckite groups is very similar to that described in similar rocks above. It is banded and cloudy with inclusions of minute dusty granules and grains of reddish limonite whilst here and there can be seen scattered grains of iron carbonate also more or less altered to limonite.

A section of the less distinctly banded portion of the rock contains none of the parallel cross-fibre form of riebeckite but asteriated groups are fairly common in narrow zones. These are usually developed about a core of altered iron ore. The iron ore in this portion seldom occurs in bands of well crystallised aggregates but is present in two forms—scattered octahedra of magnetite, and oriented elongated patches consisting of a fine black opaque skeleton aggregate of either magnetite or hematite rather similar to that described in (13973A). These skeleton aggregates are altering to limonite.

Parallel oriented lenses and bands of granular siderite are also common in this part of the specimen. These lenses often partially enclose portions of the skeleton aggregates of iron ore and may in all probability represent the protore from which they have been derived. As a result of surface weathering the carbonate is all more or less cloudy with alteration to a red opaque, amorphous looking limonite. Riebeckite groups can occasionally be seen developing in these areas of granular siderite.

The composition of the material lying immediately adjacent to the edges of the cross fibre seams in the banded iron formations, is not always the same, and often differs on opposite walls of the same seam.

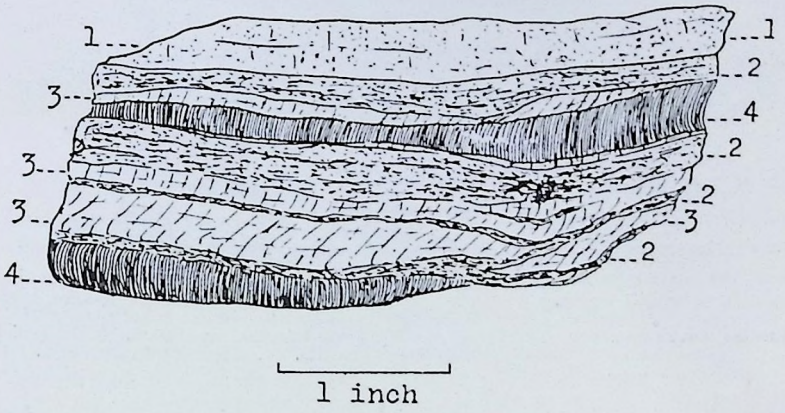


Figure 5.

Sketch of cross fibre crocidolite seams in banded ferruginous chert (2/1901), from Yampire Gorge, Hamersley Ranges. Shows interbedded layers of glassy cross-fibrous quartz. 1. Potential (mass fibre) crocidolite. 2. Crystalline magnetite. 3. Fibrous glassy quartz. 4. Crocidolite cross fibre.

One specimen (2/1898) from Wittenoom's Gorge contains a seam of typical cross fibre crocidolite about 2 inches wide. One wall is marked by a thin brown layer about .5 mms. thick containing glistening minute crystals of magnetite. On the other wall is a layer over 3 mms. thick of very fibrous pale blue to colourless glassy quartz (? quartzine). The fibres are transverse to the banding of the rock and appear to have formed in continuous sympathetic growth with the adjacent asbestos cross fibres. Next to the quartz is a sharply defined layer 3 mms. thick of dense fine grained metallic magnetite followed by alternating layers of brownish banded chert and magnetite. Fibrous quartz in a specimen (2/1901) from Yampire Gorge is illustrated in Fig. 5.

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In another specimen (2/1899) from the same locality the cross fibre is in direct contact on both walls with massive crystalline magnetite —one magnetite band, however, being much thicker than the other. (See Fig. 6.)

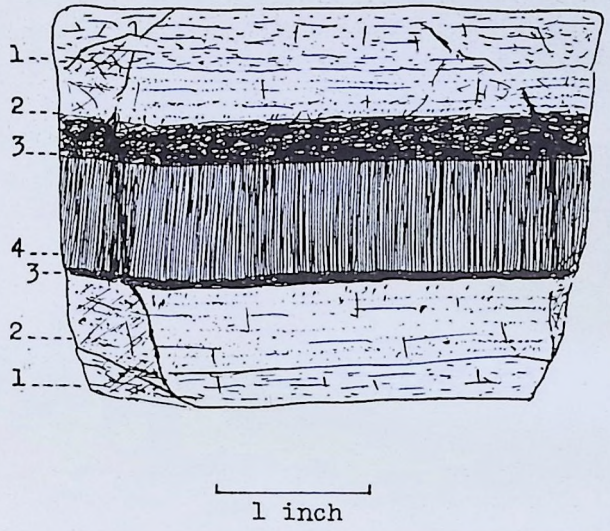


Figure 6.

Sketch of typical specimen (2/1899) of blue asbestos cross fibre in banded ironstone, from Wittenoom's Gorge, Hamersley Ranges. Shows bands of magnetite in contact with the asbestos. 1. Dark coloured banded ferruginous chert. 2. Yellowish banded chert. 3. Massive crystalline magnetite. 4. Cross-fibre crocidolite.

The effect of surface weathering on the crocidolite is interesting. In a specimen (2/1905) of highly weathered material from Wittenoom's Gorge, the cross fibre, while retaining its original form has changed from dark lavender blue to a bright yellow colour and has become brittle and friable and grinds between the fingers into a bright yellow ochre (limonite). Exposed surfaces, however, usually show a thin silicified and case hardened, buff-coloured skin which is almost as hard as the adjacent chert.

(iv) *Cone and corrugation structure.*—The fibre in these blue asbestos seams, although in general displaying an amazing uniformity in parallelism, length and continuity of growth, etc., is by no means perfect in these particulars and occasionally marked irregularities are developed in the seams. Nor do the cross fibres always trace out a perfectly straight path. They are frequently strongly curved whilst in some folded or "corrugated" specimens (2/1902) (See Fig. 7) irregularities in the growth and orientation of the crocidolite are shown by breaks or partings in the fibre.

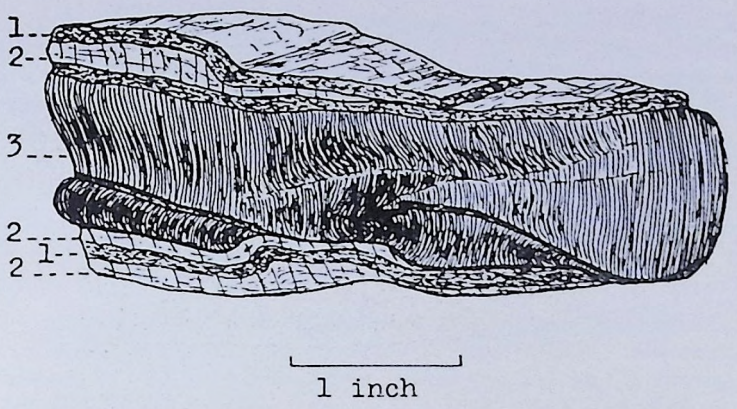


Figure 7.

Sketch of cross-fibre crocidolite seam showing parting and irregular curved growth accompanying "corrugated" structure, (spec. 2/1902) from Snell's Claim, Yampire Gorge, Hamersley Ranges. The asbestos is enclosed in banded magnetite chert containing interbedded layers of glassy cross-fibrous quartz. 1. Massive crystalline magnetite. 2. Glassy cross-fibrous quartz. 3. Cross-fibre crocidolite.

Several specimens e.g. (2/1903) from Yampire Gorge display the striking phenomenon of "cone" structures in an asbestos seam (See Fig. 8). These appear to be due to rapid and very sudden variations in the length of the fibres producing irregular peak-like protuberances and conical prolongations of country rock into the seam. In cross section the outlines of these "cones" approximate to curved equilateral triangles whose apices are directed either upwards or downwards into the seam, and whose axes more or less coincide with the common fibre orientation. It is noticeable that for any particular seam undulations and "cones" are invariably developed from the one side of the seam only. This rather suggests that the parallel growth of cross fibre proceeded always from the one side of a stratum of suitable composition, and variations in the rate of growth resulted in an irregular undulating surface for the other side of the resulting seam. Why these irregularities should assume a conical form, however, is something that is still obscure.

The material forming the cores of these cones is generally similar to the country rock of the wall from which they project.

In specimen (2/1903) (Fig. 8) the apex of the cone is formed by a thickening of the black metallic, magnetic crystalline hematite layer which separates the cross fibre from the adjacent dense blue amorphous potential crocidolite. Occasionally these cones may be partially filled with (secondary) brown carbonate of iron.

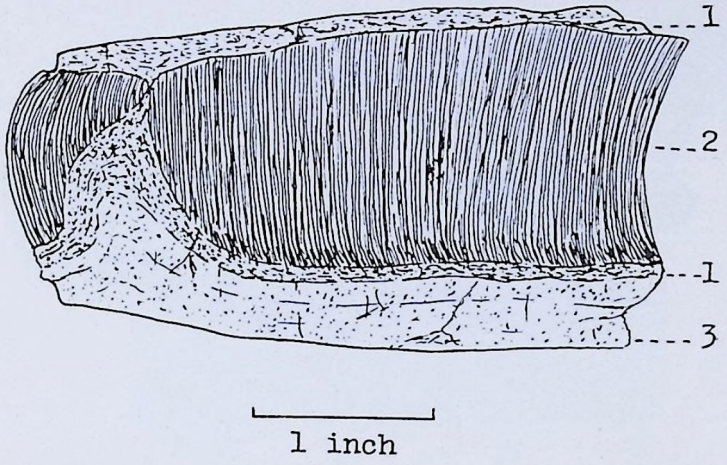


Figure 8.

Sketch of specimen (2/1903) of cross fibre crocidolite showing a cross section through a "cone," from Snell's Claim, Yampire Gorge, Hamersley Ranges. 1. Crystalline magnetite. 2. Curved cross-fibre crocidolite. 3. Dense potential (mass-fibre) crocidolite.

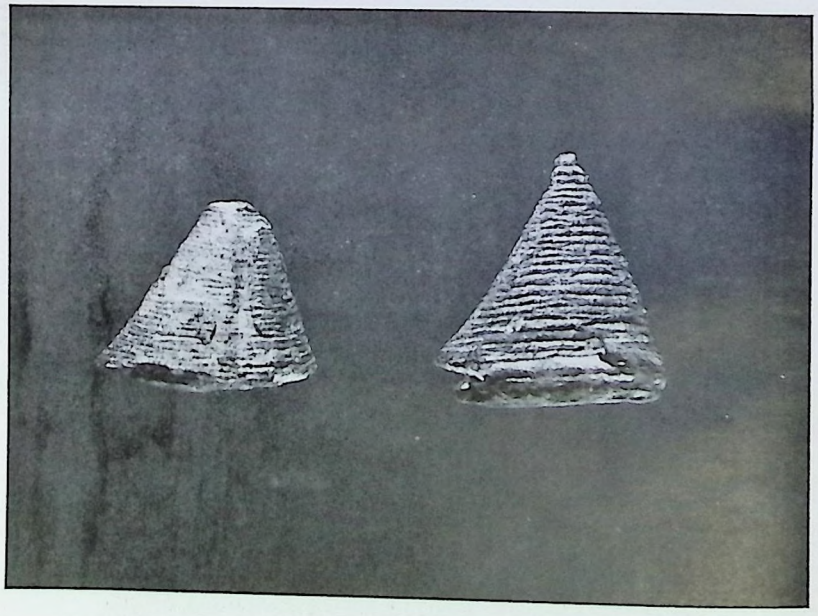


Figure 9.

Cones from crocidolite seams, Wittenoom's Gorge, Hamersley Ranges. (Spec. 2/1904.) Cones separated from enclosing fibre and showing concentric growth lines of fibre. (Natural scale.)

[Photo H. J. Smith.]

Figs. 9 and 10 illustrate several beautiful examples of these cones separated from the enclosing fibre and of one cone partially enclosed by cross fibre (2/1904 from Wittenoom's Gorge). These show on their surface concentric circular furrows marking the concentric layers of equal growth in the enclosing fibre.

Cone and corrugation structures in the South African blue asbestos deposits have been described and figured by A. L. Hall (9, pp. 78-83, pp. 258-9, and Figs. 4 and 7, Plate XVII., etc.), and their relation to the genetic problem briefly discussed. They appear to be fairly common in that country.

The presence of cone and corrugation structures in asbestos seams is of considerable economic significance since it infers a continuous variation of the fibre length with consequent increased difficulties in estimation of ore values, and in grading of the fibre, etc., which means a resulting decrease in the ultimate values of the material obtained.

K. J. Finucane (4, pp. 7-9), has made brief reference to these irregularities in the growth of the crocidolite cross fibre, and he also mentions the occasionally associated fibrous quartz bands which he calls "fibrous silica or incipient fibre." He has illustrated these features in a number of sketches, several of which are of specimens similar to those illustrated here.

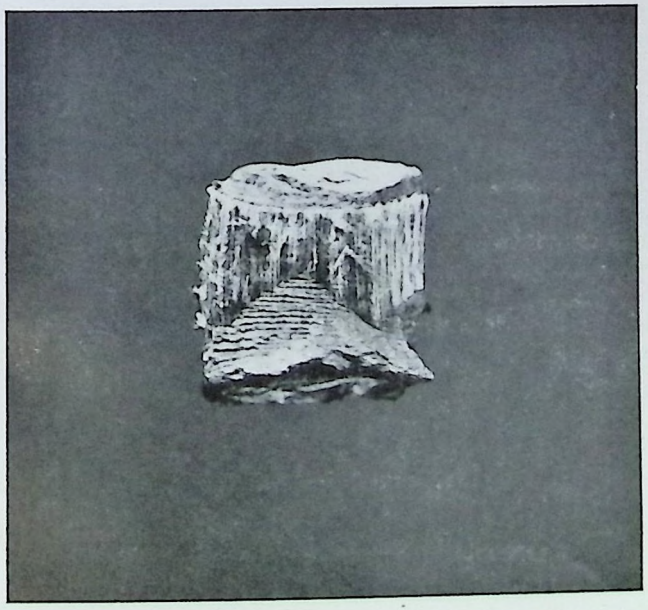


Figure 10.

A cone partially enclosed by cross fibre. (Natural scale.)

[Photo H. J. Smith.]

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Table 1.—Chemical Analyses of Crocidolite and allied Amphiboles.

		1.	2.	3.	4.	5.	6.
SiO_2	...	51·86	51·94	51·94	50·50	54·48	54·01
Al_2O_3	...	·03	·24	·20	...	2·10	·23
Fe_2O_3	...	20·26	18·93	18·64	20·20	15·79	15·70
FeO	...	14·84	15·25	19·39	15·40	5·02	9·42
MnO	...	·01	·01	...	...	·08	·14
MgO	...	3·26	3·94	1·37	3·65	12·11	10·01
CaO	...	·49	·40	·19	·80	1·04	1·52
Na_2O	...	6·12	6·00	6·07	4·40	6·34	6·22
K_2O	...	·28	·26	·04	...	·32	·35
H_2O+	...	1·97	2·67	2·58	4·15	·40	2·25
H_2O-	...	·68	·72	·31	1·05	...	...
TiO_2	...	·03	·01	...	...	*Nil*	Tr.
CO_2	...	·02	*Nil*	...	...	...	...
P_2O_5	...	·05	*Nil*	...	...	Tr.	...
Cr_2O_3	...	*Nil*	*Nil*	...	...	...	...
						·63	Residue*
		99·90	100·37	100·73	100·15	98·31	99·85
G	... ...	3·31	3·27	...	...	3·18	3·12
Analyst	...	J. N. Grace	J. N. Grace	H. E. Vassar	J. McCrae	W. F. Smeeth	Abst. Jour. Chem. Soc. No. D. XLVII., May, 1908

1. Crocidolite from three miles west of Mt. Margaret, Hamersley Range (1, pp. 38–9).
2. Crocidolite from eight miles south-east of Willi Wolli Springs, Hamersley Range (1, pp. 38–9).
3. Fine blue fibrous Crocidolite from Kliphuis, eight miles north of Prieska, Griqualand West, South Africa (7).
4. Crocidolite from Kuruman, Bechuanaland, South Africa (4, p. 6).
5. Bababudanite from Bababudan Hills, Mysore, India (6, p. 94).
6. Rhodusite from Siberia (6, p. 94).

B. *Chemical Composition of the Crocidolite.*

Chemical analyses of typical cross-fibre riebeckite (crocidolite) from the vicinity of Mt. Margaret and Willi Wolli Springs in the Hamersley Ranges were published by E. S. Simpson in 1930 (1). These analyses are given in Table 1 and with them for comparison have been placed analyses of typical crocidolite from South Africa, of bababudanite from Mysore, India, and of rhodusite from Siberia.

* 0·63 per cent. residue insoluble in HF and H_2SO_4. Not $BaSO_4$ or TiO_2. Zr or one of the earths of that group.

Simpson (1, page 39) in discussing the analyses (Nos. 1 and 2) of Western Australia crocidolite considered that they contained excesses by weight of silica and water (thought to be due to thin films of talc or opal on the surface of the fibres) over theoretical requirements (unstated) amounting to 3·54 per cent. and 3·78 per cent. of SiO_2, and 1·42 per cent. and 2·27 per cent. of H_2O respectively. By deducting these he obtained the following figures in terms of known and assumed isomorphous molecules :—

		1. Per cent. mols.	2. Per cent. mols.
$NaFe'''(SiO)$	... ...	50·8	49·5
$Fe''(SiO)$	... ...	36·8	39·5
$HFe'''(SiO)$	... ...	12·4	11·0
		100·0	100·0

From the analyses in Table 1, crocidolite is seen to be essentially a meta-silicate of iron, containing a large percentage of both ferric and ferrous iron, the former probably being slightly in excess of the latter. Soda is an essential constituent (4–7 per cent.), while magnesia, lime and alumina are low. According to Peacock (7), the general formula for crocidolite should be represented by the three molecules— $R_2O_3.RO.SiO_2$; $R_2O_3.RO.4SiO_2$; and $RO.SiO_2$, in order to maintain a balance between the silica and the bases, particularly when the analyses show notable proportions of sesqui-oxides. Peacock calculated the actual composition (empirical formula) of the South African mineral according to recent analyses, including that in Table 1 (No. 3), as

$3H_2O, 2Na_2O, 6(Fe,Mg)O, 2Fe_2O_3, 17SiO_2$, in which H_2O is wholly basic.

As a basis for comparison and in order to check the analyses of Table 1, the structural formulae of these amphiboles were calculated on the basis 24 (O,OH,F.)—these calculations made from the analyses after disregarding H_2O—and CO_2, and recalculating to 100 as shown in Tables 2 and 3. The structural formulae so obtained have then been compared with the ideal tremolite formula as determined by B. E. Warren (10).

The results of these calculations cannot be regarded as conclusive as in no case has an estimation of fluorine been made, although the possible error from this source is probably very slight owing to the small amounts of fluorine likely to be present in these comparatively low grade amphiboles.

The ideal structural formula for tremolite is—

$(OH,F)_2\ (Ca,Na,K,Mn)_{2\text{-}3}\ (Mg,Fe,Ti,Al,Mn)_5\ (SiAl)_8\ O_{22}$ (after Warren).

Table 2.—Calculation of Crocidolite from Mt. Margaret.

		Weight per cent.		Molecular Proportions.	Metal Atoms on basis of 24(O,OH.F)		Metal Groups.
SiO_2	...	51·86	52·29	·871	7·932		8·00
P_2O_5	...	·05	·05	·000[4]	·007		
Al_2O_3	...	·03	·03	·000[3]	·005		
TiO_2	...	·03	·03	·000[4]	·007		
Fe_2O_3	...	20·26	20·43	·127	2·313	·049	
						2·264	
MgO	...	3·26	3·28	·082	·747		4·90
FeO	...	14·84	14·96	·207	1·886		
MnO	...	·01	·01	·000[2]	·002		
Na_2O	...	6·12	6·17	·099	1·803		
CaO	...	·49	·49	·008[8]	·080		1·94
K_2O	...	·28	·28	·003	·054		
H_2O+	...	1·97	1·98	·110	2·002		
$H_2O—$	...	·68	...				2·00
CO_2	...	·02	...				
		99·90	100·00				

This analysis gives the formula—

$(OH)_{2\cdot00}(Ca,Na,K)_{1\cdot94}(Fe''',Mg,Fe'',Mn)_{4\cdot90}(Si,Al,Ti,Fe'''P)_8O_{22}$.

The approximate structural formula of the crocidolite from Mt. Margaret, Hamersley Range (Table 2) is—

$(OH)_2\ (Na,Ca,K)_{1\cdot94}\ (Fe''',Fe'',Mg)_{4\cdot90}\ (Si,Fe''')_8O_{22}$.

This is assuming that Si is replaced in small amounts by Fe and neglecting the very small quantities of P, Al, Ti and Mn in the analysis, and it agrees very closely with ideal formula.

The analysis of the mineral from Willi Wolli Springs (Table 3), gives the approximate formula—

$(OH)_{2\cdot66}\ (Ca,Na,K)_{1\cdot85}\ (Fe''',Fe'',Mg)_{4\cdot81}\ (Si,Fe''',Al)_8O_{22}$.

There is a distinct excess of (OH) over the requirements for the ideal amphibole structure.

Table 3.—Calculation of Crocidolite from Willi Wolli Springs.

		Weight. per cent.		Molecular Proportions.	Metal atoms on basis of 24(O,OH.F).		Metal Groups.
SiO_2	...	51·94	52·13	·868[8]	7·821		8·00
Al_2O_3	...	·24	·24	·002	·036		
TiO_2	...	0·01	·01	·000[1]	·001		
Fe_2O_3	...	18·93	19·00	·119	2·142	·142	
						2·000	
MgO	...	3·94	3·95	·099	·891		4·81
FeO	...	15·25	15·30	·213	1·917		
MnO	...	·01	·01	·000[1]	·001		
Na_2O	...	6·00	6·02	·097	1·746		1·85
CaO	...	·40	·40	·007	·063		
K_2O	...	·26	·26	·002	·036		
H_2O+	...	2·67	2·68	·148	2·664		2·66
$H_2O—$	...	·72	...	...	...		...
		100·37	100·00				

Giving the structural formula—

$(OH)_{2\cdot66}\ (Ca,Na,K)_{1\cdot85}\ (Fe''',Mg,Fe'',Mn)_{4\cdot81}\ (Si,Al,Fe''',Ti)_8O_{22}$.

The analysis of crocidolite from Kliphuis, South Africa (Table 1, No. 3) gave the structural formula—

$(OH)_{2\cdot61}\ (Ca,Na,K)_{1\cdot84}\ (Fe'',Mg,Fe''')_{4\cdot80}\ (Si,Al,Fe''')_8O_{22}$

Here again is an excess of (OH) and a corresponding deficiency in the alkalies and FeMg molecules, and this is probably due to the presence of minute quantities of adsorbed water possibly in the form of thin films of talc as suggested by Simpson.

Calculation of the formula for the crocidolite from Kuruman, South Africa (Table 1, No. 4), gave very poor agreement with the ideal amphibole structure, due to the high percentage of H_2O+, and the rather low alkali content. If only two per cent. of H_2O+ is used and the analysis recalculated it then shows a much closer approximation to the ideal tremolite formula giving—

$(OH)_{2\cdot08}\ (Ca,Na)_{1\cdot61}\ (Fe'',Mg,Fe''')_5\ (Si,Fe''')_8O_{22}$.

Removal of a little of the ferric iron would probably result in the ideal formula. This rather suggests that the mineral analysed was not entirely pure, but was probably contaminated by limonite staining the fibres.

The analysis of bababudanite (Table 1, No. 5), is apparently rather incomplete. A residue of ·63 per cent. believed to represent Zr or one of the earths of that group—was calculated as ZrO_2. This gave the structural formula—

$(OH)_{\cdot40}\ (Ca,Na,K,Mn,?Zr)_{2\cdot58}\ (Mg,Fe''',Fe'',Al,Si)_5\ Si_8O_{22}$.

This shows a very poor agreement with the ideal formula probably due to analysis of an impure sample.

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Calculation of the rhodusite (Table 1, No. 6), gave—

$(OH)_{2\cdot2}$ $(Ca,Na,K,Mn)_{2\cdot15}$ $(Mg,Fe''',Fe'')_5$ $(Si,Al,Fe''')_8O_{22}$.

which agrees fairly closely with the ideal formula, allowance being made for the replacement of Si by a little Al and Fe'''—a very characteristic feature of all the above minerals.

C. *Chemical Composition of the Riebeckite Rocks and Associated Banded Ironstones of the Hamersley Ranges.*

The chemical composition of the banded ferruginous cherts and of the riebeckite bearing rocks which form the host beds for the blue asbestos seams in the Hamersley Ranges is of interest not only for the light that may be thrown upon the origin of these rocks and for the illuminating comparison that may be made with similar rocks from South Africa, but also for certain important features bearing on the genesis of the crocidolite which are revealed by comparison with the composition of the fibre.

In Table 4, one of the analyses of Hamersley Range crocidolite quoted above is compared with those of " potential crocidolite " and host rock from Yampire Gorge and of specimens of " potential crocidolite " and host rocks of the South African deposits.

Table 4.—Chemical Analyses of Crocidolite Proper, " Potential " Crocidolite and associated Banded Ironstones from Western Australia and South Africa.

		1.	2.	3.	4.	5.	6.
SiO_2	...	51·94	45·51	50·71	51·54	45·50	43·65
Al_2O_3	...	·24	·78	*Nil*	*Nil*	1·52	1·44
Fe_2O_3	...	18·93	26·05	20·45	41·62	44·16	47·88
FeO ...	...	15·25	15·07	17·41	6·05	4·63	Tr.
MnO	...	·01	*Nil*	...	*Nil*	·57	*Nil*
MgO	...	3·94	2·49	2·28	·29	·42	·35
CaO ...	...	·40	·11	·15	*Nil*	Tr.	Tr.
Na_2O	...	6·00	5·43	5·75	·03	Tr.	Tr.
K_2O	...	·26	·05	·07	·03	Tr.	Tr.
H_2O+	...	2·67	3·50	2·50	·40	2·30	5·55
H_2O-	...	·72	1·24	·96	·07	·60	·35
TiO_2	...	·01	*Nil*	...	*Nil*	Tr.	Tr.
CO_2 ...	...	*Nil*	·03	...	*Nil*	·12	·35
P_2O_5	...	*Nil*	*Nil*	...	·13	·05	·06
Cr_2O_3	...	*Nil*	*Nil*	...	...	...	...
FeS_2	...	...	...	...	·07	...	...
		100·37	100·26	100·28	100·23	99·87	99·83
G ...	...	3·27	3·29	...	3·26, 3·31	...	...
Analyst		J. N. Grace	C. R. Le Mesurier	H. E. Vassar	H. P. Rowledge	W. D. and F. Herdsman	

1. " Crocidolite Proper " from eight miles south-east of Willi Wolli Springs, Hamersley Range (1).
2. (Spec. 2/1473) Riebeckite-rock ("Potential Crocidolite") forming 6 in. band associated with crocidolite. Yampire Gorge, Hamersley Range (4, p. 7).
3. " Incipient or Potential Crocidolite," slightly iron stained, from Kliphuis north of Prieska, South Africa (7).
4. Banded hematite-magnetite quartzite, barren host rock for crocidolite. Yampire Gorge, Hamersley Range.
5. Banded ironstone (fine grained, barren magnetite quartzite) from Prieska Kopje, Cape Province, South Africa (7).
6. Ironstone (crypocrystalline ferruginous chert adjacent to crocidolite seam) from Kliphuis, Griqualand West, South Africa (7).

The close similarity in composition of the pure crocidolite to "potential" crocidolite and to the associated host rocks from both Western Australia and South Africa is remarkable. Analysis No. 2 shows that the amorphous riebeckite rock or "potential crocidolite" which occurs as an interbedded layer a few feet below the seam of "crocidolite proper" is almost identical in chemical composition with the fibre itself, the only difference being a slight increase in ferric iron and water at the expense of silica in the former. The identity of these with the South African potential crocidolite is indicated by comparison with analysis No. 3. Analysis No. 4 of barren ferruginous chert reflects the absence of amphibole by the low soda and magnesia content, but once again its essential similarity to the composition of the pure amphibole implies a close genetic relationship.

The striking correspondence in composition of No. 4 with the barren host rocks of the South African crocidolite as shown in analyses Nos. 5 and 6 cannot be too strongly stressed. To the writer, it seems quite inconceivable that rock deposits having such an identity of chemical and mineralogical composition should not share that identity equally as regards their history and origin. Consequently, and since a considerably more detailed study has been made of the South African blue asbestos and banded ironstones than of the Western Australian deposits, it may be profitable here to review briefly the geology and petrography of the former rocks before proceeding to a discussion of the genesis of the Hamersley Range beds.

THE CROCIDOLITE-BEARING IRONSTONES OF SOUTH AFRICA.

Crocidolite seams in South Africa have been found confined to a series of banded magnetic jaspers and siliceous ironstones associated with subordinate sandstones, limestones and cherts. These beds form the lowest member of the Griqua Town Series (Pretoria Series) which in turn represents the uppermost of the three subdivisions of the Transvaal System in Griqualand West. This Transvaal System is believed to be Upper Proterozoic or Lower Palæozoic in age and consequently must approximate to the age of the Western Australian Nullagine Formation.

The crocidolite seams themselves are found without exception to be restricted to beds of banded ironstone. The nature and appearance of these banded ironstones in the field have been described by A. L. Hall (9, pp. 55 et. seq.) and his description indicates a remarkable similarity to the Hamersley Range beds. Megascopic and microscopic descriptions by Hall (9, pp. 56-8), and Peacock (7, p. 247 et. seq.) might almost be said to echo the descriptions of the Hamersley Range ironstones given above.

Mineralogically the South African rocks consist of quartz and iron ores with local crocidolite seams. The iron ores are represented by hematite or hydrated hematite and its alteration products, and magnetite. Carbonate of iron has also been recorded locally, and also nontronite. According to Peacock (7, p. 247) the quartz occurs in three phases—first in exceedingly fine grained indefinite individuals, often in cloudy bands which he considers probably to represent the original siliceous component of the sediment; secondly in clearer colourless bands of a fine even-grained mosaic thought to represent crystallisation of the original more siliceous bands under "mild metamorphic conditions"; and thirdly a clear "fibrous" mosaic form—occasionally as a fine streak-like selvage to the magnetic bands and cross fibre asbestos seams, or in massive cross fibre form associated with concordant fibrous asbestos. This is clearly the latest quartz phase. A similar condition has already been described for the quartz in the Western Australian rocks.

Of the iron ores, Peacock states that sesqui-oxide, somewhat hydrated, appears to be the earliest and most abundant form. Magnetite is often abundant and appears to represent a later crystallisation. The ferric oxides (hematite, etc.) are usually more or less amorphous. Magnetite grains tend to coalesce into opaque bands or they may be scattered quite irregularly in euhedral grains. They occur as either irregular bands of coalesced grains associated with asbestos seams or in undulating bands of discrete grains distributed with some regularity through the seams. Magnetite crystals never appear as detrital grains and are considered to have formed in situ by reduction of the earlier ferric oxides.

As regards the crocidolite itself this has been shown to occur in South African rocks in three main varieties, described above, viz:—

1. *"Crocidolite Proper"*—i.e. densely packed lavender blue coloured regularly oriented in cross fibre seams.

2. *"Potential Crocidolite"*—a term applied to certain compact banded vivid dark blue or green rocks which are composed almost wholly of "minute, pleochroic somewhat rounded units arranged either at random or in a crudely stellate manner" (7, p. 256). Thin slices often remain almost opaque so densely matted are the mass fibres, but where a ground mass can be resolved it appears to be chert.

3. The third variety has been called *"Needle-Crocidolite"* or *"Acicular Crocidolite."* This denotes the mode of occurrence of crocidolite in conspicuous needle shaped crystals. The mineral is said to form straight, fine, elongated, dark blue to black needles up to "the length and thickness of an ordinary pin." These occur plentifully disposed in random orientation through layers of ironstone usually consisting of very dark, strongly magnetic banded rocks.

"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" (9, p. 63).

It is obvious from the above descriptions that the needle form of riebeckite described in (13973A) from the Hamersley Ranges corresponds completely with the South African "Needle Crocidolite" whilst the asteriated mass fibre forms of the amphibole in (13973B) and (2/1474) are identical with the "Potential Crocidolite." It would appear that the "Crocidolite Proper" of the two countries is indistinguishable.

The unorganised "incipient" condition, the typical cross fibre condition and the acicular condition (needle crocidolite) have been regarded by Peacock (7, p. 283) as "progressive stages in the crystalline integration of the crocidolitised bands." This view is more or less supported by Hall (9, pp. 257-8) who considers that the first stage in the formation of a cross fibre seam will be the growth of non-oriented crystals of iron-amphibole, leading in the Cape to "potential" mass fibre crocidolite and locally passing further to the "needle" crocidolite condition.

GENESIS OF THE HAMERSLEY RANGE BANDED IRON FORMATIONS.

The close general similarity between the rocks of the South African Lower Griqua Town Series and the banded iron formations of the Hamersley Ranges in this State immediately suggests their identity of origin. To the writer's mind closer study of the latter definitely strengthens this opinion.

The typical non-detrital character of the banded fine grained, both ferruginous and non-ferruginous cherts of the Hamersley Range is a very distinctive feature. No detrital "heavy minerals" were found in any of these rocks whilst the microcrystalline granular nature of the primary siliceous chert matrix can only be compared in fineness to the deep sea ooze type of marine sediment. As such oozes are probably derived mainly from volcanic and meteoric dust it follows that their chemical composition is far too complex to be comparable with the siliceous cherts. The iron ore in these cherts as shown above in no way resembles detrital material.

The remarkably simple chemical composition of these banded cherts, as indicated by a study of their mineralogical composition, is borne out by the few analyses which are available, and to the writer's mind is strongly suggestive of a chemically controlled precipitation of

a very limited number of chemical constituents, under a certain long-continued and constant set of conditions.

The presence of rather abundant iron carbonate (thought to represent a primary mineral) in these ferruginous and non-ferruginous cherts is a significant feature and appears to be about the only point of difference between these and the South African rocks. In the latter siderite occurs occasionally but from all accounts is not particularly common. Furthermore doubt has been expressed as to whether this carbonate is of primary origin. The existence of altered brown limonite or hydrated hematite pseudomorphs after rhombohedral siderite and also of similar brown granular aggregates of amorphous ferric oxide in the Western Australian rocks points to a genetic relation between the ferric oxide and the carbonate.

It is considered that appreciable quantities of the original ferric material must have been either precipitated as carbonate along with the hydroxide and silica or that the originally precipitated ferric hydrate was largely converted to carbonate during the process of dehydration and conversion of the heterogeneous gel into a ferruginous chert. Either during this period or more probably under later conditions of load metamorphism after burial beneath over-lying deposits, the resulting mixture of ferric carbonate and oxide was partially re-crystallised to masses of euhedral magnetite and hematite. The magnetite probably represents partial reduction of lenses of original ferric carbonate material under higher temperatures. Minor crumplings of the rock under slight differential stress—possibly solely as a result of rock settling—during the growth of the coalesced magnetic bands caused minor deformations often relieved by localised recrystallisation of the adjacent siliceous cherty layers at points of pressure, producing the small areas and bands of clear fibrous quartz described above.

As regards the origin of the riebeckite-crocidolite in these rocks the writer has found nothing to refute the general conclusions arrived at by Peacock (7, pp. 282-3) and Hall (9, pp. 249-60) and supported by Finucane, that this mineral represents the recrystallisation of material originally present in the banded ironstone and thus can be described as a growth in situ.

Points to be noted are:—Firstly, the absolute restriction as far as is at present known, of riebeckite and crocidolite to the one type of country rock, viz., banded ferruginous cherts; secondly, the close similarity in composition of the amphibole-asbestos and this country rock. The essential constituents of riebeckite-crocidolite are silica, ferric and ferrous iron, soda and minor magnesia and water. Of these the only components which may not be found in comparable quantity in the adjacent country rocks are soda, and to a lesser extent, magnesia.

It has been noted that thin beds of dolomite are often found associated with the crocidolite bearing ironstones of South Africa and

these are also present in most of the known asbestos-bearing gorges of the Hamersley Ranges. These dolomite beds have been cited as a probable source of the small amounts of magnesia necessary for the production of crocidolite and in some localities such may have been the case. In others it must be assumed that sufficient magnesia was present in the original sediment. Peacock (7, p. 271) finds some difficulty in the postulate of magnesia-bearing solutions rising from underlying dolomite beds and transgressing the bedding of the ironstones and he "is inclined to explain magnesia in crocidolite to local concentration" within the beds.

The source of soda required for the formation of crocidolite in the South African deposits has never been proven to complete satisfaction and the writer has nothing to add to the prevailing rather speculative explanation that crocidolite now occupies the place of pre-existing soda rich layers in the ironstones. Other possibilities are that the soda may have been introduced by travelling solutions emanated from igneous sources, or that it may have been uniformly distributed throughout the ironstones and subsequently concentrated in certain layers. The absence of any trace of igneous activity in many of the asbestos-bearing localities is rather opposed to the idea of a necessarily introduced source of soda whilst in the handspecimens available for examination the writer saw no evidence for any mass leaching and reconcentration of any of the constituents.

Having postulated the presence of the requisite chemical constituents in the sediment it is still necessary to consider the geological process or agency required to convert these into the fibrous amphibole. Thermal metamorphism (due to igneous intrusion) is evidently not a factor since, as has been stated above, igneous rocks are seldom, if ever, found in the vicinity of the W.A. deposits. By their very nature and degree of crystallinity and the simple horizontal-bedded sedimentary character of the banded ironstones and associated rocks, it is obvious that there has been no high-grade regional metamorphism of the known Hamersley Range riebeckite-rocks. Probably the increased temperature and pressure conditions induced by burial beneath superincumbent strata, i.e., "load metamorphism," has been sufficient to initiate the process of crocidolitisation.

Peacock (op. cit. p. 283) has summed up this theory of the origin of crocidolite in South Africa in the following words:—

> "Crocidolitisation is conceived as a mild, static, non-additive, metamorphic process resulting in the chemical union, along soda rich bedding planes, of the necessary constituents already 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."

As regards the more striking features of the "crocidolite proper" viz., the amazingly uniform parallel cross fibre habit, the cone and corrugation structures, etc., the present investigation has thrown no

further light on the physical factors governing their development nor on the processes by which they have been produced. Consequently the writer has no useful contributions to make to this subject.

The identity of composition and close field association of the unoriented potential crocidolite with the oriented crocidolite proper suggests a close genetic relationship, and it appears a logical conclusion that the development of mass aggregates of unoriented crystal fibres about an enormous number of closely packed centres preceded that of the oriented asbestos fibres. The latter form probably resulted from a recrystallisation under increased temperature and pressure of bands of the mass fibre material. The presence of unoriented potential crocidolite bands practically inter-layered with bands of the oriented asbestos in the same specimens however, makes it rather difficult to envisage the exact conditions which were responsible for the initiation of recrystallisation in some bands of mass fibre and not in others.

As to the needle riebeckite, it has already been stated that Peacock and Hall both consider that this represents a further stage in the progressive recrystallisation of the mass fibre material. From the few examples of this needle riebeckite from the Hamersley Ranges which have been examined by him, the present writer is inclined to consider that this form is not necessarily a product of a more advanced stage of recrystallisation but that it is due to recrystallisation of tufts of mass fibres which were originally poorly developed about sparsely scattered centres of crystallisation. The scattered centres were probably due to the fact that the original constituents necessary for the formation of crocidolite were very thinly distributed through the sediment and in insufficient quantity to produce more than a very limited number of centres of crystal growth.

Probably the conditions necessary for the recrystallisation of these scattered mass fibre tufts into single well-developed and unoriented needles, would have been sufficient to produce oriented asbestos seams in bands where the aggregates of mass fibre centres were numerous and closely packed.

SUMMARY.

Blue amphibole asbestos—crocidolite—occurs in seams interbedded with banded ironstones of Nullagine age in the Hamersley Ranges in Western Australia. These banded ironstones range from fine grained cherty carbonate rocks and ferruginous sideritic cherts and quartzites, to banded jaspers or magnetite and hematite bearing cherts containing little or no carbonate.

Riebeckite occurs in three different forms associated with these rocks, viz., as scattered individual needles, as massed groups of minute asteriated or radiating needle crystals or "potential crocidolite," and as seams of parallel oriented cross fibres, or "crocidolite proper."

In their optical properties, structure, form, chemical composition and in the nature of the beds in which they are enclosed, these different types of Western Australian riebeckite appear to be very closely similar to those found in the famous blue amphibole asbestos deposits of the Cape Belt in South Africa.

It is probable that the crocidolite in both countries has been derived by an essentially similar process, viz., by crystallisation out of material originally present in the banded ironstones, under conditions of mild load metamorphism.

The banded ironstones themselves are considered to represent chemical sediments in which the bulk of the iron was originally precipitated as ferric carbonate (siderite). Under the later mild metamorphic conditions some of this siderite has reacted with other constituents of the sediment to form riebeckite, while part of the remainder has been converted to hematite and, to a lesser extent, magnetite. Recent surface weathering has tended to convert all these iron bearing minerals to amorphous limonite.

ACKNOWLEDGMENTS.

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PART II.

THE BLUE ASBESTOS DEPOSITS OF THE HAMERSLEY RANGES AND THEIR ECONOMIC IMPORTANCE,

BY

J. S. FOXALL, B.E.(Syd.), M.I.E.Aust., Assistant State Mining Engineer.

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INTRODUCTION.

The occurrence of blue asbestos (crocidolite) in the Hamersley Range has been known for more than a quarter of a century. As a result of early enquiries it was indicated that the value of this fibre was from £20 to £25 per ton. The known exposures were outcrops of flat seams situated in the faces of cliffs in deep gorges in the range, sometimes 100 to 200 feet above the creek bottom, access to which was through stony and heavily timbered creek beds. The inaccessibility of the deposits, combined with the fact that the carting distance from Roebourne, the nearest coastal town, was more than 200 miles over bad roads, rendered their exploitation at the indicated price of fibre quite uneconomical.

Some four years ago, however, parcels of high grade fibre, marketed in London, brought prices up to £75 sterling per ton. This became known, together with the fact that large quantities of asbestos were available by stripping and hand dressing methods. A rush to the area took place and an uncontrolled output by some 150 to 200 men commenced pouring into Roebourne.

Local agents, who were paying £35 to £40 per ton advance on fibre, which was shipped to London, America and Japan, found that they could not cope with the supply and suddenly stopped buying. As the advances barely covered the cost of production and transport under the primitive conditions of working, this action was the cause of considerable distress among the producers. The majority of these men had no capital whatever and were consequently dependent on advances for their immediate necessities, and numbers of them had not as yet marketed any of their product. The upshot was that all but a very few men were starved from their holdings and left the district. Speculators, it is understood, purchased outright the production of these men at prices varying from £20 to £25 per ton. It is also stated that a number of producers, who had received advances on their fibre as mentioned above, received no further money, although the value of the material was supposed to be from £60 to £70 sterling per ton.

The output over this period (1937-8) is estimated at 400 to 500 tons.

The great asbestos rush thus ended rather dismally and most unprofitably for the would-be producers. In two ways, however, it was not without value. Firstly, it demonstrated the unwisdom of uncontrolled production on a market that is not firm and, secondly, it brought into prominence the fact that high grade crocidolite is available in commercial quantities in Western Australia.

With regard to the second point, it is understood that buyers are satisfied with the quality of the fibre received, but have serious doubts as to the quantity of such material available, treating with reserve, if not actual disbelief, reports to the effect that the deposits are enormous, sufficiently accessible for economical exploitation, and containing an unusually high percentage of first and second grade fibre. It is hoped that this bulletin will clarify the position sufficiently to resolve all such doubts.

Small parcels continued to be broken out by a few remaining operators and at least two companies were floated with a view to continuous production. These companies did not reach the production stage, but eventually disposed of their holdings to the Asbestos, Molybdenum and Tungsten Company, Limited, which was operating a chrysotile plant at Lionel, near Nullagine. After the acquisition of the crocidolite leases, this company abandoned the chrysotile workings, removed the plant to Yampire Gorge in 1939, and concentrated on the production of the blue fibre.

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In the Mines Department Annual Report for 1937 there is a report by F. G. Forman, Government Geologist, on the Yampire Gorge crocidolite deposits, while a report by the writer, after a visit to Wittenoom Gorge, appears in the 1938 Annual Report. In 1938 also K. J. Finucane visited Yampire, Dale and Wittenoom Gorges and wrote a comprehensive report which was later published as Report, Western Australia, No. 49, of the Aerial, Geological and Geophysical Survey.

The two former reports are attached as appendices to this bulletin in order to make it as complete a record as possible of the present available knowledge of these deposits.

In the State Mining Engineer's Annual Reports for 1938, 1939 and 1940 it has been stressed that these deposits are well worthy of the fullest investigation with a view to large scale exploitation.

It has recently become increasingly apparent that Western Australian crocidolite continues to impress buyers favourably in different parts of the world. It is superior to chrysotile in tensile strength, in electrical insulating value and especially in its resistance to acids, alkalies and sea water, and where these qualities are necessary its value is obvious. There are doubtless numerous processes in which crocidolite may be substituted for chrysotile without detriment to the final product. An expanding market may, therefore, be anticipated once it becomes generally recognised that continuity of supply of high grade fibre is assured.

In consequence of a number of enquiries as to the availability of supplies of this mineral, the writer visited the district in July, 1941, and, after examination, compiled a report for the information of the Hon. the Minister for Mines, which appears below.

REPORT.

During my recent visit to Roebourne (July, 1941), I visited most of the places in the Hamersley Range where crocidolite, or blue asbestos, has been found outcropping in sufficient quantity to warrant production by stripping or open-cut methods of mining.

Localities visited included Yampire Gorge, where the Asbestos, Molybdenum and Tungsten Company, Limited, have their treatment plant, Dale's Gorge, Wittenoom and Joffre Gorges, and the more recently found Marramamba leases, held by Mr. L. G. Hancock of Mulga Downs Station,* who has a wide knowledge of the Hamersley Range country and who was my guide on this occasion. Time did not permit of a visit to Bee Gorge, which is some four miles westward of Wittenoom Gorge, nor to another outcrop at Range Creek, some ten miles again to the westward of Bee Gorge.

*At the time of the writer's visit, the Marramamba holdings were under option to the Australian Mines Management and Secretariat, Limited. Such option has subsequently been exercised and it is understood that the Company proposes to erect a milling plant in this area and to commence production at an early date.

On a previous visit to this district some three years ago I visited Marrilana Station homestead, and was shown a specimen of fibre about three inches in length said to have been broken off a large floater found in a gorge some thirty miles to the eastward of Dale's Gorge. As the distance from Dale's Gorge to Marramamba scales 92 miles on the map, the length of the asbestos-bearing belt is indicated as some 120 miles. It has also been reported to me that floaters have been found some 40 to 50 miles to the southward from Marramamba. This report is unconfirmed and Mr. Hancock is inclined to be somewhat sceptical as to its authenticity.

The only place where any idea may be obtained of the extent of the deposit in a north-south direction is in Yampire Gorge, where the asbestos outcrops over a line of nearly four miles.

The accompanying lithograph (Plate I.) shows the approximate positions of the various localities where fibre has actually been obtained to date.

Mr. Finucane, in 1938, made a very complete examination of the exposures at that time, to which very little can be added except that a considerable amount of work has since been done, especially in Yampire Gorge, the results of which have been very satisfactory.

THE WORKINGS.

Yampire Gorge:

In Yampire Gorge, where Finucane states that the lower horizon had been worked over a length of 1,500 feet, there must be an aggregate of nearly a mile of workings at the present time, practically all of which has been done in M.C. 10[illegible]. (See Plate II.) The average aggregate length of fibre showing in the faces, I would put at between two and three inches. This seam continues past the lease boundaries and underground as the bottom of the gorge rises to higher levels. Fibre up to 2½ inches in length is visible and the proportion of Grade 1 fibre appears to be high.

On the upper horizon, 150 to 200 feet above, Finucane traced fibre for a distance of two miles and estimates the aggregate length of fibre to average two inches.

In mining, large quantities of waste overburden have been dumped into the gorges, amongst which can be seen very appreciable quantities of good fibre. I would estimate roughly that some hundreds of tons of good millable ore have gone into these waste dumps. Much of this is recoverable by hand picking unless further buried. Such hand picking should show a handsome profit.

Much fibre remains to be won on these leases by the present open cutting methods and no attempt has yet been made at systematic mining. I believe, however, that mining can be profitably undertaken

on these flat seams by modified coal mining methods. In the meantime, elimination of waste should be aimed at while present methods of extraction are being adopted.

Dale's Gorge:

In Dale's Gorge, which is approached by proceeding up Yampire Gorge and over tableland country for a total distance of some 17 miles by road to the top of the gorge, it is necessary to climb down the cliffs to the bottom of the gorge, the vertical depth being of the order of 300 feet. Ladders are provided where the cliffs are vertical, the total length of ladders being about 100 feet. There is, I understand, an approach up to the bottom of the gorge, but it is inaccessible for motor traffic and increases the carting distance considerably.

When this deposit was being worked, the fibre was transported to the top of the cliff by an aerial ropeway, the haulage power being provided by motor truck. A small hoist would have been much more efficient and economical.

The working seam at this point appears to be immediately below the bottom of the gorge. It is somewhat difficult to see the exposure owing to water from a running creek, which, I understand, considerably hampered production. This running water is said to be permanent and would appear to emanate from a spring at the head of the gorge, where there is a large circular pool about 50 feet in diameter. The quality of the water is excellent, and I would estimate the flow at the time of my visit at approximately 20,000 gallons per hour.

I am not acquainted with the names of the claims mentioned in Finucane's report, and the gorge is deserted at present. Claims recently held in Dale's Gorge are shown in Plate II.

The impression I obtained from my visit here is that there is not as much fibre as at either Yampire or Wittenoom Gorges, although it is possible that there may be other seams at a lower horizon.

At this point it can be seen that the sediments are covered by a thickness of some 100 to 150 feet of what appears to be a volcanic breccia, and the asbestos-bearing horizon seems to be much nearer to this layer than in the other occurrences examined. It is possible, therefore, that this seam may be higher stratigraphically than, say, the horizon being worked in Yampire Gorge and that further seams exist at a depth.

It is likely that a considerable amount of fibre can still be obtained from this gorge by open cut and stripping methods, although some difficulty will be met with in regard to the disposal of waste. As a mining proposition it does not appeal at the moment as there appears to be a smaller aggregate length of fibre in the seam, and the site is somewhat inaccessible. A thorough survey of the lower levels of the gorge might modify this opinion.

Wittenoom Gorge:

I inspected and reported on the main workings in this gorge some three years ago and my report is attached as Appendix 2. As no great amount of production has taken place since that time, apart from the production by hand labour of some high grade crude fibre, and as time was somewhat limited, I did not undertake the somewhat trying task of a re-examination. I learnt, however, that in the plan accompanying that report I marked the western branch of Wittenoom Gorge as "Bee Gorge." This is incorrect, as Bee Gorge is situated some four miles to the west of the position marked. A plan of existing holdings in Wittenoom Gorge is given in Plate II. accompanying this Bulletin.

In an eastern branch of Wittenoom Gorge, Mr. Hancock has pegged a P.A. on the edge of Joffre Creek. The site of this P.A. is about two miles S.E. of the main Wittenoom Gorge workings, and no work has as yet been done on it.

Several good seams of fibre can be seen in the cliff faces here, only a few feet above the creek level. This place is very easily accessible and contains a good percentage of asbestos of first and lower grades.

At one horizon I measured three inches of fibre (in several seams) in a band of rock 12 inches thick, while at an horizon about 10 feet higher a ribbon measuring from two inches to three inches occurs six feet above a seam three feet thick carrying three inches of smaller seams. These bands can be followed by the eye for a considerable distance downstream while upstream they become covered with detrital matter fallen from the cliff face.

This is possibly a continuation of one of the horizons showing in Wittenoom Gorge proper, and should prove a good producer.

Leaving Joffre Creek, which is running in a northerly direction at this point, we walked up the next gorge, which is known locally as Eastern Creek and which ascends in an easterly direction (See Plate II.). The creek bed is narrow and very rough. It is bounded on the south side by cliffs which might be 400 to 500 feet high and from which have been shed large floaters of fibre-bearing rock, some of which carry seams of asbestos aggregating six inches over a width of two feet. We walked up this creek for a distance of about one mile, and the creek bed was full of these floaters for the whole distance traversed. The seams from which the floaters were broken are not visible from the creek bed, and may be covered by debris.

It would appear that in Eastern Creek a large tonnage of highly payable fibre is obtainable by working the floaters in the creek bed alone.

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Marramamba:

There are seven P.As. and a mineral claim pegged out in this area over a length of some 9½ miles in an east-west line, as shown on the attached litho.

The outcrops are found in a low range of hills running roughly east and west between two higher ranges. The country seems much more disturbed than in the gorges described above, where the strata of the sedimentary rocks appear to the eye to be almost perfectly flat. The strata in this locality, as seen on the hillsides, are distorted and undulating.

All of the asbestos outcrops examined dip towards the east or north-east at angles varying from, say, 15° to 25°. Whether this is due to the undulations of one seam, or whether, on the other hand, there are a number of different asbestos-bearing horizons, I am not prepared to say, but I saw no strata dipping in the opposite direction, which would be expected if the seam were undulating. Again the country may have been subjected to folding, although this is not suggested by the appearance of the strata in the range of hills to the north.

At the westernmost block—P.A. 765H, the asbestos-bearing stratum at the outcrop is seven feet thick and carries an aggregate length of about six inches of asbestos in seams from one inch to one-eighth inch in length. The asbestos seams appear to be lenticular in the ore body rather than the continuous ribbon-like seams in the gorges. The rock here shows considerable signs of weathering, much of the fibre being weathered to a brittle ochre yellow fibre at the surface, while much of the associated ironstone is weathered to a chalk-like yellow ochreous substance.

The presence of a small quantity of either the yellow fibre or the ochre quickly discolours a parcel of fibre, but the discoloration may, I understand, be removed by washing.

Some hesitation has been felt in breaking any rock containing this yellow fibre—locally termed "dead" fibre—but I think it is due merely to surface weathering and will disappear within a few feet of the surface.

The ore body at this point dips in a general easterly direction at an angle of about 15° into the hillside. It is easily accessible and should be a good mining proposition.

At P.A. 768H two horizons have been opened up on the flatly sloping side of a low hill. The extent of the seams cannot be seen, but the upper one has been opened up over a length of about 100 feet and carries two inches to three inches of asbestos, including some 3-inch fibre of excellent quality. The second horizon, which may be some 20 feet stratigraphically below the first, has been opened up over a length

of about 50 feet and is showing about two inches of asbestos in two seams.

Both of these strata dip towards the north-east at an angle of about 25°.

Two other nearby P.A's., 742H and 758H, are somewhat similar to P.A. 768H. These three holdings are situated from four to six miles eastward of P.A. 765H.

A mile further east, P.A. 766H has been pegged out, but no work has been done on it as yet. This appears to be a very rich horizon and a typical cross section over eight feet of the cliff face is as follows:—

2-2½ inches	asbestos ribbon.
3 „	decomposed rock.
3-4 „	asbestos ribbon.
6 feet	rock.
18-inch seam	containing four inches aggregate fibre.

This totals nine inches to 10½ inches asbestos over a width of eight feet to eight feet six inches. The dip is about 10° towards the north-east.

This horizon can be traced for a length of 50 feet east and west. At the western side it then appears to be covered with debris. On the easterly continuation the asbestos seams continue for a further 50 feet as decomposed or "dead" fibre and then go into the ground where they can be traced as "dead" fibre for a further 150 feet before disappearing.

A large quantity of high grade fibre should be obtainable from this holding.

About two miles south-east of P.A. 766H lies M.C. 201H. This is situated on the easternmost side of a comparatively shallow gorge. A considerable amount of work has been done here on a seam of rock about three feet wide carrying an average aggregate length of 4½ inches of fibre of good quality. The length opened up is roughly 12 chains, being the full length of the claim. The dip is to the east or north-east, and the ledge worked comes down to the level of the creek bed, making the accessibility very easy.

A P.A. has been pegged and some work done on the opposite side of the gorge where a continuation of the same seam is visible over the same length. It was from this P.A. that was produced a specimen of particularly long and good quality fibre that was left by Mr. Hancock with the Department some months ago. On these two holdings a large amount of fibre remains to be easily won by open cutting and stripping.

These Marramamba exposures appear to me generally to contain more fibre in a normal mining width than the deposits in the gorges.

The Blue Asbestos Bearing Banded Iron Formations of the Hamersley Ranges, Western Australia (Bulletin No. 10... Published by AsbestosClaims.Law
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They would also be easier to mine and are certainly much more accessible by road.

The present road access from Roebourne is via the Tableland Road to Mt. Florence Station and thence through Hamersley Station, the distance being roughly the same as to Wittenoom Gorge. There is, however, a gap in the range to the north of M.C. 201H, through which a truck has been driven, and the distance to Roebourne might possibly be shortened to perhaps 100 miles.

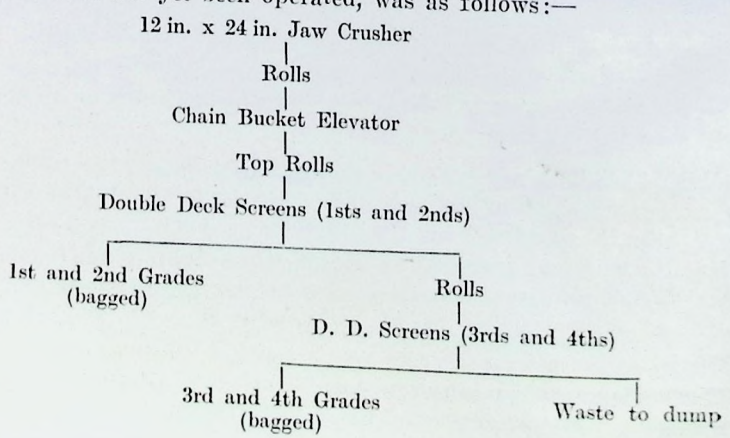
PRODUCTION TO DATE.

It is somewhat difficult to arrive at the total production of this field to date. At the time of my visit three years ago the total was stated to have been about 500 tons, whereas our records showed only about 120 tons. The figure to date estimated by the manager of the Asbestos, Molybdenum and Tungsten Company, Limited, is placed at about 1,000 tons, but our statistics give that company's production as 355 tons, and Mr. Hancock's at 41½ tons. It is rather obvious that considerable quantities were shipped without being reported to the Department. However, as the only present producers are the company and Mr. Hancock, this condition should not recur.

The asbestos exports from the State for the years 1937 to 1940, inclusive, have been reported as 1,149 tons, valued at £53,707. This total includes a small proportion of white asbestos, but the two varieties have not been segregated. It is probable, however, that, of this total, approximately 1,100 tons would represent blue fibre.

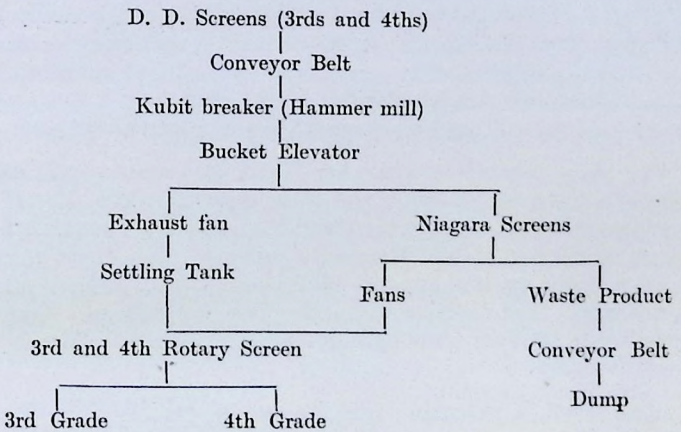
TREATMENT.

The flow sheet of the Asbestos, Molybdenum and Tungsten Company's mill at Yampire Gorge prior to the recent plant additions, which have not yet been operated, was as follows:—



It will be noted that there are no fans included in this plant, and the resulting products appear to me to be rather dusty, and the 3rd and 4th grades particularly, appear to carry an excessive amount of rock.

The new section of the mill was apparently added to treat the 3rd and 4th grade product and the flow sheet is as follows:—



This new plant has been given a trial run only on some of the discarded waste material from the old plant. The resultant product, which is classed as 4th grade, is a very clean short fibre free from dust and stones and should, I think, find a ready market.

In addition to this grading by means of the plant, a quantity of 1st grade fibre is produced by hand cobbing methods. I understand that buyers prefer this product to the 1st grade fibre that has been through the mill.

I think that the 1st and 2nd grade mill products would be considerably improved by the introduction of a fan in the circuit to remove dust and short fibre.

The plant is said to be capable of producing two tons of fibre per shift from run of mine ore.

As the company's only work on the field at the present time is the production of some hand-cobbed fibre at Wittenoom Gorge by two men, the mill was idle at the time of my visit.

Mr. Hancock has ingeniously constructed a light portable plant mounted on an old truck chassis and driven by the truck engine by means of belt drives off the rear wheel of the truck.

The plant consists of a small jaw crusher, a small hammer mill discarded by the company and purchased from them, a crude shaking screen and a suction fan.

As the motor engine is not powerful enough to drive both the crusher and the remainder of the plant, the crushing is done first and the crushed material is shovelled in two stages from the ground to an elevated platform and thence into the hammer mill where the fibre is separated from the adhering stone. From the hammer mill it is fed on to the shaking screen and small pieces of stone are screened off while the fibre and larger pieces of stone travel down the screen to the suction pipe which sucks the fibre up, through the fan into a bin. The rock passes over the end of the screen. It seemed rather remarkable to me that the mass of fibre passed the fan without clogging. Some trouble was experienced by clogging at the start, but it was overcome, I understand, by cutting and altering the shape of the fan vanes.

The plant presents a somewhat Heath Robinson appearance, but produces a surprisingly good and clean product which Mr. Hancock classes as grade 2. Comparison with the company's grade 2 fibre is, I think, in favour of Mr. Hancock's product. This plant is only as yet in a more or less experimental stage and is capable of much improvement. The addition of another fan, for instance, would make it possible to produce short fibre, a fair percentage of which is lost in the waste dump.

This plant is portable under its own power and it is Mr. Hancock's intention to take it wherever ore is available, extracting the fibre on the spot and eliminating carting costs. The plant is at present located at Mulga Downs Station, and trial runs have indicated that it is possible to obtain from it as much as one ton of fibre per shift.

Seeing this plant working gave me an idea that a portable plant on similar lines would be of great assistance in putting the production of chrysotile asbestos on a sound footing. There are fairly large areas of chrysotile bearing country in this part of the State, but to date no deposit has been found sufficiently extensive to make large scale production payable. There are admittedly, however, numerous small occurrences from which individuals could make a good living if the ore were treated for them on the spot.

A portable plant could move from mine to mine cleaning up prospector's ore paddocks in rotation at a fixed charge per ton. The quantity and quality of the fibre would be known and advances on fibre could be made available to the prospector pending the sale of the product.

TRANSPORT.

The Tableland road, from Roebourne to Mulga Downs, is now in fair condition, and further improvements are in progress. There are fair good-weather roads into the Gorges, and a good road from Mt. Florence to the Marramamba leases.

Transport costs to the coast are from £6 to £8 per ton, according to the distance carted, but it is considered that a new road to Marramamba will practically halve the transport costs to and from that area.

CONCLUSIONS.

(1) After visiting most of the known exposures of blue asbestos on the Hamersley Range field, I am more than ever impressed with the possibility of establishing one of the most profitable industries in Australia, and I am firmly convinced that Roebourne should be and must eventually be one of the principal asbestos distributing centres of the world.

(2) There are large areas that can be cheaply mined by open-cutting, stripping and salvaging methods before actual underground mining need by undertaken, and I am of the opinion that normal underground mining methods may be profitably applied where open-cutting is no longer feasible, the order of merit in this regard for the various exposures visited being—

(i) Marramamba.
(ii) Wittenoom Gorge.
(iii) Yampire Gorge.
(iv) Dale's Gorge (doubtful).

(3) Exposures have been located at various points over a total distance of some 120 miles in an east-west direction, and a distance of four miles in a north-south direction and there is a possibility that the asbestos bearing horizons are continuous over long distances.

A thorough geological survey of the district is necessary in order to throw more light on this matter. This would be a big undertaking and would be enormously facilitated by a preliminary aerial survey of the area under discussion, as no reliable maps of the district are in existence.

(4) It would be idle to endeavour to estimate the potential quantity or value of the fibre available for exploitation at the present stage, but it is of interest to compare the possibilities for a moment with the State's principal primary industry, the gold industry.

The total value of gold produced in this State to date has been approximately £246,000,000.

Taking the average value of available fibre at £40 per short ton, this figure would represent the value of 6,150,000 short tons of asbestos.

The specific gravity of crocidolite, according to Dana's Mineralogy is 3.2, equivalent to 200 lbs. per cubic foot, or 10 cubic feet to the short ton.

At this rate one square mile of country, averaging 1 in. length of asbestos carries 232,320 short tons of fibre and it would take 26½ square miles to produce asbestos to a value equivalent to the total value of gold produced. In my opinion there is a possibility of the existence of hundreds of square miles of productive country. In addition there are more asbestos bearing horizons than one and in every exposure examined the average aggregate length of fibre was considerably in excess of one inch.

Estimates on a less conservative basis result in figures of astronomical proportions which need not enter into the present report, but I believe that there is a definite possibility of the total value of crocidolite production eventually eclipsing the value of gold production in this State.

(5) To establish this industry on a sound footing will require a considerable amount of organisation in preparatory work, production and marketing. While it is possible under present conditions for comparatively small operators to produce fibre profitably, it will probably be necessary for both State and Commonwealth Governments to co-operate in building up a large industry. Asbestos to the value of some £400,000 (Australian) was imported into Australia in 1940 and since that time a trade agreement has been entered into for the supply of asbestos from Rhodesia. I do not know how much of the annual Australian requirements consist of blue asbestos, nor how much of this fibre might be substituted for chrysotile imports, but the amount would probably make a satisfactory start for a local market.

A local market for long fibre could be made by the establishment of factories for the manufacture of asbestos products. This should prove a lucrative industry and I would suggest that manufacturers be urged to look into the matter carefully.

The establishment of industries in the North-West has long been a knotty problem for both State and Commonwealth Governments. They will not find an industry more ready to hand than this one.

(6) It is understood that a number of American buyers are keenly interested in this fibre. Inquiries have been instituted through the Australian Trade Commissioner in New York to confirm this. If a market is proved to exist in U.S.A., every encouragement should be given to producers now to fill immediate American requirements, thus making dollar exchange available for war purposes.

(7) In estimating the capital required for the commencement of large scale operations in this area, provision will require to be made for decent living conditions for all employees. While the winter climate is pleasant, the reverse obtains in summer and the right class of man will be unobtainable unless the conditions are made sufficiently attractive.

(8) Finally, I believe that, properly organised, this district will be able to meet all demands that may be made on it for the production of blue asbestos during the next century.

GENERAL REMARKS.

The writer would not wish it to be inferred from the above report that he considers the establishment of this industry on a large scale is possible of accomplishment without any difficulty.

The most economical system of mining remains to be evolved and systematised. The elimination of waste, especially of low grade material is essential. The best of equipment and personnel will be required and the highest degree of organising ability is called for to cope with problems connected with mining, dressing and transport, but principally marketing.

Adequate capital is necessary in order to provide against possible initial setbacks, particularly with regard to marketing. Some trouble may be experienced in selling large quantities of high grade fibre without a corresponding quantity of low grade material. As pointed out above, the proportion of long to short fibre recovered to date appears to be unusually high. The great bulk of the world's asbestos consumption is short fibre.

It is most desirable, in the opinion of the writer, to carry adequate stocks, at some central distributing point, of all grades of dressed fibre, with a view to fulfilling orders as and when required by customers. Supplying orders direct from the mine is apt to lead to irritating delays and consequent loss of trade.

It is highly desirable to endeavour to supply the Australian requirements as far as possible. Australian imports during 1940 were reported as 281,944 cwt., valued at £321,832 sterling, or £402,290 Australian, which works out at an average price of approximately £25 10s. per short ton. This price indicates a great predominance of short fibre. No figures are available as to the proportion of blue asbestos in this total. It may be accepted, however, that present Australian requirements are predominantly short fibred chrysotile. Every effort

must be made to replace as much as possible of this with crocidolite. This will possibly involve extensive and perhaps costly investigation. Markets for the long fibre, until such time as more Australian manufacturers turn their attention to the fabrication of asbestos products, must be almost entirely sought overseas.

The world production of asbestos of all grades and qualities is in the neighbourhood of half a million tons per annum. The total estimated value is, unfortunately, not available, but the following sales are quoted in "The Mineral Industry during 1939."

Year.	Country.	Metric Tons.	Value.
1939	Canada	364,454	$15,858,492
	U.S.A.	15,459	$512,788
	Southern Rhodesia	58,313	£1,088,872
1938	Union of South Africa—		
	Amosite	7,246	£134,810
	Chrysotile	7,740	£110,166
	Blue	7,297	£179,102

An analysis of these figures again indicates the great predominance of short fibre in the total world consumption, the South African blue being the only material averaging over £20 per ton. This predominance is particularly stressed if we examine a tabulation of prices prevailing for Canadian chrysotile of various grades throughout 1938, which are as follows:—

Grade.	Price per Metric Ton.
Crude No. 1	$700—$750
Crude No. 2	$150—$350
Spinning Fibres	$110—$200
Magnesia and Compressed sheet fibres....	$110—$130
Shingle Stock	$57— $78
Paper Stock	$40— $45
Cement Stock	$21— $25
Floats	$18— $20
Shorts	$12— $16·50

There is no universally accepted system of grading asbestos, but the Canadian system* is probably the most elaborate in operation to-day, although it would not be wholly applicable to crocidolite. Some standard system of grading will require to be evolved and adopted as the industry progresses.

It will be seen from the foregoing remarks that, although there is no doubt as to the quantity of material available in the ground, its exploitation presents a number of problems which will require careful handling.

Finally it is suggested to producers that, once having established markets, a profitable extension of the industry is possible in the chrysotile deposits in adjoining districts, either by working the somewhat scattered deposits with one or more mobile plants, or by purchasing fibre from small individual producers. With a ready market at hand there is little doubt that numerous small deposits would be taken up and worked.

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*Following is a description of the Canadian system of grading extracted from the publication of the Imperial Institute, Mineral Resources Department, entitled "Asbestos."

Canada.—The Canadian system of grading milled fibre is now in use in all the Canadian mines, and the testing machine employed is coming into favour in other countries. It consists of a nest of three rectangular wooden sieves with a collecting box beneath. The top sieve is of ½-in. mesh, the second of 4-mesh, and the third of 10-mesh. Sixteen ounces of fibre are placed in the top sieve, the lid is closed, and the whole nest shaken for two minutes horizontally by means of a standardised mechanical device. The contents of each sieve and the box are then weighed and the grade of the fibre is determined by the number of ounces contained in each. Thus, if 2 oz. remain in the top, 8 oz. in the second, 4 oz. in the third sieve, and 2 oz. in the box, the fibre is known as 2-8-4-2; one of the spinning grades. The complete grading system consists of nine groups, the milled fibres being named according to the purposes for which they are mainly employed.

The grades are:—

Crude Asbestos.

Group 1	Crude No. 1	No machine test; crude ¾ in. and over.
Group 2	Crude No. 2	No machine test; crude ⅜ in. to ¾ in.
	Crude, run-of-mine	Unsorted crudes.
	Crude, sundry	Crudes other than above.
Group 3	Spinning of textile fibre	Testing 0–8–6—2 and over.
Group 4	Shingle fibre	Testing below 0–8–6–2 and including 0-1½-9½-5.
Group 5	Paper fibre	Testing below 0–1½–9½–5 and including 0–0–8–8.
Group 6	Waste, stucco or plaster	Testing below 0–0–8–8 and including 0–0–5–11.
Group 7	Refuse and shorts	Testing below 0–0–5–11 and including 0–0–1–15; also finer products weighing 35 lb. or less per cub. ft.
Group 8	Sand	Mill product weighing over 35 lb. and under 75 lb. per cub. ft.
Group 9	Gravel	Mill product weighing 75 lb. per cub. ft. and over.

Grades 3, 4 and 5 are each further subdivided into seven sub-grades designated by the letters D, F, K, M, R, T, and Z, group 6 into two sub-grades D and F, and group 7 into five sub-grades of fibre testing down to 0-0-1-15, the lowest grades being classified by weight per cubic foot.

APPENDIX 1.

THE YAMPIRE GORGE CROCIDOLITE DEPOSITS, HAMERSLEY RANGE, NORTH-WEST DIVISION.

F. G. Forman, B.Sc., Government Geologist.

[*Extracted from the Annual Report of the Geological Survey of Western Australia, 1937.*]

"Yampire Gorge in the Hamersley Range carries a north flowing tributary of the Fortescue River and lies about 20 miles due south of Mulga Downs Station.

The Hamersley Range is made up of flat dipping sediments belonging to the upper part of the Nullagine series, presumably of late pre-Cambrian age. The rocks exposed in Yampire Gorge consist predominantly of quartzites interbedded with siliceous or cherty ironstone. The deposits of crocidolite asbestos are everywhere associated with a banded ironstone which is highly siliceous and of a dark brown colour.

Bands of crocidolite occur at two horizons in the sedimentary beds. The lower horizon is close to the base of the cliff of the gorge, and contains a vein of crocidolite averaging about 2½ inches in thickness and lying parallel to the bedding planes of the ferruginous ironstone in which it occurs. The crocidolite immediately overlies a thin bed of dark green massive rock, which by microscopic examination appears to have a composition identical to that of the fibrous crocidolite. This massive rock, which weathers to a dark brown colour, is thought to be identical with "potential crocidolite," which is commonly associated with the fibrous variety in the deposits of the Cape Province of Africa.

The second crocidolite bearing horizon occurs at an elevation of about 200 feet above the base of the cliffs, and the crocidolite here occurs in a number of narrow parallel veins lying in the bedding planes of a ferruginous quartzite in an exactly similar manner to the asbestos in the lower horizon. In this upper horizon some half dozen veins of crocidolite varying in width from one inch to ¼ or ⅛ of an inch are distributed through a ferruginous quartzite band over a width of about five feet, the aggregate thickness of crocidolite being about 4½ inches.

My examination did not include all the prospecting areas being worked, but from information supplied to me in conversation with a number of prospectors I was able to form the opinion that all the crocidolite occurred in a manner similar to that described above.

A considerable amount of fibre is available in the cliff faces and can be won without much difficulty at the outcrop. It is doubtful, however, whether the narrow width of the veins will permit of these deposits being worked economically by underground methods, owing to the large amount of worthless rock material which would necessarily have to be removed in recovering the valuable fibre.

These deposits are interesting in that they appear to be similar in their mode of occurrence to the deposits of blue asbestos, or crocidolite, in Africa. The asbestos in the Cape Province of Africa is commonly referred to as "Cape Blue," and is found in seams interbedded with the banded ironstone of the Lower Griqua Town series of the Transvaal system, which is probably the equivalent in age to the upper part of the Nullagine series in Western Australia. These deposits are fully described in Memoir No. 12 of the Geological Survey of the Union of South Africa. The conclusion is there arrived at that the crocidolite is of sedimentary origin and has been formed by the metamorphism of ferruginous quartzites, which are postulated to have had an original composition peculiarly suited to the formation of crocidolite.

Although no examination of the chemical composition of the Hamersley Range ferruginous quartzites has yet been made, the striking megascopic resemblance, and the mode of occurrence of the rocks to the abovementioned published description, suggest that they are similar in all respects."

APPENDIX 2.

REPORT ON HAMERSLEY RANGE BLUE ASBESTOS

J. S. Foxall, B.E. (Syd.), M.I.E. Aust.,
Assistant State Mining Engineer.

[*Extracted from the Annual Report of the Mines Dept.*, 1938.]

"On my recent visit to the Hamersley Range district, accompanied by Inspector G. Matheson, I made a detailed examination of the workings in Wittenoom Gorge, a plan of which, together with Bee Gorge, was made from field notes prepared by Mr. Surveyor F. G. Medcalf, who recently surveyed Mineral Claims 163H-168H inclusive.

General Description:

Ascending a steep declivity eastward from about midway along the western boundary of M.C. 167, the ledge on which the principal workings exist was reached at a point some 150 to 200 feet vertically above the creek bed. The last 12 to 15 feet was ascended by scrambling up a cleft in the face of a vertical cliff.

This ledge is almost perfectly flat and has been cleaned down to a width varying from three to 20 feet. The asbestos here appears in two horizontal seams, about four feet apart. The bottom seam consists of a practically unbroken ribbon of asbestos varying in width from 1½ inches to two inches, all long fibre. This can be followed for a distance of about 30 chains. The top seam is about 12 inches thick and contains a number of veins of asbestos with fibre lengths varying from one-eighth inch to one inch.

Towards the southern boundary of M.C. 163H the deep gorge appears to terminate abruptly in a cliff, halfway across which the wide ribbon has been worked. After reaching this point it was necessary to descend to the creek bottom and scale, by means of a rope, a precipice about 60 feet high. Above this precipice the workings were continued on the western side of the gorge, until the wide ribbon of asbestos disappears into the floor of the gorge, some three or four chains upstream from the cliff. At this point the upper layer of this seam has widened out to a thickness of two feet, with lenticular veins showing fibre from a quarter inch to two inches in length.

In addition to the seam described above, there exist two other parallel seams of asbestos, one about 20 feet above and the other 20 feet below the working seam. I examined these at one or two accessible points, and the top seam showed fibre up to two inches in length, while the bottom one show two ribbons about two feet apart with ½in. to ¾in. fibre. It is difficult to say whether these seams would be payable or not as they have not been opened up sufficiently for a reliable inspection to be made.

From the eastern side of the gorge, all three seams may be seen for the full length of the western side, but they are inaccessible for close inspection excepting at the cliff across the creek, where the asbestos in the working seam appears to be of better quality if anything than on the eastern side.

Geological:

In the immediate vicinity of the asbestos deposits, the stratification of the rock appears to be as follows:—

Dolomite	18in. to 2ft.
Jasperoid Rock	6in. to 9in.
Ironstone casing	½in. to 1in.
Asbestos	1½in. to 2½in.
Ironstone casing	½in. to 1in.
Banded quartzite.	

Working:

The working to date has been confined to the main ribbon of long fibred material, as the hand dressing of the short fibres would be too costly under the present primitive conditions. The ironstone casing is very hard and very strongly attached to the fibre and it is a day's work for a man to clean from one to two bags (of 100 lb.) by hand knapping.

No actual underground work has been done. To date it has been possible to remove the overburden and get at the main asbestos ribbon.

This method, however, has advanced in most places as far as is compatible with safety, as it is not permissible to undercut the cliff to any extent.

As it is probable that larger scale operations will commence in the near future, regular inspections will be necessary to see that safety precautions are observed. If larger scale operations are to be undertaken, a certain amount of experimental work will be necessary in order to finally decide on the best and most economical method of mining.

Although to all appearances the deposit seems to be enormous, yet it is not known how far the asbestos extends into the face of the cliffs, and it is impossible at this juncture to give even an approximate estimate of reserves.

It is certain that, in mining, it will be necessary to leave a large proportion of pillars. In this the operations will bear some resemblance to coal mining. The proportion to be left cannot be estimated until such time as the deposit is opened up, and the nature of the ground tested. Many of these pillars may possibly be eventually won by packing behind them with the mullock which will form the greater part of the rock broken during mining operations. Until some experimental work is done, the quantity of fibre lost in pillars cannot be estimated.

Before entering into any contract to supply regular quantities to consumers, a certain amount of blocking out will be necessary in order to secure regularity of production.

Certain grading tests will be required to ascertain the percentages of different length fibre that can be anticipated, and the treatment of rock mined from development would be, I think, the only reliable indication of the amount of fibre in the blocked out ore.

The method of handling ore and materials in this particular locality would doubtless be some sort of flying fox, to transport the ore to the plant and material to the miners on the cliff side.

Transport will also be an initial problem. At present donkeys are used to transport the bags of fibre to a point outside the gorge whence it can be handled by motor transport, but the provision of a passable road will be a necessity if major operations are to commence. Government assistance will doubtless be sought later in regard to this matter.

The Australian Blue Asbestos Company, N.L., have purchased M.Cs. 163H, 164H, and 167H and have taken up M.C. 169H and are considering commencing immediate operations. It is not known at present what their exact intentions are, but in my opinion they would be wise if for the present they considered themselves in the light of a development and exploration company, installing a small plant for

the treatment of their development ore, and developing and blocking out future ore reserves whilst making tentative marketing arrangements for the future.

Although it is impossible to make an estimate of reserves, I am confident that there is sufficient fibre in this gorge alone to warrant preparations for large scale mining operations, provided that a market can be found for the product at reasonable prices.

I also visited Yampire Gorge, but owing to rain setting in, which made climbing very dangerous, and promised to make the road to Mulga Downs impassable, I returned without an examination of this or Dale Gorge. From descriptions received, however, and samples of asbestos seen from these two localities, I have no reason to disbelieve that the deposits there are similar to that at Wittenoom Gorge.

Good floaters of long fibre have also been found as far as 30 miles eastward from Yampire Gorge, which leads to the belief that there are other as yet undiscovered deposits in the Hamersley Range.

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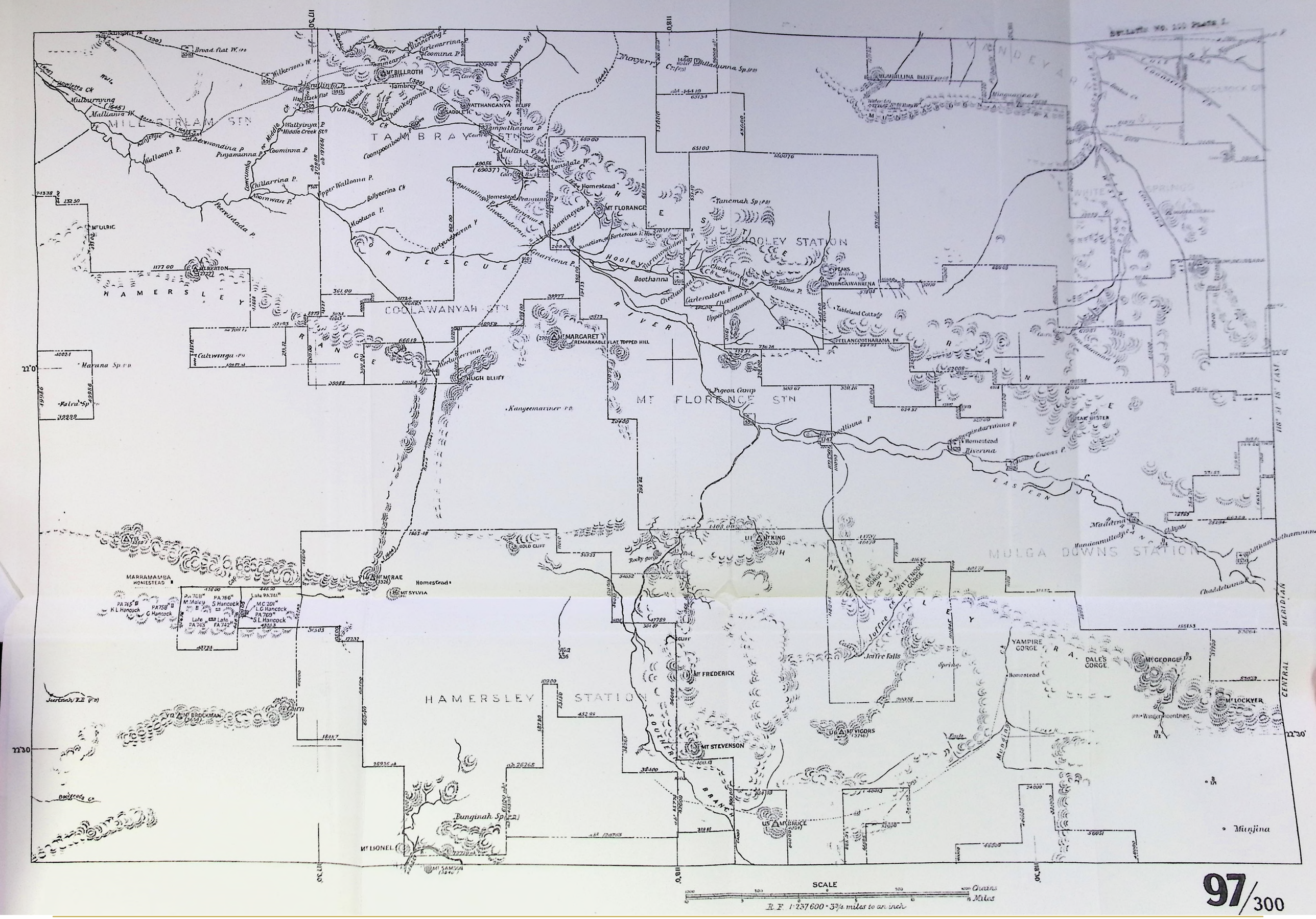
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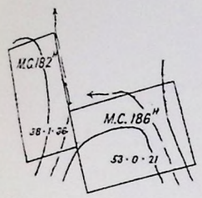
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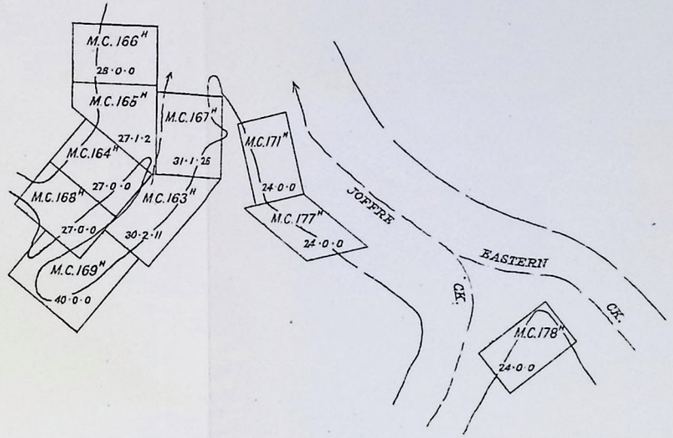


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BEE GORGE
(4 miles W of Wittenoom Gorge)

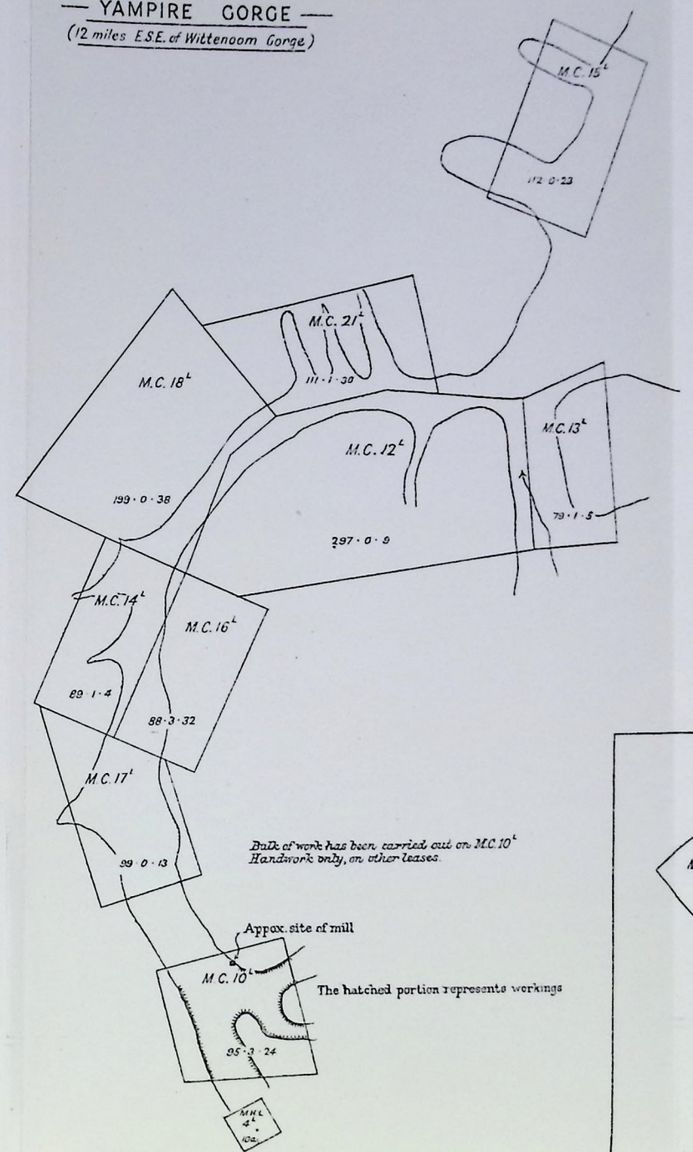


WITTENOOM GORGE

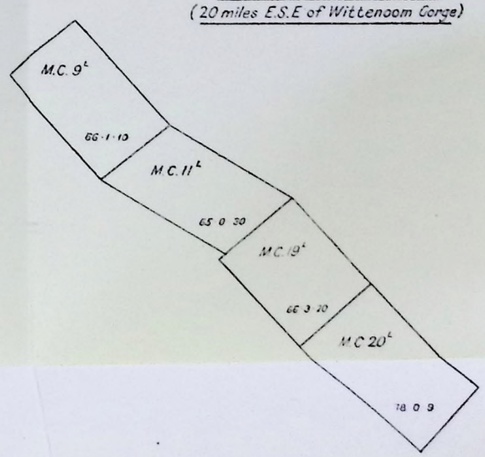


GROUPS OF ASBESTOS HOLDINGS
AT
HAMERSLEY RANGE
Scale 40 chains to an inch

YAMPIRE GORGE
(12 miles E.S.E. of Wittenoom Gorge)



DALE'S GORGE
(20 miles E.S.E of Wittenoom Gorge)



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