THE MINERAL INDUSTRY OF NEW SOUTH WALES

☆

No. 4

ASBESTOS

COMPILED BY A. A. MacNEVIN

1970

☆

GEOLOGICAL SURVEY OF NEW SOUTH WALES
DEPARTMENT OF MINES

G 48363 [75c]

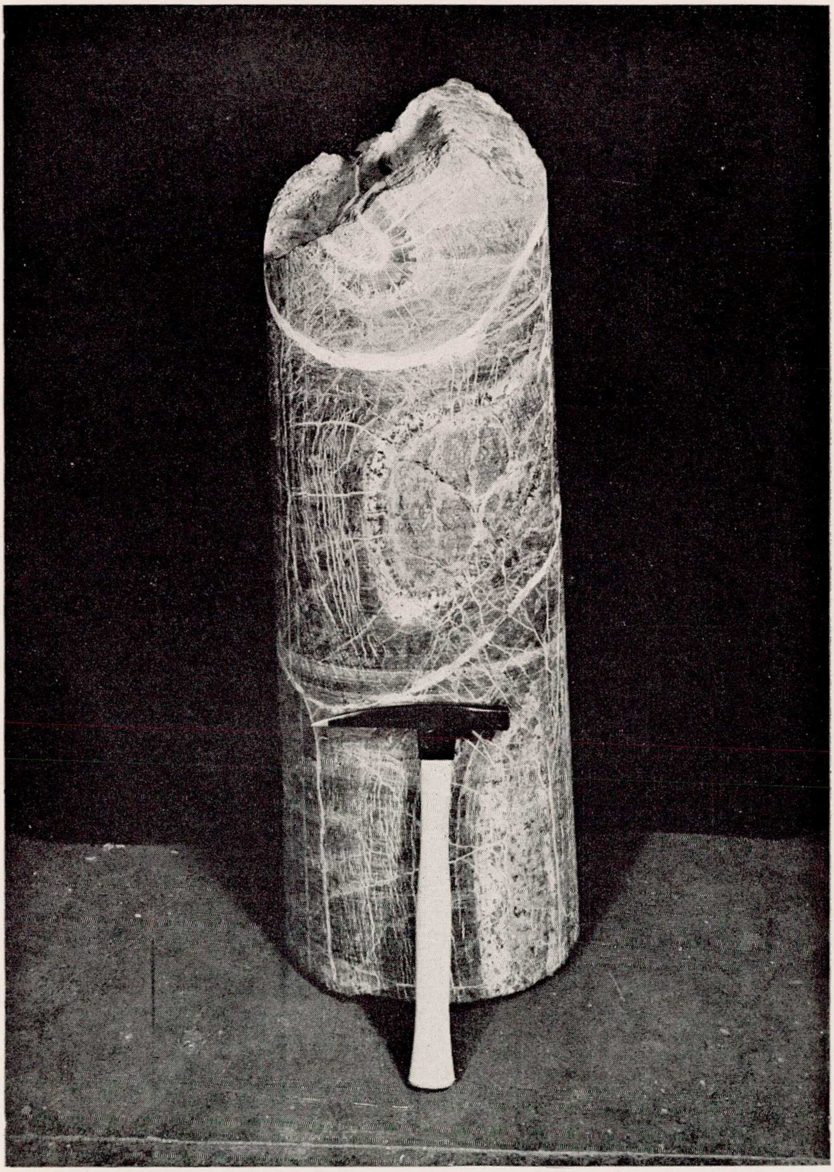


Photo 1 (*frontispiece*).—**Twelve-inch core from Woodsreef. The chrysotile asbestos shows as white veins on the darker serpentine. Note the radial structure about a centre, each structure being separated by a major fracture (now an asbestos vein)**

DEPARTMENT OF MINES

GEOLOGICAL SURVEY OF NEW SOUTH WALES

G. ROSE, DIRECTOR

THE MINERAL INDUSTRY OF NEW SOUTH WALES

No. 4

ASBESTOS

Compiled by A. A. MacNevin

September, 1970

Issued under the authority of

Hon. Wallace Clyde Fife, M.L.A., Minister for Mines

CONTENTS

	Page
HISTORY	5
MINERALOGY	5
Fibre Types	5
Description of Asbestos Minerals	7
Chrysotile	7
Picrolite	13
Anthophyllite	13
Amosite	13
Actinolite	13
Tremolite	14
Crocidolite	14
GENESIS AND STRUCTURE	14
Massive Chrysotile Deposits	14
Tabular Ore Bodies	16
Irregular Amphibole Asbestos Deposits	16
EXPLORATION AND EVALUATION	16
MILLING	17
CLASSIFICATION	20
PRICES	23
USES	24
Properties of Commercial Importance	24
Quality and Composition Affecting Uses	25
Incombustibility	25
Insulation	25
Durability	25
Fibrous structures	25
Surface area	25
Principal Products	26
Textile	26
Asbestos-cement products	27
Insulating products and other articles	27

CONTENTS—*continued*

	Page
Uses of Individual Asbestos Minerals	28
Chrysotile	28
Amosite	28
Crocidolite	28
Anthophyllite..	28
Tremolite–actinolite	28
Synthetic Asbestos and Substitutes	28
PRODUCTION AND CONSUMPTION	30
World	30
Australia	32
NEW SOUTH WALES ASBESTOS OCCURRENCES ..	33
Gordonbrook Serpentinite Belt	33
Baryulgil	33
Fine Flower	36
Great Serpentine Belt	36
Woodsreef	36
Spring Creek	40
Girilambone-Kiandra Serpentinite Belt	40
Broken Hill District	42
Orange District	43
Rockley District	43
Newbridge	43
Wellington District	44
Other Localities	44
SELECTED BIBLIOGRAPHY	45
APPENDIX 1—Production of Asbestos in New South Wales, 1880–1969	47
APPENDIX 2—Mining Leases for Asbestos in Force as at 31st December, 1969	49
Key to Localities on Spot Map	50

No. 4

ASBESTOS

Compiled by A. A. MacNevin (September, 1970)

HISTORY

Asbestos has been utilized by man for over two thousand years. The early Greeks used the fibre in lamps for wicks which burned without being consumed—hence the name asbestos (meaning incombustible). The early Chinese civilizations, and later the Roman civilization, wove the fibre into cloth, though this was more as a curiosity than an industry. After the fall of the Roman Empire there is no record of asbestos until 1250, when (in East Siberia) Marco Polo saw textile cloths that resisted fire, and in 1676 when a Chinese merchant exhibited a handkerchief made of asbestos in London. These were claimed to be of salamander's wool.

Asbestos was established as an industrial mineral in the late 1700's and after 1860, when the large Canadian deposits were opened up, the use of asbestos increased greatly as new applications were discovered.

The major producers in the world today are Canada, the U.S.S.R., Southern Rhodesia, the Union of South Africa, the United States of America, and Swaziland.

MINERALOGY

Fibre Types

The term "asbestos" is commercial, not mineralogical. It embraces the fibrous varieties of the serpentine and amphibole groups of minerals, which are characterized by a highly developed prismatic cleavage allowing their ready separation into fibres or filaments. These minerals may be classified in terms of the orientation of the fibres.

Cross fibre. The fibre is oriented perpendicular to the vein walls or sometimes distorted from the perpendicular by movement along the vein either during or after fibre development. If this movement is localized, a bend in the fibre may result, causing a weakness which detracts from the quality of the fibre. The maximum length of the fibre is the vein width, but fine partings subparallel to the vein may occur which will result in a shortening of the length of fibre won.

Slip fibre. The fibre lies matted together parallel to the vein walls due to an advanced stage of rock movement, often of one vein wall against the other. Although this type has a greater percentage of longer fibre than the cross-fibre variety, it is usually of inferior strength.

Mass fibre. The fibre interlocks in all directions forming radiating groups. This arrangement is common in the amphibole varieties of asbestos.

TABLE 1

PROPERTIES OF ASBESTOS MINERALS

Mineral Group	Mineral Name	Chemical Formula	Crystal System	Mineralogical Structure and Occurrence	Form of Vein	Hardness (Mohs scale)	Specific Gravity	Fusion Point °C
Serpentine	Chrysotile	$Mg_6(Si_4O_{10})(OH)_8$	Monoclinic	Fibrous veins in serpentinite.	Cross and slip fibre	3–3·5	2·14–2·64	1,521
Amphibole	Anthophyllite	$(Mg,Fe)_7(Si_4O_{11})_2(OH)_2$	Orthorhombic	Lamellar, fibrous, and asbestiform.	Slip, mass fibre	5·5–6	2·85–3·2	1,468
	Amosite *	$(Mg,Fe)_7(Si_4O_{11})_2(OH)_2$	Monoclinic	Lamellar, fibrous, and asbestiform.	Cross fibre	5·5–6	3·14–3·43	1,399
	Actinolite	$Ca_2(Mg,Fe)_5(Si_4O_{11})_2(OH)_2$	Monoclinic	Reticulated long prismatic crystals and fibres.	Slip or mass fibre	6	3·0–3·2	1,316–1,393
	Tremolite	$Ca_2Mg_5(Si_4O_{11})_2(OH)_2$	Monoclinic	Long prismatic and fibrous aggregates.	Slip or mass fibre	5·5	2·9–3·2	1,316–1,393
	Crocidolite †	$Na_2^{+}Fe_3^{++}Fe_2^{+++}(Si_4O_{11})_2(OH)_2$	Monoclinic	Fibrous veins in ironstone	Cross fibre	4	3·12–3·29	1,193

* Amosite is an asbestiform variety of the cummingtonite-grunerite series.

† Crocidolite is an asbestiform variety of riebeckite.

Description of Asbestos Minerals

Asbestos mineralogy is summarized in table 1.

Chrysotile

Chrysotile, commercially known as "white asbestos", is economically the most important asbestos mineral, comprising about 95 per cent of the world's asbestos production. Although usually green in the natural state, it is white when separated into fibres (fiberized).

Chrysotile is a fibrous mineral, chemically expressed as $Mg_6 (Si_4O_{10})(OH)_8$ but usually containing varying amounts of iron, alumina, water, and lime (see table 2), and is chemically similar to its serpentinite host rock.

Serpentinite is an ultrabasic rock composed mainly of serpentine minerals and is formed by the alteration of the olivine and pyroxene crystals of a parent peridotite. It usually occurs along major crustal fractures as elongate, lenticular bodies which have been altered either before or during their final emplacement.

Although chrysotile nearly always occurs as cross-fibre veins in serpentinite, it has also been found in impure limestones and dolomites.

TABLE 2

COMPARATIVE ANALYSES OF CHRYSOTILE ASBESTOS

	Canada (1)	South Africa (2)	Australia (3)
	Thetford	Barberton	Woodsreef
SiO_2	41·00	40·05	41·24
Al_2O_3	2·50	1·90	0·06
Fe_2O_3 and FeO	1·35	2·00	4·56
MgO	40·75	38·35	38·43
CaO	....	0·15	....
Na_2O and K_2O	....	0·40	....
Total H_2O	14·25	16·60	15·42
CO_2 and SO_3	....	....	0·61
Total	99·85	99·45	100·32

(1) Becker and Haag 1928

(2) Hall 1930

(3) Raggatt 1924 (analyst W. A. Greig)

Veins of chrysotile are usually short and often intersect to form a stockwork or lie in closely spaced parallel zones forming "ribbon structure". The width of these veins ranges from microscopic to several inches and the better grades of fibre are extremely fine with a silky lustre and a high tensile strength. If this fibre is of sufficient length it is particularly suitable for spinning. Minute partings in the vein usually result in a fibre length of less than the vein width.

Because of its high magnesia content and the tubular structure of its fibres, which contain air within the mass, chrysotile is heat resistant up to 260° C but can be heated to 600° C without significant decomposition. However, at about 550° C the hydroxyl group water is lost and the fibre no longer retains its shape if subjected to stress.

Chrysotile is susceptible to chemical attack and is decomposed by acids and sea water, and so depends on its physical properties, particularly length, tensile strength, and heat resistance, for its commercial usefulness. Hence, the quality is variable and must be determined for each individual deposit to ascertain product suitability. Chrysotile with a low percentage of combined water tends to have less flexible fibres.

The characteristics of chrysotile cross-fibre veins are tabulated below for purposes of easy reference. These data are based on the observations of Cirkel (1910), Dresser (1913), Graham (1917), and Cooke (1936) (after Riordon 1955).

(a) *Widths*—range up to four inches; however these are rare and most veins are under three-eighths of an inch.

(b) *Form*—minute gash veins, or lenses, or persistant veins up to several tens of feet in length. They may be straight, curved or irregular. They may intersect, branch or have minor offshoots.

(c) *Color*—normally shades of apple-green to dark green and olive-brown, which is generally constant across the width of the vein, and commonly approaches the color of the wall rock.

(d) *Fibers*—vary from silky and soft, to harsher varieties that generally have a higher content of iron and lower content of water. . . . They are parallel, and may lie normal to the walls of the vein or occupy any position between this and parallel to the plane of the vein, but generally lie somewhere between vertical and normal to the vein wall. They are rarely perfectly straight, and normally display minute corrugations, some of which may be pronounced. These corrugations may be persistent along the vein but individually may fade out to be replaced by others, or may coalesce; they give the vein a banded appearance. . . .

(e) *Partings*—one or more may be present and are generally parallel to the vein but are commonly irregular. The orientation of the fibers is generally the same on either side of a parting.

(f) *Magnetite*—occurs along the partings as fine grained sheets or lenses. These are seldom continuous, normally display extreme irregularities, and may occupy any position in the vein, although they tend roughly to parallel the walls. Some disseminated grains may be present, and strings of magnetite in places are parallel to the fibers. Magnetite is usually abundant in the wall rock immediately adjacent to the vein, and in inclusions.

(g) *Walls*—are commonly sharply defined; minute irregularities are normal. Some veins have distinctly crenulated margins suggestive of some replacement. Major irregularities in opposing walls can normally be matched [see photo 2]. In some cases one wall may be slickensided and coated with picrolite. Vein material may separate more readily from one wall than the other.

(h) *Inclusions*—of wall rock take the form of thin selvages or angular fragments. Many, although not all, of these match irregularities in the wall. Some have evidently been displaced along the vein. Inclusions of picrolite may be present; some of these may run oblique to the vein, which is thus broken up into a series of en echelon lenses.

Photo 2.—**Photomicrograph of a fine asbestos vein cutting a serpentinized pyroxene crystal. The vein appears to be a simple fissure filling, and structures on either side of the vein can be matched. Specimen from Fine Flower (40 miles by road northwest of Grafton) (×30)**

(i) *Intersections* [figure 1]—the fibers of both veins may tend to coalesce [see photo 3], or there may be a confused mixture of magnetite, picrolite, and asbestos. Cross-cutting veins are extremely rare [figure 1, F]. Junctions are commonly marked by the presence of much magnetite [figure 1, E]. At some intersections the fiber of the marginal portion of one vein may be seen to swing around the corner to merge with the fiber of a similar portion of the other vein [figure 1, A, B, D].

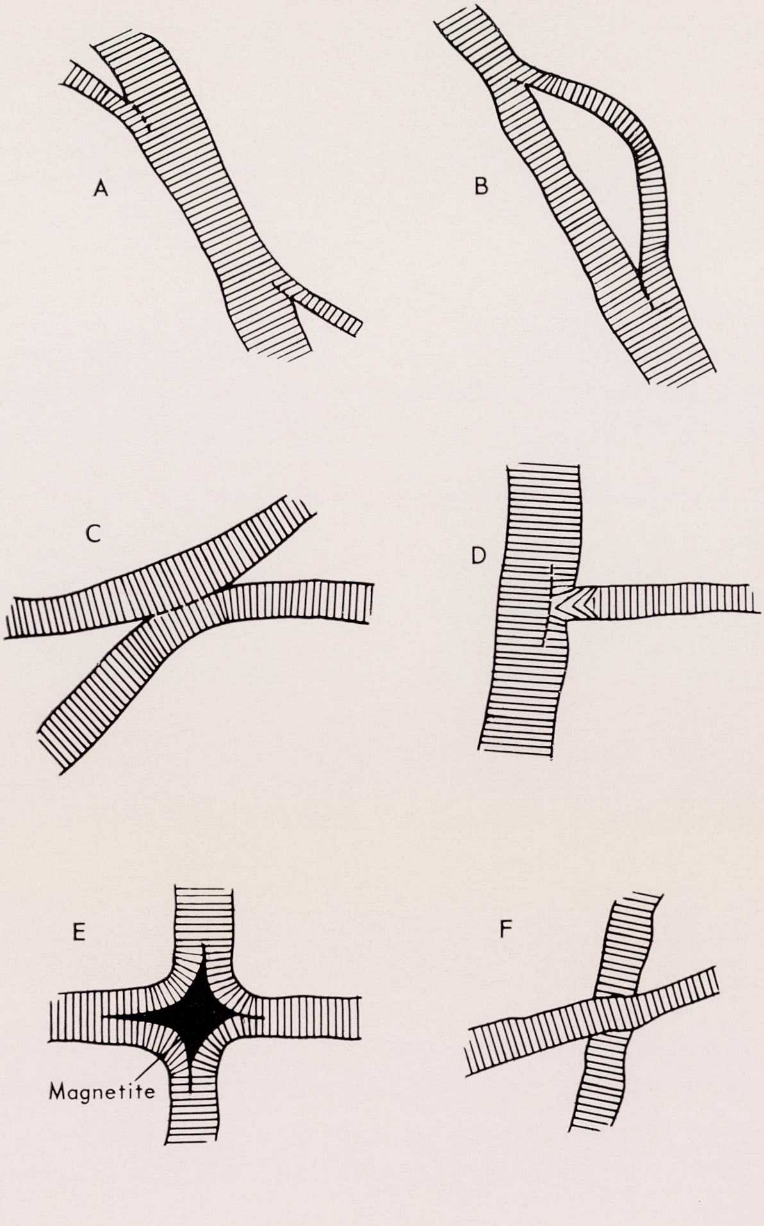


FIGURE 1. Intersections of chrysotile asbestos veins

(j) *Displacement*—post-asbestos faulting is not common, and is generally very local.

(k) *Gradations*—asbestos may give way to picrolite either laterally, or along the length of the vein, and in places appears to lens out. . . . Veins

Photo 3.—**Specimen of asbestos from Jones Creek (near Gundagai), showing that many small veinlets may coalesce to form a large vein**

Photo 4.—**A specimen from Baryulgil showing that the asbestos occurs in a composite vein made up of successive lenses of chrysotile separated by threads of picrolite**

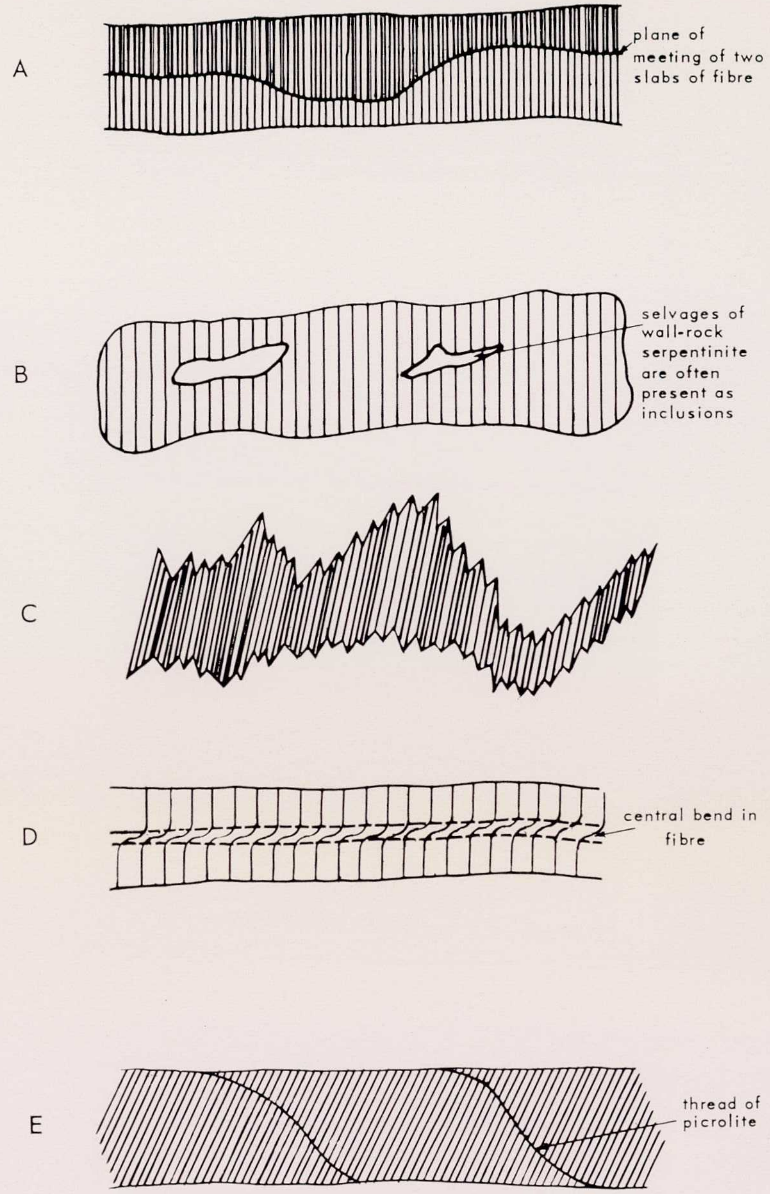


FIGURE 2. Types of chrysotile asbestos veins

may terminate abruptly, or fade out into wall rock, without any gradual decrease in width.

(1) *Types of veins* (figure 2)—Two slabs of fibre may meet in the centre without cohering; usually this occurs in fault fissures (figure 2, A). Fibre is usually unbroken between the walls of closed veins; these veins may have either a smooth (figure 2, B) or serrated (figure 2, C, and photo 8) vein boundary. Fibre may be unbroken between the walls of an open vein and display bending of the fibre in the centre of that vein. This bend indicates either a change in the direction of wall movement during growth of the fibre or post-asbestos movement along the vein (figure 2, D). A common vein type is made up of successive lenses of asbestos separated by threads of picrolite (figure 2, E, and photo 4). These have formed in small faults with picrolite walls, with later separation of the picrolite by either the growth of asbestos or post-asbestos movement.

Picrolite

Picrolite is a columnar serpentine mineral of the same chemical composition as chrysotile, but it is of no commercial value. In thin section it often shows marked banding parallel to the vein wall which almost obscures the fibrosity normal to it. The fibres are harsh, brittle, and difficult to separate. Picrolite is removed as waste in mining operations for chrysotile with which it is often found.

Anthophyllite

Anthophyllite has variable specific gravity and colour (white to yellow brown) depending on its iron content. It is usually found as slip- or mass-fibre and may be arranged in stellate bunches. The separated fibres are white, brittle, weak, short, and harsh. They are valued because of their high fusion point and high resistance to acids and other chemicals. Anthophyllite occurs as a constituent of certain metamorphosed basic or ultrabasic rocks, such as anthophyllite schist and gneiss.

Amosite

Amosite, the most important of the amphibole asbestos minerals, is known only from South Africa where it was named after the company that developed the deposits, Asbestos Mines of South Africa.

It is now classed as a fibrous variety of the cummingtonite–grunerite amphibole series. The colour is grey, white, or yellow when compact, and off white when in fibrous form.

Amosite is unaffected by acids and is generally resistant to the effects of chemical solutions. The fibre is harsh in texture but flexible and fairly strong, and can attain lengths of up to 12 inches. (Generally length varies from half an inch to 6 inches.) Amosite occurs in banded ironstones and jaspers, and seems to have been formed by metamorphism caused by the injection of dolerite dykes.

Actinolite

Actinolite has splintery and brittle fibres, and is not commercially useful. This mineral rarely occurs in a fibrous form though it is a common metamorphic mineral formed by the metamorphism of pyroxene and hornblende. Actinolite occurs in derivatives of basic and ultrabasic rocks such as actinolite schists and greenstones.

Tremolite

Tremolite has certain distinct advantages in industry, as the fibre is low in iron and is highly resistant to heat, acids, and alkalis. Fibres may be short or long, strong or weak, but are usually brittle. Its value as a fibrous mineral is limited because the deposits are usually small and uneconomic. Tremolite occurs in impure crystalline limestones, calc-silicate hornfels (contact metamorphic impure calcareous rocks), and in metamorphosed basic and ultrabasic rocks such as serpentinites and greenstones.

Crocidolite

Crocidolite, commercially known as "blue asbestos", is a fibrous form of riebeckite and is important commercially because of its chemical-resistant properties. It is highly resistant to acids and other chemical solutions and despite its low water content the fibres withstand high temperatures. Crocidolite is easily recognizable by its blue colour both in the natural state and when separated into fibres. These fibres are usually from a quarter of an inch to 1 inch in length with a maximum of 3 inches.

The fibres possess exceptional tensile strength, fair flexibility, and are of the cross-fibre variety. The longer fibres are suitable for spinning.

Crocidolite occurs as bands in metamorphosed sedimentary rocks, particularly ferruginous quartzites (banded iron formations) and impure dolomites where the mineral has formed as a metamorphic product.

No crocidolite asbestos has been found in New South Wales although it has been mined at Wittenoom Gorge in the Hamersley Range, Western Australia.

GENESIS AND STRUCTURE

Massive Chrysotile Deposits

Massive chrysotile deposits occur in fractures, as stockwork veins, or in pyroxene cleavage in serpentinite. There is no regular form to these deposits so ore bodies must be delineated by closely spaced diamond drilling. The rapid variation in width and sudden termination of individual veins in this type of deposit make evaluation difficult.

The genesis of chrysotile is controversial and no established theory is adequate to explain all the features displayed. However, crystallization of chrysotile is known to take place in the latter stages of metamorphism of a serpentinite body either during or after serpentinization. The metamorphic processes may be attributable to the fluids of the ultrabasic mass itself, (autometamorphism) or to later extraneous hydrothermal solutions.

Four main theories have been advanced to explain the formation of cross-fibre chrysotile asbestos veins.

(1) The veins are replacements: solutions entered along a tight crack which is now the central fissure and caused the recrystallization of the adjacent serpentine wall rock to asbestos (Dresser 1913, Graham 1917). This theory states that the crystals grow in the direction of least pressure (expansive strain) normal to the original fissure. Serpentine inclusions in the veins are regarded as islands of country rock surrounded by subsidiary cracks.

Objections to this theory are that: 75 per cent of all veins lack a central fissure; recrystallization should give irregular boundaries to the vein (which is often not the case); where asbestos is in a fault fissure, the fibre grows directly on slickensided surfaces and "as the asbestos has formed in this fissure without destruction of these walls, neither replacement nor solution of the original walls can have taken place" (Cooke 1936).

(2) The veins are fissure fillings: open cracks were filled with fluid which either contained the components of chrysotile in solution or obtained them by dissolving part of the wall rock, and the dissolved material crystallized as asbestos (Cirkel 1910, Keith and Bain 1932). As permeability of the wall rock is independent of the nature of the vein, and structures can be matched across the vein (see intersection F on figure 1, and photo 2), fissure filling seems tenable. However, the "size and number of asbestos veins in rich ground make it inconceivable that the spaces they now occupy were once open fissures" (Dresser 1913), and also the fissure filling hypothesis cannot explain partings or unconnected (closed) veins as in the relict cleavage of serpentinized pyroxene crystals at Woodsreef (see photo 10).

(3) Taber's theory: solutions or vapours penetrated through the pores of the wall rock, extracted serpentine, and deposited it as asbestos in tight fissures. The growth of the fibre gradually pushed the walls apart to form the existing veins (Taber 1916, 1917; Cooke 1936). This theory can explain closed veins but assumes that the fissures are so tight as to be bridged by the first-formed fibre, that addition is to the ends of the fibre from pores in the wall rock, and also that the force exerted by the growing fibres is sufficient to push the walls apart. By this theory single fibre veins with fibre extending from wall to wall and matched structures at the ends of the same fibres would be expected and this is not always the case.

(4) Riordon's theory: an amorphous serpentine mineral leached from the surrounding wall-rock is introduced into open fissures and crystallizes as picrolite (with iron thrown out as magnetite). Then picrolite is recrystallized to chrysotile if a favourable pressure/temperature environment exists. Wall-rock replacement also occurs, and asbestos is a composite, fissure-filling, wall-rock replacement vein mineral (Riordan 1955). A gradation, picrolite to chrysotile, occurs in some instances but in others picrolite is clearly a separate vein mineral.

In the opinion of the present writer, both fissure filling and wall-rock replacement occur, either separately or together, and a tensional state of stress existed at the time of asbestos formation. Some closed veins cannot be fissure filling and are most likely recrystallization or replacement of a susceptible zone aided by hydrothermal solutions permeating the pores in the rock.

The fact that chrysotile asbestos and its serpentinite host rock are chemically the same is an important consideration.

Tabular Ore Bodies

Chrysotile, crocidolite, and amosite occur in sedimentary beds such as dolomites, limestones, and fine-grained ferruginous slates and quartzites (banded ironstones) which occur as thinly and evenly bedded strata.

Chrysotile asbestos deposits in dolomite have been attributed to direct crystallization from hydrothermal solutions rich in magnesium, produced by dolerite intrusions (Poldervaart 1950, 1951).

Chrysotile and crocidolite are thought to have been the result of channel filling in the lamination planes of the sediment, opened up by expansive stresses set up during hydration (Sinclair 1955).

Study of chrysotile formed in this environment may throw light on the origin of more complex massive deposits in serpentinite.

Irregular Amphibole Asbestos Deposits

Irregular amphibole asbestos deposits occur as anthophyllite and tremolite in schistose rocks which are formed by the alteration of basic and ultrabasic rocks.

EXPLORATION AND EVALUATION

Exploration entails a preliminary literature search and appraisal to delineate potential areas. With chrysotile, areas of serpentinite are the prime factor. Surface float and outcrop need to be inspected and detailed geological surface mapping carried out.

Using the dip needle magnetometer, geophysical methods have been found useful in outlining massive chrysotile deposits in serpentinite where magnetite occurs in the asbestos zones. Such work, followed by a magnetometer survey with readings taken along lines at close intervals, gives a reasonably accurate outline of the ore body.

If the project has potential, surface work in the form of trenches at regular intervals across the strike of the deposit is used. Test pits and shafts may also be used to get a better depth of penetration.

If evidence of a potentially commercial ore body is obtained from the above preliminary work, diamond drilling programmes may be undertaken to delineate ore bodies of economic grade and obtain samples for testing.

The evaluation of an asbestos ore body differs largely from that of most base metal deposits in that several variables must be considered other than grade and tonnage.

The most important factors to be evaluated are:

(a) The area over which commercial fibre occurs and the percentage of fibre in the rock.

(b) The proportional percentage of different lengths of fibre (grades). The greater the percentage of long fibre the higher is the value of the rock.

(c) Milling characteristics: Does the fibre separate easily from the host rock (free milling) or not ("tight" fibre)? How does the host rock respond to crushing?

(d) The amenability of the fibre to splitting.

(e) Estimated percentage yield.

(f) The physical characteristics of the fibre, such as tensile strength, filtration rate, magnetic and colour ratings, and dust content. (See later under heading Properties of Commercial Importance.)

(g) Market value of the estimated fibre yield.

(h) Expected profit.

(i) Possible extensions to the ore body.

The erratic nature of asbestos ore bodies demands a very close drilling pattern so that the factors outlined above may be accurately determined. Core samples will show the number of seams per unit length, width of each seam, quality of fibre, and whether any partings will reduce the measured length. However, a large volume of fibre and fibre-bearing rock is needed to test the worth of the deposit and design an efficient mill to process the ore. (The mill is the greatest capital cost in the development of an asbestos ore body.) These bulk samples may be obtained by deep trenching, shafts, or large diameter diamond drill cores. The last method is being more widely used now and was adopted by White Asbestos (Mining) Pty Ltd on their property at Woodsreef, New South Wales. If underground methods of mining are to be employed, test adits and shafts may be used to obtain bulk samples.

MILLING

Milling is the process of extracting fibre from ore and is a purely mechanical process (figures 3 and 4). Milling practice is varied as the mill must be designed to suit the particular ore to be treated. The mill is designed to accommodate a certain maximum tonnage and to provide a product free of impurities and uniformly graded.

The three processes involved in milling are:

(a) comminution (crushing) to reduce the ore,

(b) screening and aspiration (fans) to separate fibre, grit, and dust, and

(c) grading of the cleaned fibre.

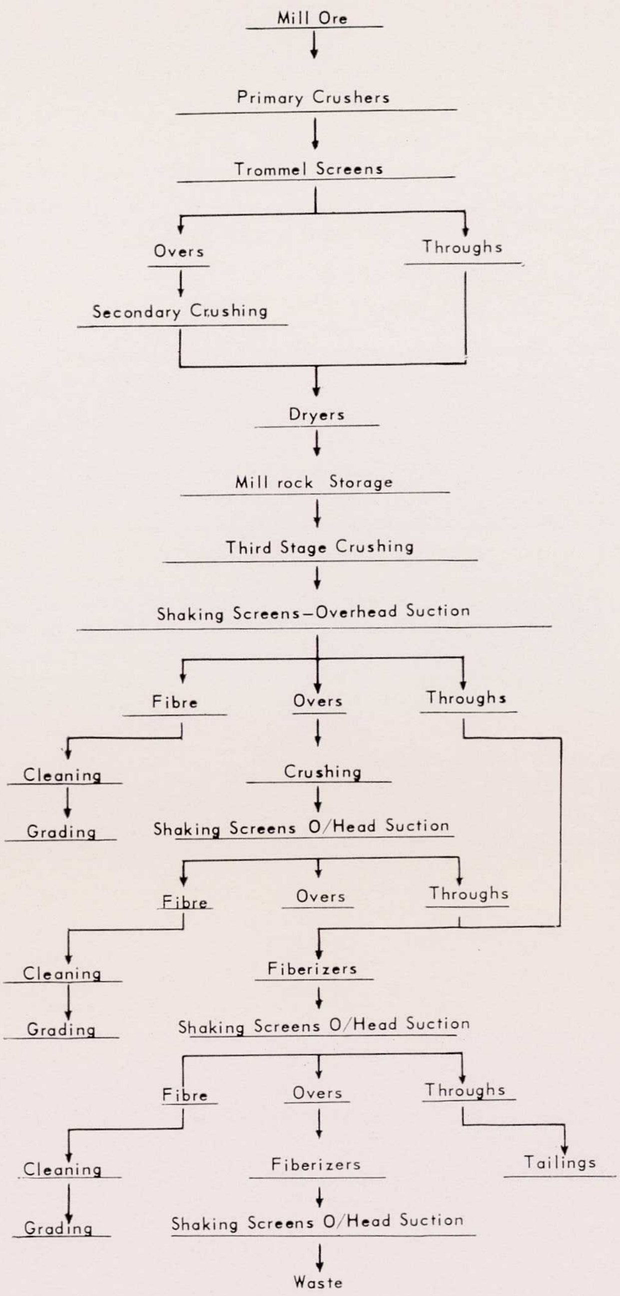


FIGURE 3. Type of mill flowsheet showing essential operations (after Sinclair 1955)

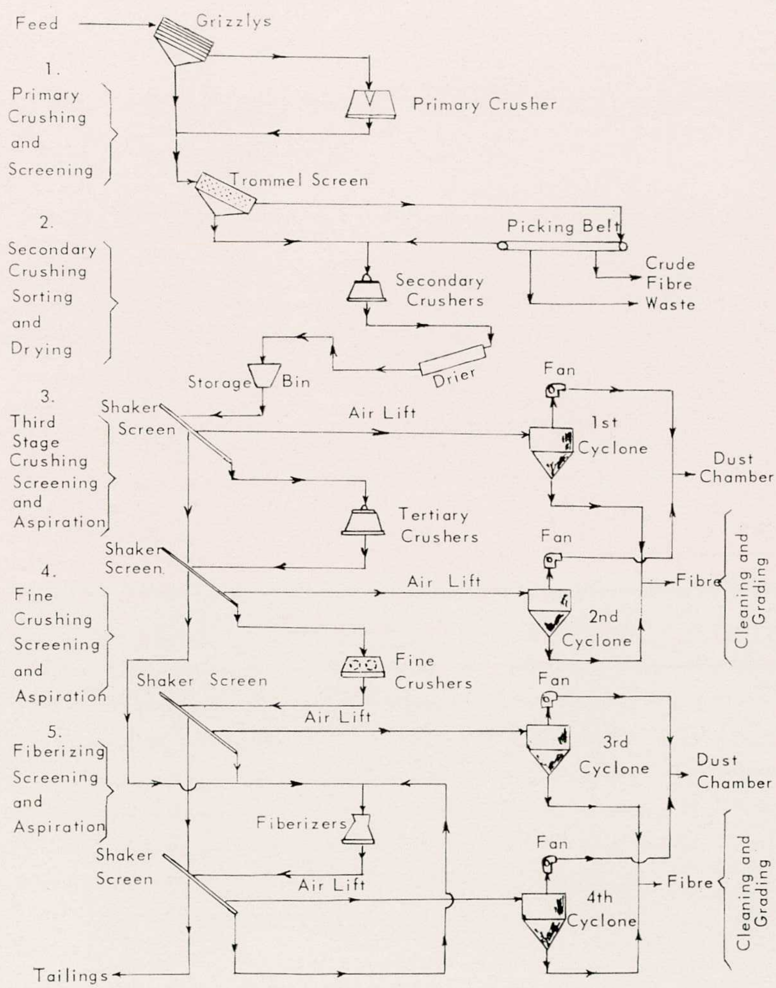


FIGURE 4. Flowsheet to indicate graphically the general principles of asbestos milling (after Sinclair 1955)

The factors affecting the milling of chrysotile are:

(a) humidity of the ore,

(b) softness of the parent rocks,

(c) soft and silky nature of the fibre,

(d) high value of spinning fibre,

(e) demand for even the shortest fibres,

(f) accepted classification and grading to specified standards, and

(g) infrequency of associated impurities in the ore.

The milling process is exceptionally complex because up to thirty-seven different grades of fibre each containing differing proportions of varying lengths of fibre must be produced to consumer specification. Approximately 100 tons of representative ore are needed to effect beneficiation and mill testing.

It is possible after an initial crushing stage to discard some of the waste rock before it enters the concentrating or milling plant. This is called beneficiation and can often reduce the tonnage of rock entering the mill by 45 per cent while losing only 5 per cent of the fibre. If the fibre breaks easily from the enclosing rock it may be possible to crush a maximum size of half an inch and to scalp off all plus three-sixteenths inch rock so reducing greatly the rate of wear and tear on mill machinery for a minimal loss of fibre. Bulk tests are needed to calculate beneficiation methods. As the specific gravity and chemistry of the fibre and ore are essentially the same, separation is effected by differential disintegration. After the fibre has been crushed and dried it fluffs and has a lower density than the crushed ore particles, thus responding differently to an impulsive force of air either by vacuum (air lift) or by blowing.

Wet milling has been utilized where a flowing stream of water moves the less dense fibre further than the rock particles. This method is currently being used to recover mill tailing "shorts".

CLASSIFICATION

Consumers make exacting demands for fibre of definite lengths and other specified qualities so producers are compelled to classify their product. "Crude" asbestos is hand-selected cross-vein material in its unfiberized form. "Milled" asbestos is any grade produced by the mechanical treatment of asbestos ore.

In Canada the Quebec Standard Asbestos Testing Machine is used to classify milled fibre. This machine consists of a set of three screens and a base pan. A 16-oz sample is shaken for 2 minutes and then the fibre in each tray is weighed to give an expression of the length and the proportion of different lengths of fibre in the sample. For example:

	Standard sizes used	Weight (oz)
Screen 1	½-inch opening	0
Screen 2	4 mesh	7
Screen 3	10 mesh	6
Pan	. . . .	3
		16

This sample would be expressed 0–7–6–3 and be a group 4 or shingle fibre. This system of grading asbestos is the most commonly used.

In South Africa each mine has a separate system. Classes defined by the Canadian System are as follows (modified from Sinclair 1955).

CRUDE ASBESTOS

Class	Standard Designation of Grade	Description
Group No. 1 . .	Crude No. 1 . .	Consists basically of crude ¾-inch staple or longer.
Group No. 2 . .	Crude No. 2 . .	Consists basically of crude ⅜-inch staple up to ¾-inch.
	Crude run-of-mine	Consists basically of unsorted crudes.
	Crudes sundry . .	Consists of crudes other than above specified.

MILLED ASBESTOS

Class	Standard Designation of Grade	Description
Group No. 3 . .	Spinning or textile fibre.	Consists of fibre testing 0–8–6–2 and over.
Group No. 4 . .	Shingle fibre . .	Consists of fibre testing below 0–8–6–2 to and including 0–1½–9½–5.
Group No. 5 . .	Paper fibre . .	Consists of fibre testing below 0–1½–9½–5 to and including 0–0–8–8.
Group No. 6 . .	Waste, stucco, or plaster.	Consists of material testing below 0–0–8–8 to and including 0–0–6½–9½.
Group No. 7 . .	Refuse or shorts . .	Consists of material testing 0–0–5–11 and below, including material testing below 0–0–1–15 and specified as weighing 35 lb or less per cu ft loose measure.
Group No. 8 . .	Sand	Consists of such asbestos mill products as sand weighing over 35 lb per cu ft loose measure and under 75 lb per cu ft loose measure, and containing a preponderance of rock.
Group No. 9 . .	Gravel and stone . .	Consists of such asbestos mill products weighing 75 lb and over per cu ft loose measure.

SUBDIVISION OF THE GROUPS OF MILLED ASBESTOS

	Standard Designation of Grades	Guaranteed Minimum Shipping Test
No. 3 Textile and spinning fibres.	3D	8–6–1–1
	3F	7–7–1½–1½
	3K	4–7–4–1
	3M	2–9–4–1
	3R	2–8–4–2
	3T	1–9–4–2
	3Z	0–8–6–2
No. 4 Shingle fibres	4D	0–5–10–1
	4F	0–3–12–1
	4K	0–4–9–3
	4M	0–4–8–4
	4R	0–3–9–4
	4T	0–2–10–4
	4Z	0–1½–9½–5
No. 5 Paper fibres . .	5D	0–½–10½–5
	5F	0–½–9½–6
	5K	0–0–12–4
	5M	0–0–11–5
	5R	0–0–10–6
	5T	0–0–9–7
	5Z	0–0–8–8
No. 6 Waste, stucco, or plaster.	6D	0–0–7–9
	6F	0–0–6½–9½
No. 7 Refuse or shorts.	7D	0–0–5–11
	7F	0–0–4–12
	7H	0–0–3–13
	7K	0–0–2–14
	7M	0–0–1–15
	7R	0–0–0–16
	7–20	20 lb per cu ft loose measure.
	7–25	25 lb per cu ft loose measure.
	7–30	30 lb per cu ft loose measure.
	7–35	35 lb per cu ft loose measure.
No. 8 Sand	8–40	40 lb per cu ft loose measure.
	8–45	45 lb per cu ft loose measure.
	8–55	55 lb per cu ft loose measure.
	8–75	75 lb per cu ft loose measure.
No. 9 Gravel and stone.	9	75 lb and over per cu ft loose measure.

The standardized grades in each of the groups are of special value in certain end-uses. The full import of this aspect as it affects the manufacturers is considered in the section "Principal Products".

Definite proportions of coarse and fine, or short and long, fibre can be produced by screening and air concentration to obtain a material with the desired filtration rate, wet volume, and other properties required by industry.

PRICES

Despite the regular quotations of asbestos prices on world metal and mineral markets, there is in fact no standard price. Average quotations based on past sales do not cover the wide range of grades of fibre quality. Quoted asbestos prices for 1970 are given in table 3.

TABLE 3

QUOTED ASBESTOS PRICES, 1970

Canadian Standard	Minimum Guaranteed Test	Price* Canadian Funds
		$
No. 1 Crude	....	1,525.00
No. 2 Crude	....	825·00
3F	10·5–3·9– 1·3– 0·3	650·00
3K	7·0–7·0– 1·5– 0·5	551·00
3R	4·0–7·0– 4·0– 1·0	468·50
3T	2·0–8·0– 4·0– 2·0	425·50
3Z	1·0–9·0– 4·0– 2·0	396·50
4A	0·0–8·0– 6·0– 2·0	368·50
4D	0·0–7·0– 6·0– 3·0	248.00
4J	0·0–5·0– 7·0– 4·0	248.00
4K	0·0–4·0– 9·0– 3·0	243.00
4M	0·0–4·0– 8·0– 4·0	243.00
4T	0·0–2·0–10·0– 4·0	218.00
5D	0·0–0·5–10·5– 5·0	184.00
5K	0·0–0·0–12·0– 4·0	184.00
5M	0·0–0·0–11·0– 5·0	173.00
5R	0·0–0·0–10·0– 6·0	156.50
6D	0·0–0·0– 7·0– 9·0	113.30
7D	0·0–0·0– 5·0–11·0	94.30
7F	0·0–0·0– 4·0–12·0	85.00
7H	0·0–0·0– 3·0–13·0	72.60
7K	0·0–0·0– 2·0–14·0	59.70
7M	0·0–0·0– 1·0–15·0	53.60
7R	0·0–0·0– 0·0–16·0	50.50
7T	0·0–0·0– 0·0–16·0	48.40
7MS	No test	52.00
7RS	No test	52.00
7TS	No test	52.00
8S	No test	44.30
8S	No test	31.40
8T	No test	24.20

* Prices quoted per ton of 2,000 lb F.O.B. cars, mine. $A1.0 = $C1.20.

The increase in asbestos prices has been about 3 per cent per annum. Regular quotations of asbestos prices are available in Industrial Minerals, published monthly by Metal Bulletin Ltd, London.

The cost of transport, etc., from Canada to Australia varies between $A30 and $A40 per long ton.

USES

Properties of Commercial Importance

The commercial suitability of asbestos depends on the length, tensile strength, and flexibility of the fibres and to a lesser degree on colour, elasticity, impurities, and the degree of resistance to heat, salt water, and acids.

The qualities tested are:

(a) Length distribution—determined by the Quebec Standard test which gives preliminary value estimation.

(b) Dust content—fibre is wash tested to determine the fine fraction (—200 mesh).

(c) Strength unit test—a measure of how much asbestos product is needed to impart a certain shear strength to an asbestos-cement mix. This is a function of dust content, openness of the fibre, and the inherent fibre strength.

(d) Filtration rate—the time it takes for a fibre mix to be de-watered, a factor which is important in the economics of processing.

(e) Colour rating.

(f) Magnetic rating.

These tests determine the properties of the asbestos fibre, its value, and its commercial applications. The last two tests are particularly important in shorter grade fibres where utilization as a plastics filler and in the tile industry is high.

The properties of amphibole asbestos vary greatly because of impurities which may replace the normal elements of the crystal lattice, resulting in wide variations in chemical composition. Impurities, including silicification, hydration, and oxidation products, are common in amphibole asbestos deposits. Impurities are uncommon in chrysotile, although magnetite may occur as discrete particles in the chrysotile veins rendering the fibre unsuitable for electrical insulating purposes.

Many tests of the properties of the fibre are required, and product improvement is gained by improved fibre selection, removal of iron impurities for electrical insulating purposes, and elongation of short fibres (this is still not perfected). Cotton, rayon, and glass fibres are blended with asbestos fibres to produce a fabric with superior strength which is less expensive though slightly inferior in insulating properties.

An idea of the quality of asbestos can be obtained by twisting and bending the fibres with the fingers. High-quality asbestos will break up readily into silky threads of great elasticity whereas low-quality material will break up into coarse, brittle fibres.

The demand for fibres of shorter lengths has grown until at present the greatest consumption is in groups 6 to 9. This is a result of the development of moulded asbestos products (brake linings for cars and vinyl asbestos floor tiles).

Of the 250,000 short tons per year consumed by Japan, 60 per cent is in the 6D (formerly waste) classification. Recovery of tailings from former production is being undertaken by some Canadian mines in response to this demand. However, sales of groups 8 and 9 (floats) are small.

Quality and Composition Affecting Uses

Incombustibility.—Most fibres under extreme heat retain their identity even though they lose their fibrous flexibility. Chrysotile withstands heat up to 550° C and amphibole varieties up to 370° C. These temperatures are as high as that of superheated steam and higher than the melting point of some of the common metals.

Insulation.—Asbestos is a good heat insulator and if low in iron content it can be used as an electrical insulating material (chrysotile is a non-conductor of electricity). The insulating property of asbestos also extends to the absorption of noise (asbestos is a good sound-insulator).

Durability.—Chrysotile fibres are attacked by acids and decompose if continuously exposed to humid air or sea water. The amphibole varieties are unaffected by sea water and most acids. This enhances their use as filtration media for acids or corrosive substances (particularly the crocidolite and amosite varieties).

Fibrous structures.—Length and strength of the fibre is most important. Fibres of spinning quality depend for their value on their strength and flexibility, and the effect of heat on tensile strength. The fibre must retain its original form even when strongly bent and heated.

Surface area.—When fiberized, good asbestos is light and has a large surface area making it useful as an insulating material, a filler, and a binding agent.

Table 4 (taken from Sinclair 1955, p. 270) gives the physical properties of the different varieties of asbestos.

TABLE 4

PHYSICAL PROPERTIES OF THE DIFFERENT VARIETIES OF ASBESTOS

(From Sinclair 1955, p. 270)

	Chrysotile	*Amosite*	*Anthophyllite*	*Crocidolite*	*Tremolite*	*Actinolite*
Specified heat B.Th.U./lb./°F.	0·266	0·193	0·210	0·201	0·212	0·217
Tensile strength, lb./sq. in.	80,000–100,000	16.000–90,000	4 000 and less	100,000–300,000	1000–8000	1,000 and less
Temp. at maximum ignition loss	1800	1600–1800	1800	1200	1800	—
Filtration properties	Slow	Fast	Medium	Fast	Medium	Medium
Electric charge	Pos.	Neg.	Neg.	Neg.	Neg.	Neg.
Fusion point °F	2770	2550	2675	2180	2400	2540
Spinnability	Very good	Fair	Poor	Fair	Poor	Poor
Resistance to acids and alkalies	Poor	Good	Very good	Good	Good	Fair
Magnetite content	0–5·2	0	0	3·0–5·9	0	—
Mineral impurities present	Iron, chrome, nickel, lime	Iron	Iron	Iron	Lime	Lime, iron
Flexibility	High	Good	Poor	Good	Poor	Poor
Resistance to heat	Good. Brittle at high temps.	Good. Brittle at high temps.	Very good	Poor Fuses	Fair to good	—
Ionizable salts. Micro-mhos (relative-elect. conductance)	1·82	1·34	0·58	0·84	—	—
Colour	Green, grey to white	Yellowish-brown	Yellow brown to white	Blue	White	Greenish
Texture	Fine and silky	Harsh and coarse	Soft to friable	Rough, harsh but flexible	Harsh or friable	Harsh, brittle

A comparison of tensile strengths with other fibrous material is given below.

Material	*Tensile strength* lb/in^2
Rock wool	60,000
Cotton fibre	73,000–89,000
Piano steel wire	300,000

Principal Products

Textile

Cloth and yarn are produced by the spinning and weaving of longer fibres. The cloth is used for safety clothing, curtains, lagging cloth, brake-band linings, clutch facings, packing, and gaskets that must not only resist high temperatures and pressures but must have adequate strength and abrasive qualities.

Spinning-grade fibres are also used for certain non-spinning products such as compressed-sheet packings of high strength for boilers, gaskets, and especially strong electrically resistant paper, in tape form, used for insulating electric wires (low-iron chrysotile is generally used).

Amosite is often used to fill spaces in groups of insulating cables on ships although, despite its exceptional fibre length and fair tensile strength, it is difficult to fabricate as a textile product because of its coarse nature and its tendency to pulverize in textile machines.

Crocidolite textiles are used for insulating acid-proof or sea-waterproof products.

The higher the asbestos content in a blend with organic fibre the more difficult is the manufacturing process and the weaker is the material, but the greater is its resistance to heat. A compromise of these desirable properties must be reached.

Asbestos-cement products

Asbestos-cement products consume the greatest quantity of all grades (mostly group 4 is used). Flat sheeting, tiles, slates, corrugated roofing, and pipes are produced consisting of 15–20 per cent asbestos with cement.

Insulating products and other articles

(1) Millboard and paper products are used as insulating materials. Usually group 5 asbestos is used, but shorter fibre is used in asbestos paper. Millboard consists of 80 per cent asbestos fibre, 18 per cent china clay, and 2 per cent starch.

(2) Magnesia-asbestos pipe covering for steam pipes consists of 15 per cent asbestos and 85% $MgCO_3$ (group 4 chrysotile is used).

(3) Sound insulators are made of millboard or paper asbestos products, but for acoustical purposes asbestos is used as a plaster.

(4) Felted insulation is an all-asbestos product, often of chrysotile but crocidolite and amosite are used where insulation is exposed to sea water, weathering, or other corrosive agents. The fibres are not woven.

(5) Filtration products are used particularly in sugar refineries and breweries (chrysotile), and in chemical plants where acid solutions are filtered (amphibole asbestos must be used).

(6) Cold-moulded products made from a fine asbestos-cement mixture are used in the electrical industry and household appliances.

(7) Moulded brake-linings can utilize short fibres down to 7F, as opposed to high grades needed for woven brake-linings.

(8) Electrical products such as paper, cell insulating tape, and mesh around electric wires are made from low-iron chrysotile.

Uses of Individual Asbestos Minerals

Chrysotile has the widest range of uses and constitutes 90 per cent of asbestos consumed. It is used in all asbestos products (depending on its grade) except those exposed to chemical attack. Short grades, even groups 8 and 9, can be used in boiler cements for heat insulation, and the best shorts are used as a filler in greases and roofing paints.

Amosite has inferior strength and flexibility to chrysotile and crocidolite, but commonly occurs in very long fibres. It is used as felted lagging for insulation up to 470° C on marine turbines, jet engines, and steam-pipe covering, as mattresses around boilers and kilns (all asbestos), in magnesia insulating materials (85% $MgCO_3$), and in asbestos-cement products in which it is blended with chrysotile. The resiliency of the fibres allows it to withstand shock and absorb heat and noise.

Crocidolite is not used as much as chrysotile because of its colour and inferior spinning qualities. However, it has a very high tensile strength and superior acid- and sea water-resistant qualities. It is spun into yarn and fabrics for chemical-resistant packing and is used as felted insulation for flexible boiler and steam-pipe coverings for mercantile use. Long fibres are used in gas masks and for the filtration of gas, acids, and other corrosive solutions. It finds a use in asbestos-cement products, especially pipes, because of its high tensile strength and harshness in a wet mix. Also crocidolite is used in packings and millboard in preparations for electrical insulation and in asbestos products for building.

Anthophyllite is resistant to high temperatures and chemical attack but its use is limited by the weakness of the fibres. It is used in chemical laboratories, as welding-rod coatings (with other minerals as a flux), as a plastic cement for boiler pipes or furnace insulation, as a filler in battery boxes, and as a chemical-resistant filter.

Tremolite–actinolite asbestos has weak fibres and few industrial uses. It is used as a filler in paints and in the manufacture of filter pads for the liquor industry.

About 63 per cent of all asbestos used is fabricated into insulating materials. The uses of asbestos are summarized in table 5 (taken from Sinclair 1955).

Synthetic Asbestos and Substitutes

The synthetic asbestos so far produced has only very short fibres and is not a satisfactory substitute for the natural material.

Substitutes are used as blends with asbestos fibre. Cotton, woodbark, rayon, nylon, rock wool, and fibre glass are used but at the moment only as a means of reducing the consumption of asbestos. Rock wool is proving to be superior to cotton and other vegetable fibres, can be

TABLE 5
UTILIZATION OF ASBESTOS
(From Sinclair 1955)

Class and Grade of Asbestos Used	*Basis of Asbestos Products*	*Application of Products*				
		Electrical Industry	*Building Construction*	*Engineering and Motor Industry*	*Chemical Industry*	*General*
Group 3 Chrysotile; Amosite; Crocidolite	Unprocessed	Special insulations	Cable filler in ship-building	Wicks; Packing; Insulation	Filters; Pads; Caulking	Gas masks
Group 1/2 Chrysotile; Crocidolite Spinning	Asbestos yarn	Tape; Stocking for lead cable; Wire covering and cable covering		Brake lining; Clutch facing; Packing; Gaskets; Rope and cord		Thread
Group 1/2 Chrysotile; Crocidolite Spinning	Asbestos cloth	Insulation	Floor lining and insulation	Packing, gaskets; Brake lining; Clutch facing; Mattresses, Pipe covering; Welding, linings; Lagging	Liquid filters; Dust filters; Testing apparatus; Belting for conveying hot materials	Fireproof clothing Tapestry; Blankets; Mailbags; Theatre curtains; Oven linings
Amosite; Crocidolite	Asbestos felt		Felted roof insulation	Covering pipes and boilers; Naval insulations	Insulations; Chemical plant	Acoustics and sound insulations
Chrysotile long and short grades	Asbestos tape	Armature winding; Winding coils; Bus-bars			Conveyor belting; Insulation and caulking	Oil wicks; Glass works
Group 5 Chrysotile; Crocidolite; Amosite	Asbestos paper	Tubes; Insulation; Lining electrical appliances	Insulations	Air-cell pipe covering; Boiler covering; Gaskets and lining	Diaphragms; Laboratory appliances	Linings for stoves, heaters and insulation
Group 5 Chrysotile; Crocidolite; Amosite	Millboard	Conduit covering; Washers; Lining	Lining and insulation	Lining; Insulation; Gaskets	Lining and insulations	Insulation appliances; Stove lining; Table and stove mats
Group 4 Chrysotile (5 and 6 blended); Crocidolite "S"; Amosite	Asbestos-cement	Conduits; Insulations; Spark arresters	Roofing tiles; Shingles; Siding and wall boards; Sewage pipes	Pipes for water	Gas and acid conduits	Lining cookers; Table tops; Ventilators; Other appliances
Chrysotile and Amphibole short grades	Composition and compounds	Insulation; Fittings and appliances; Battery boxes	Flooring and roofing tiles; Plaster; Stucco; Paints	Boiler cement; Insulation; Magnesia pipe covering	Furnace cement insulation	Plastic appliances; Pottery and Vases; Acoustic appliances; Plaster and paint

easily made from sand, lime, and alkalis, and may eventually replace vegetable fibres altogether in the manufacture of asbestos textiles. However, this glass fibre has a resistance to heat and abrasion inferior to that of asbestos. Silicon rubber is proving a successful substitute in electric-wire covering. Fibre glass may eventually replace amosite if economics permit and is already replacing crocidolite in the manufacture of filter pads. However, glass fibres cannot be used in cement products as they are attacked by the lime.

Reclamation of asbestos by the removal of impurities from worn products has not been successful as yields are low and damage to the fibre is difficult to avoid.

New uses for asbestos are constantly being found, and satisfactory substitutes are uncommon, so a strong and growing demand is anticipated.

PRODUCTION AND CONSUMPTION

World

Ninety per cent of the world's production comes from Canada, the U.S.S.R., and South Africa (table 6). The major consumers are the United States of America, Europe, and Japan. Hence, there is a drive by the consuming countries to produce synthetics and substitutes in order to become more self-sufficient. Canadian mines now meet 25 per cent of the world's asbestos needs as opposed to 50 per cent a decade ago.

Ninety-five per cent of the Canadian asbestos production is exported, and about 75 per cent of this enters asbestos-cement materials (table 7).

TABLE 7

CANADIAN EXPORTS OF FIBRE IN 1969

(Short tons)

Importer	Crude	Milled		
		Group 3	Group 4–5	Group 6–9
U.S.A.	89	15,850	201,955	443,436
U.K.	..	5,042	58,808	55,304
South America	..	202	48,502	15,007
Europe	24	12,434	213,852	115,394
Japan	89	2,621	30,939	63,831
Others	..	2,022	13,374	742,423
Total	202	38,171	567,430	1,435,395

TABLE 6

WORLD PRODUCTION OF ASBESTOS FIBRE, 1954–1969

(Thousands of short tons)

Country	1954–58 average	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Australia	10	18	16	17	18	15	14	12	13	1	1	1
Canada	994	1,050	1,118	1,174	1,216	1,272	1,420	1,388	1,489	1,452	1,596	1,596
China (estimates)	33	90	90	100	100	110	130	140	150	165	165	140*e*
Cyprus	15	14	23	16	22	22	14	18	24	19	23	20*e*
Finland	9	10	11	10	11	10	12	13	13	12	13*e*	13*e*
France	15	23	29	31	28	26	24	8	8	†	†	†
Italy	37	53	61	63	61	63	76	79	91	111	117*e*	100*e*
Japan	10	14	17	19	15	18	18	16	21	27	28	26*e*
South Africa (Republic) . .	140	182	176	195	221	206	216	241	277	268	261	273*e*
Southern Rhodesia . .	113	120	134	162	142	142	153	176	176*e*	150*e*	170	150*e*
Swaziland	30	25	32	31	33	33	40	41	36	40	43	40*e*
U.S.S.R. (estimates)‡ . .	475	600	660	880	1,100	1,250	1,500	1,500	1,721	1,925	2,000	2,200
U.S.A. (sales)	44	45	45	53	53	67	101	118	126	123	121	127
Other countries*	15	16	28	19	35	16	23	25	27	26	33*e*	42*e*
Total (estimates) . .	1,940	2,260	2,440	2,770	3,055	3,250	3,741	3,775	4,172*e*	4,319*e*	4,571*e*	4,728*e*

* Estimate of small production in about twenty countries, Yugoslavia being the most important of these

† Less than 500 short tons *e* Estimate

‡ Various different estimates of the production of asbestos by the U.S.S.R. are available. However, it is currently accepted that their production exceeds Canadian production

Compiled from:

Engr. Min. J. **169** (3), March 1968; **171** (3), March 1970

Minerals Yearbook, 1966, 1967, 1968. *U.S. Bur. Mines, Washington*

Australian Mineral Industry, Review. 1967, 1968. *Bur. Miner. Resour. Geol. Geophys. Aust., Canberra*

Industrial Minerals **30**, March 1970. Metal Bulletin Ltd, London

Mineral Facts and Problems. *Bull. U.S. Bur. Mines* **630,** 1965

Can. Min. J., February 1970, **91** (2)

Australia

Australia consumes about 60,000 short tons of asbestos per year with a projected annual increase calculated at 5 per cent. Most of this demand is satisfied by Canadian fibre, and short fibre is consumed at a rate well below the world average because of import costs. The consumption of short fibre is expected to increase greatly when the Woodsreef deposit comes into production as this will constitute a local, cheap source of this material. Australian production of asbestos fibre, 1964–1968, is given in table 8. The sole producer in Australia at present is Asbestos Mines Pty Ltd, a wholly owned subsidiary of James Hardie Asbestos Ltd, operating a quarry and plant at Baryulgil in northeastern New South Wales. All deposits in New South Wales have been exploited by open-cut mining methods. Rock is broken from a working face, and often hand picked to upgrade the ore before milling. At Baryulgil, the broken rock contains 2–3 per cent fibre and is hand picked to produce a milling ore of 6–7 per cent.

Production of West Australian crocidolite ceased at the end of 1966 due to the closure of the mine at Wittenoom Gorge by Australian Blue Asbestos Ltd, the high cost of transport from this remote region being an important factor.

For details of past production in New South Wales, see appendix 1.

TABLE 8

AUSTRALIAN PRODUCTION OF ASBESTOS FIBRE

(Short tons)

	1964	1965	1966	1967	1968
Chrysotile—					
N.S.W.	1,057	722	494	515	821
W.A.	600	450	133	85	75
Crocidolite—W.A. ..	11,888	10,394	12,841	..	..
Total	13,545	11,566	13,468	600	896

Australian fibre consumption in asbestos-cement products (by far the most important use) is as follows:

Year:	1963–1964	1964–1965	1965–1966	1966–1967	1967–1968
Short tons:	41,618	47,367	47,571	49,110	50,407

Compiled from Australian Mineral Industry Review, 1967, 1968. *Bur. Miner. Resour. Geol. Geophys. Aust., Canberra.*

NEW SOUTH WALES ASBESTOS OCCURRENCES

The commercial deposits of chrysotile are associated with the serpentinite belts of New South Wales, particularly the Gordonbrook Serpentinite Belt and the Great Serpentine Belt. For a list of leases in force at December, 1969, see appendix 2.

Gordonbrook Serpentinite Belt

Asbestos occurs throughout the Gordonbrook Serpentinite Belt, particularly at Baryulgil and Fine Flower.

BARYULGIL (52 miles by road northwest of Grafton, northeastern New South Wales; Grafton 1: 250,000, GR 571377)

Portions 12 *and* 122, *Parish Yulgilbar, County Drake*

This deposit was first developed during the 1914–1918 war although no production was recorded for that period. At present the deposit is covered by Private Mining Leases (PML's) 6, 8, 9, 27, and Mining Lease (ML) 1, and open-cut mining operations have been carried out continuously since 1941 by Asbestos Mines Pty Ltd, now a wholly owned subsidiary of James Hardie Asbestos Ltd (for production figures see appendix 1). The quarry is at present being worked on a level about 100 feet below the surface. The ore is hand picked and upgraded from

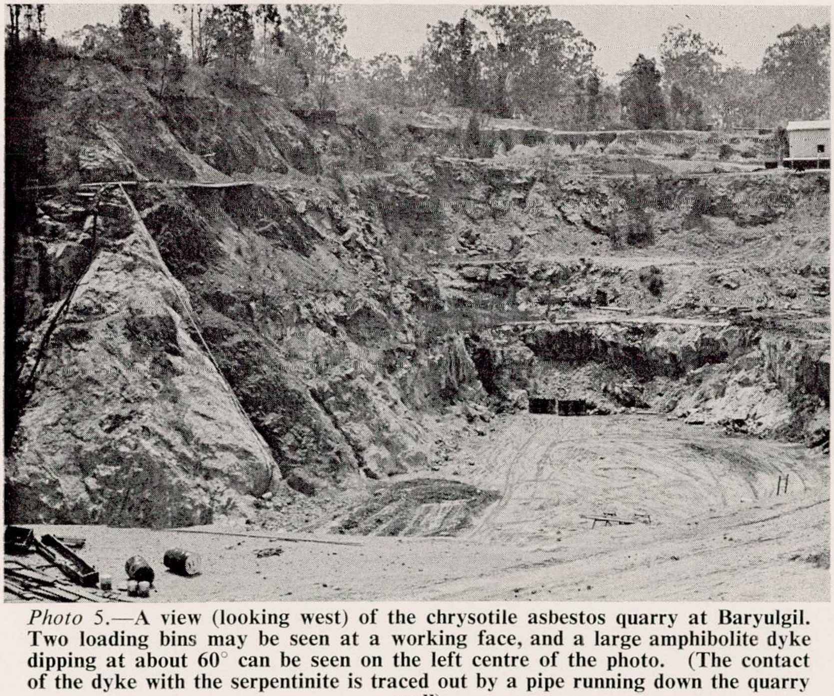


Photo 5.—**A view (looking west) of the chrysotile asbestos quarry at Baryulgil. Two loading bins may be seen at a working face, and a large amphibolite dyke dipping at about 60° can be seen on the left centre of the photo. (The contact of the dyke with the serpentinite is traced out by a pipe running down the quarry wall)**

Photo 6.—**A view (looking east) of the chrysotile asbestos quarry at Baryulgil. A drilling rig (right foreground) is being used to test extensions to the deposit**

an average grade of 2 to 3 per cent fibre in the ground to 6 to 7 per cent fibre before milling on the site (see photos 5 and 6).

The serpentinite belt occurs at the junction of the Mesozoic Clarence-Moreton Basin sediments and Palaeozoic rocks including granite and metasediments. Asbestos occurs as cross-fibre veins of chrysotile (see

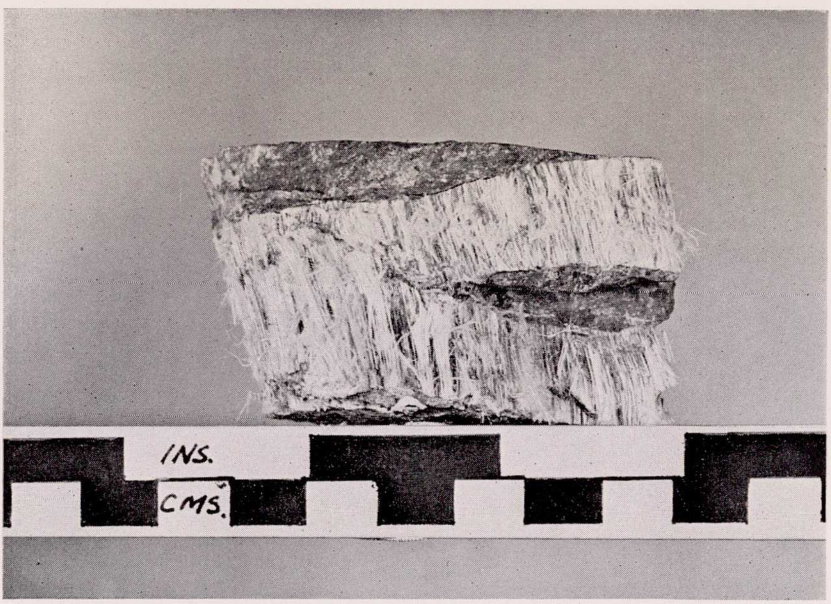


Photo 7.—**Best quality cross-fibre chrysotile asbestos from Baryulgil. The vein reaches a maximum width of 1 inch**

KEY TO LOCALITIES ON SPOT MAP

Gordonbrook Serpentinite Belt

1. Baryulgil
2. Fine Flower

Great Serpentine Belt

3. Woodsreef
4. Spring Creek

Girilambone-Kiandra Serpentinite Belt

5. Jones Creek
6. Wallendbeen

Broken Hill District

7. Rockwell Paddock

Others

8. Orange
9. Rockley
10. Newbridge
11. Wellington

APPENDIX 2

MINING LEASES FOR ASBESTOS IN FORCE AS AT 31st DECEMBER, 1969

Mining Division	No. of Lease	Lessee	Portion Number	Parish (County)
Barraba ..	5825	White Asbestos (Mining) Pty Ltd	ML 26 ..	Woodsreef (Darling)
	5826	White Asbestos (Mining) Pty Ltd	ML 27 ..	Woodsreef (Darling)
	5827	White Asbestos (Mining) Pty Ltd	ML 28 ..	Woodsreef (Darling)
	5866	White Asbestos (Mining) Pty Ltd	ML 22 ..	Woodsreef (Darling)
	5867	White Asbestos (Mining) Pty Ltd	ML 23 ..	Woodsreef (Darling)
	5868	White Asbestos (Mining) Pty Ltd	ML 24 ..	Woodsreef (Darling)
	5879	White Asbestos (Mining) Pty Ltd	ML 30 ..	Woodsreef (Darling)
	5918	White Asbestos (Mining) Pty Ltd	ML 29 ..	Woodsreef (Darling)
	5928	White Asbestos (Mining) Pty Ltd	ML 31 ..	Woodsreef (Darling)
	6151	White Asbestos (Mining) Pty Ltd	ML 35 ..	Woodsreef (Darling)
	3685	White Asbestos (Mining) Pty Ltd	PML 10	Woodsreef (Darling)
	454	White Asbestos (Mining) Pty Ltd	ML 36 ..	Woodsreef (Darling)
	456	White Asbestos (Mining) Pty Ltd	ML 33 ..	Woodsreef (Darling)
	464	White Asbestos (Mining) Pty Ltd	ML 34 ..	Woodsreef (Darling)
	63	White Asbestos (Mining) Pty Ltd	PML 14	Woodsreef (Darling)
Rylstone ..	1143	Nowasad	PML 35	Dungeree (Phillip)
Copmanhurst	3074	Asbestos Mines Pty Ltd	PML 9 ..	Yulgilbar (Drake)
	3444	Asbestos Mines Pty Ltd	ML 1 ..	Yulgilbar (Drake)
	543	Asbestos Mines Pty Ltd	PML 5 ..	Yulgilbar (Drake)
	544	Asbestos Mines Pty Ltd	PML 6 ..	Yulgilbar (Drake)
	545	Asbestos Mines Pty Ltd	PML 8 ..	Yulgilbar (Drake)
	989	Asbestos Mines Pty Ltd	PML 27	Yulgilbar (Drake)
	1002	Asbestos Mines Pty Ltd	PML 28	Yulgilbar (Drake)
	1158	Asbestos Mines Pty Ltd	PML 31	Yulgilbar (Drake)
	1205	Asbestos Mines Pty Ltd	PML 32	Yulgilbar (Drake)
	3579	Woodsreef Asbestos Co. Ltd	PML 21	Yulgilbar (Drake)
	3581	Woodsreef Asbestos Co. Ltd	Part PML 22	Yulgilbar (Drake)
	3585	Woodsreef Asbestos Co. Ltd	PML 1 ..	Ogilvie (Drake)
	1052	Woodsreef Asbestos Co. Ltd	PML 29	Yulgilbar (Drake)
	1054	Woodsreef Asbestos Co. Ltd	Part PML 22	Yulgilbar (Drake)
	1065	Woodsreef Asbestos Co. Ltd	PML 2 ..	Ogilvie (Drake)
	1068	Woodsreef Asbestos Co. Ltd	PML 23	Yulgilbar (Drake)

APPENDIX 1—*continued*

	Gundagai District		Orange District		Barraba District		Copmanhurst District	
	Jones Creek		Byng and Lewis Ponds		Woodsreef		Baryulgil	
	Amphibole		Amphibole		Chrysotile		Chrysotile	
Year	Tons	Value	Tons	Value	Tons	Value	Tons	Value
		$		$		$		$
1949	..	..	59	2,900	..	..	221	29,346
1950	..	..	..	..	..	..	374	67,526
1951	..	..	..	..	..	..	432	74,694
1952	..	..	..	..	..	..	466	85,410
1953	..	..	..	..	..	..	569	111,910
1954	..	..	..	..	..	..	616	113,356
1955	..	..	..	..	..	..	590	108,638
1956	..	..	..	..	..	..	622	114,082
1957	..	..	..	..	..	..	604	132,136
1958	..	..	..	..	..	..	636	137,392
1959	..	..	..	..	13	2,006	635	131,100
1960	..	..	..	..	..	..	957	213,432
1961	..	..	..	..	..	..	709	172,620
1962	..	..	..	..	..	..	774	190,610
1963	..	..	..	..	..	..	838	206,044
1964	..	..	..	..	..	..	1,040	218,078
1965	..	..	..	..	..	..	645	135,664
1966	..	..	..	..	..	..	441	92,681
1967	..	..	..	..	..	..	460	106,804
1968	..	..	..	..	..	..	734	180,141
1969	..	..	..	..	..	..	704	174,000
Total	72·4	1,906	338·2	7,052	2,491	99,056	15,095	2,963,600

† Calculated from 180 tons of milling rock.

* Estimated.

Note.—In 1931 a parcel of 8 tons of asbestos was produced from the Broken Hill Division and valued at $128 (Red Hill, half a mile east of Menindee road, 10 miles east of Broken Hill).

In 1942, 50 tons of asbestos ore were raised from Sewells Creek near Rockley.

Asbestos fines contribute in a minor amount to the tonnage from Baryulgil, e.g., 1968, fibre 728 tons, fines 6 tons.

APPENDIX 1

PRODUCTION OF ASBESTOS IN NEW SOUTH WALES, 1880–1969

	Gundagai District		Orange District		Barraba District		Copmanhurst District	
	Jones Creek		Byng and Lewis Ponds		Woodsreef		Baryulgil	
	Amphibole		Amphibole		Chrysotile		Chrysotile	
Year	Tons	Value	Tons	Value	Tons	Value	Tons	Value
		$		$		$		$
1880	12·4	646	..	..	..	..	..	..
1881	7·5	150	..	..	..	..	..	..
1882–1884	6·0	180	..	..	..	..	..	..
1885–1907	5·0	100*	..	..	..	..	..	..
1908	15·0	300*	..	..	..	..	..	..
1909–1915	0·5	10	..	..	..	..	..	..
1916	10·0	200*	..	..	..	..	..	..
1917	..	..	..	..	..	..	..	..
1918	..	..	..	..	9†	244*	..	..
1919	..	..	12·0	96	143	3,876	..	..
1920	..	..	8·0	128	656	14,680	..	..
1921	16·0	320	24·0	232	905	46,880	..	..
1922	..	..	..	..	561	22,836	..	..
1923	..	..	..	..	204	8,534	..	..
1924–1931	..	..	4·5	40	..	..	..	..
1932–1939	..	..	8·0	160	..	..	..	..
1940	..	..	37·0	740	..	..	..	..
1941	..	..	37·0	680	..	..	144	11,800
1942	..	..	74·0*	1,400	..	..	103	8,240
1943	..	..	..	..	..	..	406	36,378
1944	..	..	..	..	..	..	347	27,760
1945	..	..	..	..	..	..	254	16,956*
1946	..	..	..	..	..	..	238	19,984*
1947	..	..	34·7	312	..	..	251	22,094
1948	..	..	40	364	..	..	285	24,724

JAQUET, J. B., 1896. Geological report on the Berthong Estate, near Wallendbeen. *A. Rep. Dep. Mines, N.S.W.* for 1895, 180.

JAMES, D. H., 1955. The genesis of asbestos in ultrabasic rocks. *Econ. Geol.* **50** (4), 438.

KEITH, S. B. and BAIN, G. W., 1932. Chrysotile asbestos: 1, chrysotile veins. *Econ. Geol.* **27**, 169–188.

LLOYD, A. C., 1950. Baryulgil asbestos deposit. *Geol. Rep. Dep. Mines, N.S.W.* for 1939–1945, 78–80.

—————, 1942. Asbestos deposit, Baryulgil. *Rep. geol. Surv. N.S.W.* **GS 1942/059** (unpubl.).

—————, 1943. Yulgilbar asbestos deposit. *Rep. geol. Surv. N.S.W.* **GS 1943/037** (unpubl.).

—————, 1948. Sewell's Creek, asbestos, (Rockley, N.S.W.). *Rep. geol. Surv. N.S.W.* **GS 1948/032** (unpubl.).

—————, 1948. Baryulgil asbestos deposit. *Rep. geol. Surv. N.S.W.* **GS 1948/033** (unpubl.).

MCELROY, C. T., 1958. Inspection of asbestos deposits, Fine Flower near Copmanhurst. *Rep. geol. Surv. N.S.W.* **GS 1958/048** (unpubl.).

MACNEVIN, A. A., 1969. The geology of the Baryulgil area with special reference to the Gordonbrook Serpentinite Belt. *B.Sc.Hons Thesis, Univ. N.S.W.* (unpubl.).

MAY, T. C., 1965. Asbestos, *in* Mineral Facts and problems. *Bull. U.S. Bur. Mines* **630**, 81–90.

METAL BULLETIN LTD, 1970. Industrial Minerals, **28**, January 1970, *Metal Bulletin Ltd, London.*

MINISTRY OF POST-WAR RECONSTRUCTION, 1945. Report on Asbestos cement sheet industry and crude asbestos deposits in Australia. *Rep. Secondary Industries Division, Ministry of Post-War Reconstruction* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1945/020**).

NOAKES, L. C., 1948. Asbestos, *in* Mineral Resources of Australia, *Summ. Rep. Bur. Miner. Resour. Geol. Geophys. Aust.* **17**.

POLDERVAART, A., 1950. Chrysotile asbestos produced by dolerite intrusions in dolomite. *Colon. Geol. Miner. Resour.* **1** (3), 239–245.

—————, 1951. Brit. Ceramic. Abstr., 1951, **445A**.

PROUD, J. S. and OSBORNE, G. D., 1952. Stress-environment in the genesis of chrysotile, with special reference to the occurrence at Woodsreef, near Barraba, New South Wales. *Econ. Geol.* **47** (1), 13–23.

RAGGATT, H. G., 1924. Asbestos, Emery, Fluorspar, Fuller's Earth, Graphite, Phosphates, Talc, and Soapstone. *Bull. Geol. Surv. N.S.W.* **14**.

RIORDON, P. H., 1955. The genesis of asbestos in ultrabasic rocks. *Econ. Geol.* **50** (1), 67–81.

SELFRIDGE, G. C., 1936. An x-ray and optical investigation of the serpentine mineral. *Am. Miner.* **21** (8), 463–503.

SINCLAIR, W. E., 1955. ASBESTOS, ITS ORIGIN, PRODUCTION AND UTILIZATOIN. 365 pp. Mining Publications Ltd, London.

SMITH, C. L., 1922. Asbestos mining in N.S.W. *Chem. Engng Min. Rev.* Dec. 1922, 101–102.

TABER, S., 1916. The genesis of asbestos and asbestiform minerals. *Bull. Am. Inst. Min. Engng* **119**, 1973–1998.

—————, 1917. The origin of chrysotile veins. *Econ. Geol.* **12** (5), 476–479.

TAYLOR, B. L., 1955. Asbestos in Tasmania. *Miner. Resour. geol. Surv. Tasm.* **9**.

WALLIS, G. R., 1964. Woodsreef asbestos deposit. *Rep. geol. Surv. N.S.W.* **GS 1964/022** (unpubl.).

WOOD, H., 1882. Mineral Products of New South Wales. *Geol. Surv. N.S.W., Sydney.*

SELECTED BIBLIOGRAPHY

Annual Reports of the Department of Mines, New South Wales, for 1880–1968.

ASBESTOS—Trade Magazine. Published monthly since July, 1919. Western Saving Fund Building, Philadelphia, Pa.

ADAMSON, C. L., 1957. Quality Earths Pty. Ltd., re asbestos at Gundagai. *Rep. geol. Surv. N.S.W.* GS 1957/027 (unpubl.).

BADOLLET, M. S., 1948. Research on asbestos fibres. *Can. Min. J.*, April 1948, 213–216.

——————, 1950. Processing asbestos fibres. *Trans. Can. Inst. Min. Metall.* **53.**

——————, 1951. Asbestos, a mineral of unparalleled properties. *Trans. Can. Inst. Min. Metall.* **54,** 151–160.

BATES, T. F., SAND, L. B., and MINK, J. F., 1950. Tubular crystals of chrysotile asbestos. *Science* **111**, 512–513.

BECKER AND HAAG, 1928. ASBESTOS. 88 pp. Becker and Haag, Berlin.

BENSON, W. N., 1907. The geology of Newbridge, near Bathurst, N.S.W. *Proc. Linn. Soc. N.S.W.* **32** (3), 525–526.

BOWLES, O., 1955. The Asbestos Industry. *Bull. U.S. Bur. Mines* **552**, 122 pp.

BUTT, B. C., 1967. Progress report on the exploration on the area covered by exploration licence No. 30, New South Wales, Australia. (Baryulgil area). *Rep. by Watts, Griffis, and McOuat for Woodsreef Asbestos Co. Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1966/188**).

——————, 1967. Preliminary feasibility report on the Woodsreef asbestos project N.S.W., Australia. *Rep. by Watts, Griffis, and McOuat to Merit Oil Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1967/196**).

——————, 1968a. Preliminary feasibility report on the Woodsreef asbestos project, New South Wales, Australia. *Rep. by Watts, Griffis, and McOuat to Merit Oil Ltd and Castle Tin Mines Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1968/078**).

——————, 1968b. Report to the Under Secretary for Mines on the proposed programme for the final exploration phase on the Woodsreef asbestos property near Barraba, New South Wales. *Rep. by Watts, Griffis, and McOuat to White Asbestos (Mining) Pty Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1968/256**).

CARROLL-PORCZYNSKI, C. Z., 1956. ASBESTOS FROM ROCK TO FABRIC. The Textile Institute, Manchester.

CIRKEL, F., 1910. Chrysotile Asbestos. *Can. Mines Branch.*

COOKE, H. C., 1936. Asbestos deposits of Thetford district, Quebec. *Econ. Geol.* **31** (4), 355–376.

DRESSER, J. A., 1913. Asbestos. *Mem. Geol. Surv. Can.* **22**, 60–65.

FLACK, D. S., 1958. Inquiry re chrysotile, crocidolite and asbestos deposits in N.S.W., *Rep. Geol. Surv. N.S.W.*, **GS 1958/049** (unpubl.).

FOSKETT, W., 1950. Magnetometer survey at Woodsreef. *Rep. geol. Surv. N.S.W.*, **GS 1950/054** (unpubl.).

FRANKEL, J. J., 1953. South African asbestos fibres. *Min. Mag.*, August-September 1953, **89** (2, 3), 73–83, 142–149.

GRAHAM, R. P. D., 1917. Origin of massive serpentine and chrysotile-asbestos, Black Lake–Thetford area, Quebec. *Econ. Geol.* **12** (2), 183–202.

HALL, A. L., 1930. Asbestos in the Union of South Africa, *Mem. geol. Surv. S. Afr.* **12.**

HOLCOMBE, R. J., 1967. Report on prospecting activities, Mineral Exploration Licence No. 74, Wellington district N.S.W. *Rep. Placer Prospecting Pty Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1967/046**).

——————, 1968. Final report on prospecting activities, MEL 74, Wellington district, N.S.W., *Rep. Placer Prospecting Pty Ltd* (unpubl.). (*Geol. Surv. N.S.W., File* **GS 1968/349**).

Wellington District

Portion 48, *Parish Nanima, County Bligh* (Approximately 7 miles northeast of Wellington; Dubbo 1: 250,000, GR 197975)

A small creek exposure of sheared and altered basic volcanics and a small amount of serpentinite is reported. Over 15 feet of this exposure, widely spaced and flat-lying veinlets of asbestos between one-tenth of an inch and 1½ inches wide occur. The fibre is brittle and of poor quality. The occurrence could not be traced away from the creek due to extensive soil cover and has been assessed to be of small size and poor quality. (Holcombe 1968)

Burruba Creek, County Wellington

Asbestos is reported from this locality.

Other Localities

Asbestos has been reported from the following localities. No further information is available.

County Bathurst: Lucknow Gold Field (cross-fibre tremolite in altered volcanics), Icely, Caloola, Cow Flat copper mines (tremolite asbestos), Mount Lawson, Guyong, Mount Macquarie (near Carcoar), Blayney, and Millthorpe.

County Georgiana: Lachlan River, Abercrombie Range, Porters Retreat, and Trunkey.

County Lincoln: near Dubbo.

County Phillip: at Gulgong, Kings Plains with auriferous quartz in diorite.

County Selwyn: near Tumbarumba.

County Clarendon: near Sebastopol.

County Cumberland: at Pennant Hills in basalt.

County Arrawatta: at Bukkulla.

County Wentworth: at Wentworth.

County Gipps: near Moonbi.

County Rous: near Kyogle.

Orange District

At Lewis Ponds, 9 miles east of Orange, in PLL 639 and PML 1, Parish Freemantle, County Bathurst (Bathurst 1: 250,000, GR 225885), and at Byng, 10 miles southeast of Orange in Parish Byng (including Portion 9), County Bathurst (Bathurst 1: 250,000, GR 227878), there has been sporadic production from 1919 to 1949 yielding 338·2 tons of asbestos fibre (see appendix 1).

The asbestos won has been used in the manufacture of boiler lagging and is probably an amphibole variety.

Rockley District (Bathurst 1: 250,000)

Asbestos has been found near Tea Pot Swamp and the Back Creek Railway Station; at Briar Park, Campbell River, Parish Irene, County Westmoreland; and at Thomsons Gully, Sewells Creek, 5 miles from Rockley, in PML's 10, 11, and 12, Parish Adderley, County Westmoreland.

At Thomsons Gully tuffs, serpentinite, talc schists, and altered limestones crop out, and a number of shallow cuts have been opened up revealing talc schists and serpentinite. In places the serpentinite has been altered to a low-grade amphibole asbestos within slippage planes. The asbestos is usually brittle and of low tensile strength. Examination of all exposures indicates that the amount of asbestos available forms a very small proportion of the rock mass and as such could not be economically worked as a source of asbestos. In 1942, 50 tons of asbestos ore were raised from this location but the fibre won was of low tensile strength and was not sold. This fibre has little if any application in industry "although a small amount of fibre of similar quality was used in 1943 in the production of powder for use in munitions work" (Noakes 1948).

Newbridge (Bathurst 1: 250,000, GR 233848)

Benson (1907) recorded the occurrence of amphibole asbestos in veins about half an inch wide and not exceeding 3 inches in length in Portions 5 and 17, Parish Galbraith, now in County Bathurst.

Analysis, Department of Mines 1902/573

	Per cent
SiO_2	56·10
Al_2O_3	1·86
Fe_2O_3	0·40
FeO	7·16
MgO	19·59
CaO	12·36
K_2O	0·03
Na_2O	0·30
CO_2	0·12
H_2O	1·68
	99·60

Photo 12.—**Cross-fibre tremolite asbestos from Jones Creek near Gundagai which has been curved along the vein presumably due to movement of the vein walls. Much of the slip-fibre from this locality appears to be sheared cross-fibre**

Analysis, Department of Mines 1916/2398 (from Raggatt 1924, analyst H. P. White)

	Per cent
SiO_2	57·38
Al_2O_3	0·13
Fe_2O_3	1·10
FeO	4·50
MnO	0·19
MgO	21·34
CaO	13·22
CO_2	0·02
H_2O	2·10
P_2O_5	trace ($<$0·01)
	99·98

Broken Hill District

Asbestos occurs at Red Hill and Rockwell Paddock about 10 miles southeast of Broken Hill in ML's 20, 26, 27, and 112, Parish Sebastopol, County Yancowinna (Menindee 1: 250,000, GR 461039).

In 1931 a parcel of 8 tons of chrysotile asbestos was produced. The fibre is of good quality though rendered hard by metamorphism. There is little likelihood of large-scale production. Serpentinite, the host rock for this asbestos, occurs at other localities in the district as small masses, sills, or dykes. The largest of these does not exceed 2,640 feet long by 200 feet wide so any major production of asbestos is doubtful.

Photo 11.—**Cross-fibre tremolite asbestos from Jones Creek near Gundagai. The fibres tend to be weak but of good length**

Jones Creek workings, 3 miles northwest of Gundagai Railway Station in Portions 158, 159, 160, and 161, Parish North Gundagai, County Clarendon (Wagga Wagga 1 : 250,000, GR 608672), the tremolite occurs as cross fibre up to 1½ inches long (see photo 11) and slip fibre up to 2 feet long. The cross fibre is white weak, fine, and easily separable into fibres. The slip fibre is pale green, very weak, coarse, and brittle. In some cases this slip fibre is sheared cross-fibre and has been developed by movement along cross-fibre veins subsequent to their formation (see photo 12).

Some cross-fibre chrysotile asbestos is also present in this deposit and this may warrant further testing.

Between 1880 and 1921, 72·4 tons of fibre were produced (see appendix 1) from a costean and several small adits following the narrow (up to 3 feet) fibre-rich zones. No production has been recorded since 1921 and as amphibole asbestos has a relatively low tensile strength it is probably only suitable for such use as the manufacture of boiler lagging.

Numerous angular pods of dolerite and rodingite are distributed throughout the body and have the appearance of xenolithic inclusions. However, these may have been dykes which have been disjointed at a later stage of deformation. Magnesite in seams up to 3 inches wide and usually horizontal occurs near the dolerite.

In places the serpentinite is capped by Tertiary gravels up to 50 feet thick.

The host rock of the asbestos fibre is the unsheared serpentinite, and the percentage of fibre ranges from 0 to 10 per cent with large areas of less than 1 per cent fibre. The Chrysotile Corporation of Australia (formerly White Asbestos (Mining) Pty Ltd) has outlined a body of fibre-bearing serpentinite of economic grade which is 3,000 feet long, averages 500 feet wide, and extends to a vertical depth of 700 feet below the surface. This gives an estimated 26 million tons valued at $160,000,000 (average $6 per ton) with potential ore reserves of 90 million tons. (Butt 1967, 1968 a, b.)

The mine will be a mechanical shovel and scraper open cut, and should commence operations in 1971. It is expected that the mine and mill will initially produce 70,000 short tons of fibre per year, in grades 4 to 7, from 1·5 million short tons of 4·5 per cent recoverable-asbestos grade ore. Provision is being made to increase this to 100,000 short tons of fibre per year from 2,150,000 short tons of ore after 1974.

An export market is being established and contracts are being negotiated with Japan for the purchase of nearly 60 per cent of the first 5 years' production (210,000 short tons) of grades 4 to 7. The growth rate of Japan's present consumption of asbestos fibre is 10 per cent per annum.

SPRING CREEK (Tributary of the Mummel River, Portion 99, Parish Rowley, County Hawes; Hastings 1: 250,000, GR 500093).

Cross-fibre chrysotile and picrolite veins occur in a massive serpentinite. The chrysotile veins (generally of good quality) are often in parallel groups, and vary from extremely fine veinlets up to a quarter of an inch wide veins. The picrolite veins are parallel to or transect the chrysotile veins at angles in the vicinity of 90°.

Girilambone-Kiandra Serpentinite Belt

Occurrences of asbestos are recorded from the southern section of the Girilambone-Kiandra Serpentinite Belt. Thin veins of cross-fibre chrysotile are common in the massive serpentinites from 6 miles north of Wallendbeen Railway Station (Parish Berthong, County Bland) to Yarrangobilly. However, the thickest vein reported was one-tenth of an inch wide and no concentration of economic interest has been discovered.

Tremolite asbestos is best developed in that part of the serpentinite belt trending northwest from Gundagai for about 7 miles. At the old

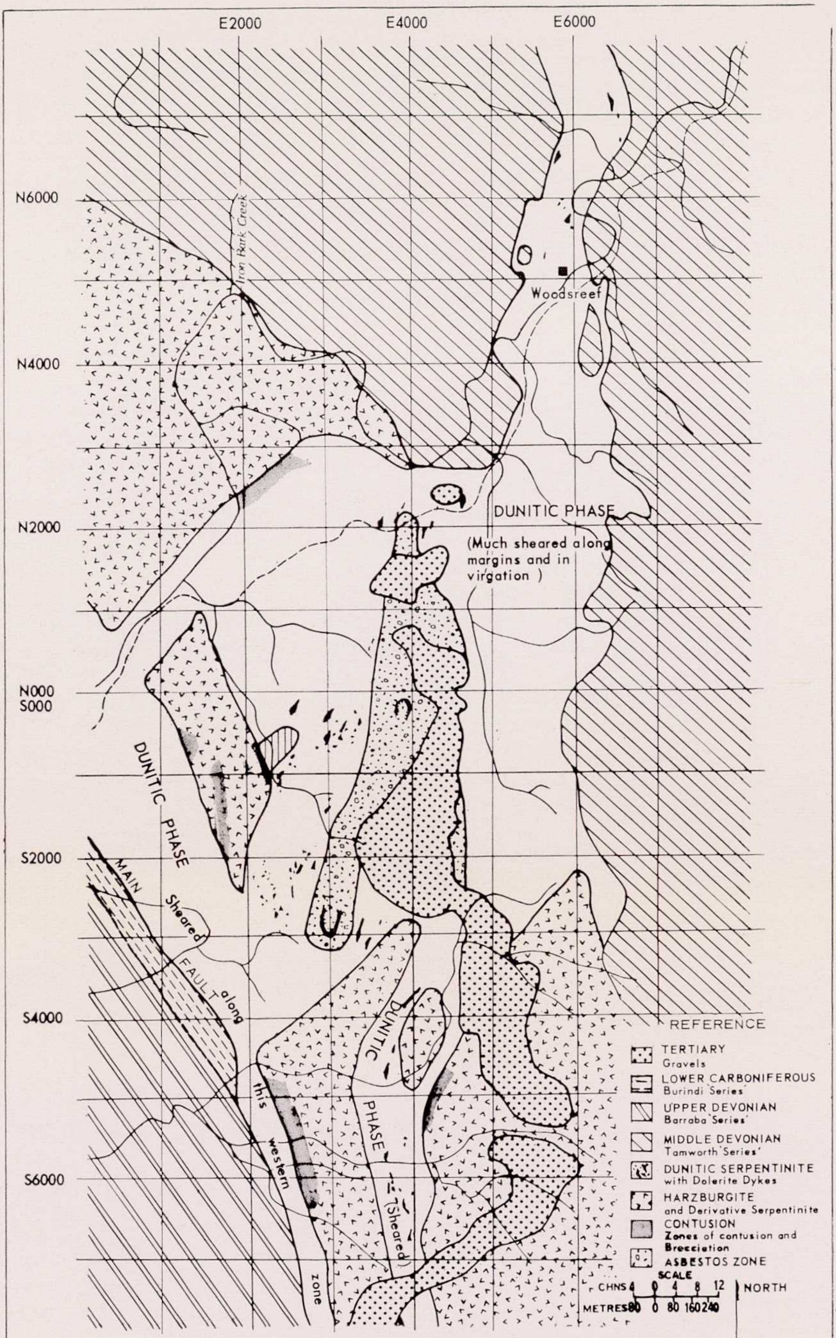


FIGURE 5. Geological Map of the Ultrabasic Complex at Woodsreef N.S.W. (Modified from Proud and Osborne 1952)

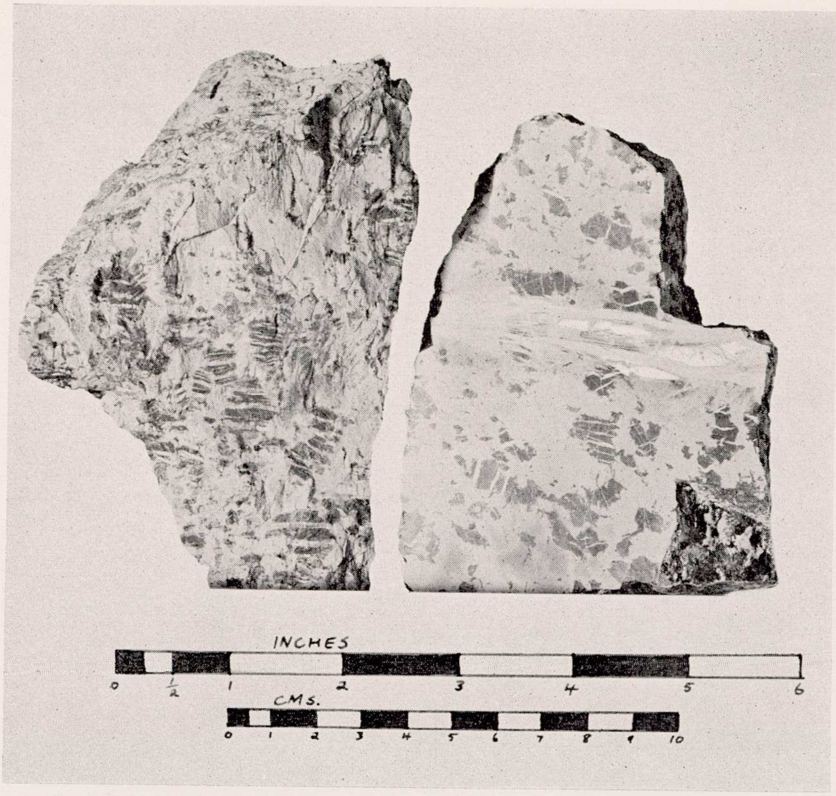


Photo 10.—**A common type of Woodsreef ore. The chrysotile asbestos in these specimens occurs as closed veins in the relict cleavage of serpentinized pyroxene crystals. The right hand specimen also shows lenses of chrysotile in a picrolite vein**

The fibre is cross-fibre chrysotile of pale-green colour in the compact state with the fibre oriented at an angle other than 90° to the walls of the vein, with a deviation of between 5° and 15°. No broad regional structural control of the fibre-bearing ground has been determined.

Figure 5 (after Proud and Osborne 1952) shows the geological setting of the Woodsreef asbestos deposit. Lower Carboniferous and Devonian rocks adjoin the serpentinite belt which is fault bounded.

Final emplacement of this ultrabasic body has been controlled by the Peel Fault System which separates Carboniferous strata to the west from more highly deformed rocks of undetermined age (possibly Devonian) to the east.

The serpentinite belt consists of serpentinized harzburgite and a "pyroxene-poor" or dunitic phase with sheared zones of foliated serpentinite trending approximately north-south (particularly at the margins of the belt) separating zones of massive material. Generally the serpentinite belt is well sheared but at Woodsreef it reaches its greatest width where a central core of massive material has been unaffected by the shearing action. This has allowed the preservation and/or development of asbestos fibre. If this hypothesis is correct it seems unlikely that further large reserves of fibre-bearing material would exist in the rest of the belt.

In 1964 White Asbestos (Mining) Pty Ltd formed by a merger of Merit Oil Ltd and Castle Tin Mines Ltd (both of Canada) as a wholly owned subsidiary of the Canadian parent company, Pacific Asbestos Ltd. This company carried out extensive costeaning and diamond drilling. Up to 1968, five diamond drilling programmes were completed for 52,319 feet of core recovered in one hundred holes (see photo 9). About 500 samples were sent to the Department of Natural Resources, Quebec, Canada, for milling, testing and grading. This testing established that the fibre was of a quality comparable to the Canadian product.

Also, bulk samples obtained by 2,046 feet of 12-inch diamond drill cores from twelve holes were sent for test milling (see photo 1, frontispiece). This was assumed to be a more satisfactory method of obtaining bulk samples than deep trenching or shaft sinking. About 160,000 lb were milled and tested so that beneficiation and mill design could be determined.

The test milling indicated that production would be mainly in groups 5 to 7 for use in moulded asbestos products and that there are large reserves of this short fibre.

Magnetometer surveys and stripping of overburden have also been carried out.

The chrysotile occurs in faults and associated tension cracks as veins up to 1 inch wide, but seldom greater than a quarter of an inch wide (see photo 9), and as fine parallel veins rarely wider than one-tenth of an inch, along the relict cleavage of serpentinized pyroxene crystals in a massive serpentinite and serpentinized harzburgite (see photo 10).

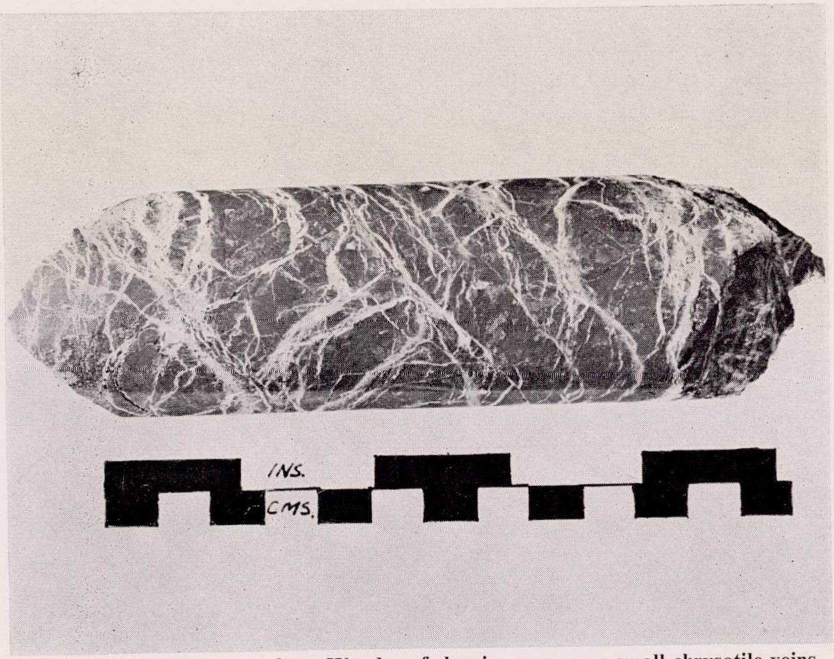


Photo 9.—**NX drill core from Woodsreef showing numerous small chrysotile veins apparently formed in tensional fractures**

Portion 145 (*PML* 21), *Parish Yulgilbar, County Drake*

Cross-fibre chrysotile occurs as veins in joints in the serpentinite. The mineralized zone is at least 1C feet wide and 70 feet long and dips at 60° to 010°. The fibre is one-eighth to three-eighths of an inch long and of fair to good quality. It has been exposed by a shallow trench 50 feet long and a shaft 21 feet deep.

Portions 111 *and* 144 (*PML's* 17 *and* 22), *Parish Yulgilbar, County Drake*

Chrysotile asbestos veins have been reported at this locality.

FINE FLOWER (Portions 34, 35, 119, 120, 123, and 125, Parish Yarrcalkiarra, County Drake; Grafton 1: 250,000, GR 577363).

Fine "ribbon" asbestos occurs as numerous fine subparallel veins with smooth margins traversing a massive serpentinized harzburgite. These veins often occupy the relict cleavage of serpentinized pyroxene crystals. About 90 per cent of the asbestos fibre in this area would be less than one-tenth of an inch long. Several diamond drill holes and costeans were completed in 1958 but the proportion of asbestos was only 1 per cent of the rock and there is at present no evidence to indicate that satisfactory grades or sufficient asbestos reserves exist in the area.

Reference: McElroy 1958.

Great Serpentine Belt

WOODSREEF (11 miles east of Barraba and 354 miles from Sydney, Parish Woodsreef, County Darling; Manilla 1: 25C,000, GR 372236)

The deposit is covered by ML's 22–24, 26–31, 33–36 and PML's 10 and 14, on Portions 50, 52, and 56. These leases were held at 31st December, 1969, by White Asbestos (Mining) Pty Ltd, a wholly owned subsidiary of the Canadian parent company, Pacific Asbestos Ltd. The leases were recently transferred to Woodsreef Mines Ltd when that company was floated on the Sydney Stock Exchange.

During 1918–1924, 2,478 tons of fibre (see appendix 1) were recovered by the Asbestos Mining Co. of Aust. Ltd (James Hardie) and Wunderlich Ltd from two quarries to a maximum depth of 70 feet. The fibre was milled and graded on the property, about 50 per cent being discarded prior to milling. Production ceased in 1923 as asbestos from the deposit could not compete with imported South African fibre. The milling rock contained 5 per cent asbestos fibre. This fibre was suitable for the manufacture of building materials. (Raggatt 1924)

In 1950 a magnetometer survey was carried out by the Geological Survey of New South Wales on Portion 50, Parish Woodsreef. This survey indicated that the bulk of old workings lie within zones of medium to high anomaly; drilling was carried out by Hardies Pty Ltd but no mining operations ensued. (Foskett 1950)

In 1958 and 1959 development work was carried out by Marcal Asbestos Pty Ltd and 13 tons of fibre were produced from ML 22.

In 1963 Superfine Asbestos Pty Ltd carried out extensive prospecting on leases held by Marcal Asbestos Pty Ltd.

photo 7) in a massive deep-green antigorite serpentinite. The fibre is of good quality, being group 3Z from the mill, but fiberization reduces the length of the fibre and the final product falls into group 5R. This material is suitable for use in asbestos-cement products in the manufacture of roofing and building materials (Mr F. Page, pers. comm.). The veins are up to 2 inches across, though these larger veins are usually parted by small oblique shears so that the fibre won is rarely longer than 1 inch and is usually in the range of a quarter to half an inch. The asbestos-bearing veins are extremely irregular in orientation and intersect to form a stockwork.

Slip-fibre is only rarely developed and has been formed by shearing along the vein.

The vein walls are often sharply serrated in thin section (see photo 8), though they appear smooth to the unaided eye. This serrated nature indicates that the asbestos has not formed by simple fissure-filling but has grown in situ by recrystallization of the wall rock. This theory of genesis is further supported by the occurrence of "closed" veins. Post-asbestos faulting has not been observed at this location.

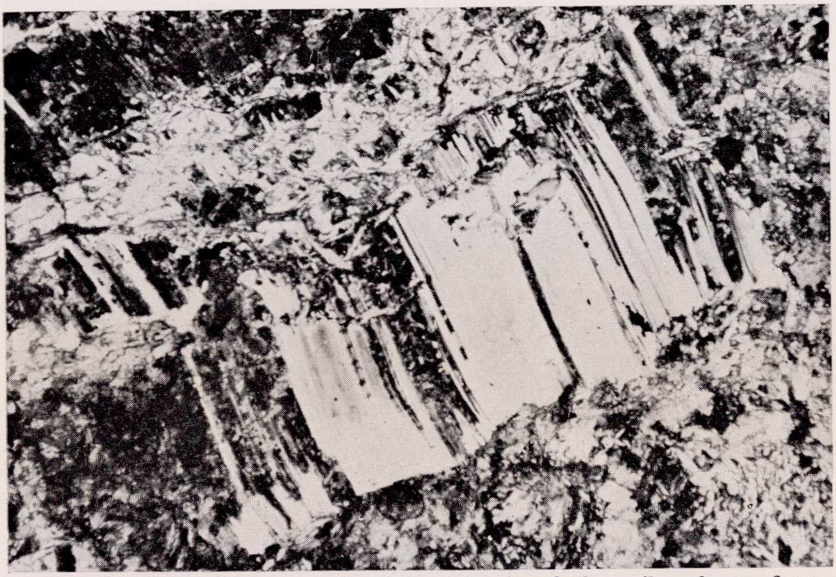
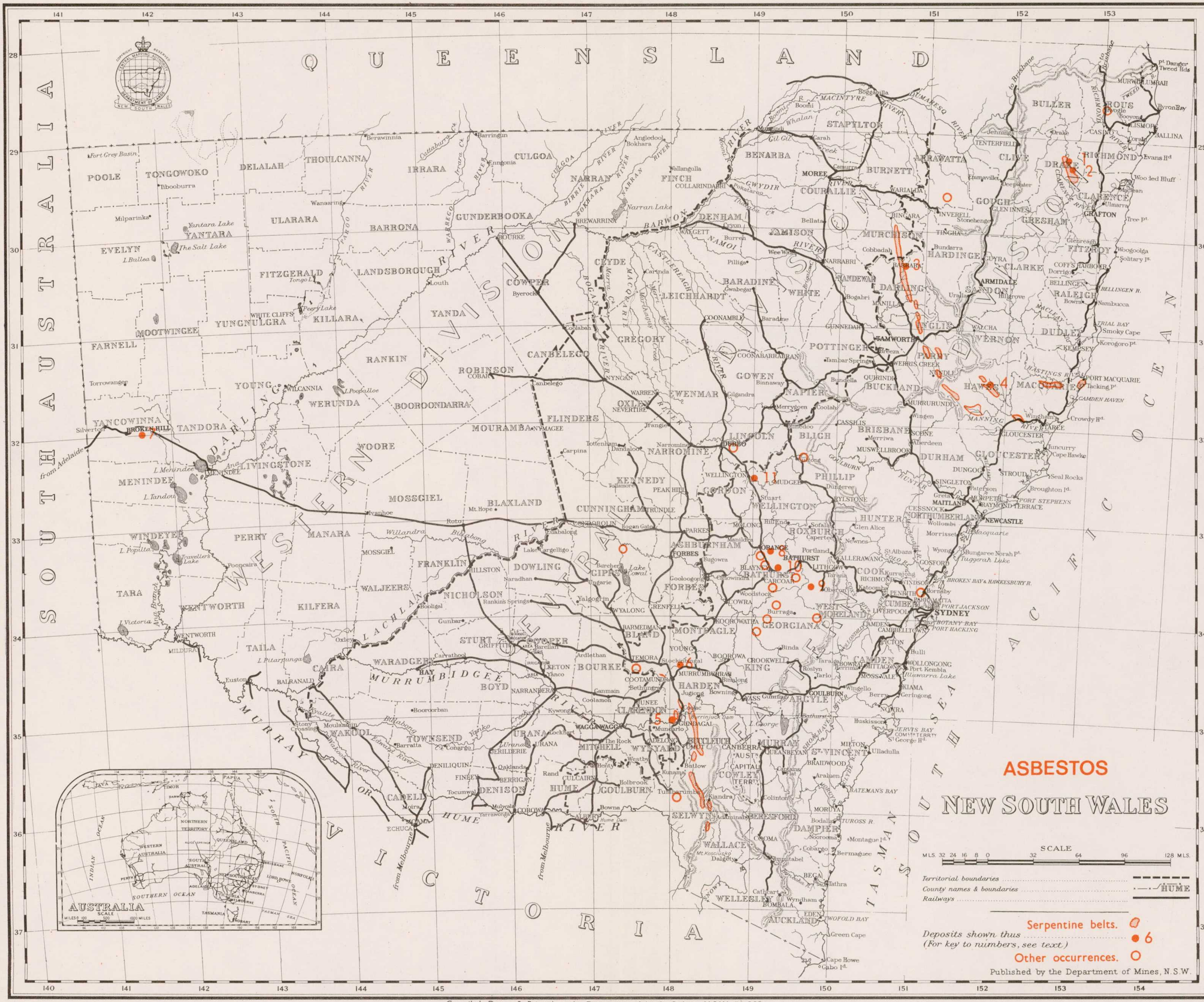


Photo 8.—**Photomicrograph of a "closed" vein of chrysotile asbestos from Baryulgil. The vein has a serrated boundary and is strongly suggestive of a replacement-recrystallization origin as opposed to a fissure-filling origin (see photo 2) (× 26·4)**

Picrolite is relatively abundant with a poorly developed fibrosity normal to the vein wall and a marked banding parallel to the vein wall. This banding reflects the smooth undulating boundaries of these veins and is possibly caused by compositional variations in the picrolite.

Further exploration for chrysotile (involving trenching, diamond drilling, prospecting shafts, and magnetometer surveys) has been carried out since 1960 by Asbestos Mines Pty Ltd, to prove extensions of the deposit at present being quarried, and to delineate an asbestos-bearing zone (within Portions 13 and 49, and covered by PML's 12, 23, 28, and 29) south of the present quarry.



Compiled, Drawn & Printed at the Department of Lands, Sydney, N.S.W. 59·305

MINERAL INDUSTRY OF NEW SOUTH WALES

Summary Report Series

It is proposed that the following reports will be published separately, not necessarily in the order listed, and collectively will represent a revised equivalent of "The Mineral Industry of New South Wales" (1928) now out of print.

1. Aluminium (Bauxite)
*2. Antimony
*3. Arsenic
*4. Asbestos
5. Barium (Barite)
*6. Beryllium
7. Bismuth
*8. Chromium
9. Clays
10. Coal
*11. Cobalt
12. Constructional Materials
13. Copper
*14. Diatomite (Diatomaceous Earth)
*15. Feldspar
16. Fluorite (Fluorspar)
17. Fullers Earth and Bentonite
*18. Gemstones (Opal, Diamond, Sapphire, Emerald, etc.)
19. Gold
*20. Gypsum
*21. Iron
22. Lead-zinc-silver
†23. Limestone and Dolomite (and Lime and Cement)
*24. Magnesium (Magnesite)
*25. Manganese
26. Mineral Pigments
27. Minor Metals
28. Miscellaneous Minerals
29. Molybdenum
30. Oil-shale
*31. Perlite
32. Petroleum and Natural Gas
*33. Platinum
34. Silica
35. Sillimanite
36. Sulphur (including Pyrite)
*37. Talc, Steatite and Pyrophyllite
38. Thorium
39. Tin
40. Titanium (Rutile and Ilmenite)
*41. Tungsten (Wolframite and Scheelite)
42. Underground Water
43. Uranium
44. Zirconium
*45. Nickel
*46. Rhenium

* Published   † Part 2, Dolomite, published

V. C. N. Blight, Government Printer, New South Wales—1971