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Re: Classification see p. 416.

Asbestos *†

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PLAINTIFF'S EXHIBIT

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Asbestos is the generic name given to a group of fibrous mineral silicates found in nature. They are all incombustible and can be separated by mechanical means into fibers of various lengths and cross sections, but each differs in chemical composition from the others. The commercial grades of asbestos consist of a spectrum of lengths and sizes and are not definitive as are most organic fibers.

It is generally recognized that there are two main groups of asbestos. The first only contains the fibrous serpentine called chrysotile and comprises about 94% of the world production of asbestos. The second group contains five minerals in the amphibole series—crocidolite, amosite, anthophyllite, tremolite, and actinolite. The latter two have no commercial importance.

* Previous editions—1937, 1949, and 1960—have developed a format describing the general physical properties of asbestos, the distribution of deposits throughout the world; description of mining and milling methods, tests and specifications, grades produced, prices, uses, and markets.

In this edition, certain phases are discussed in more detail. The sections relating to world occurrences, geology of deposits, and methods of evaluation are more fully covered. Statistics have been augmented and up-dated whenever possible and the bibliography enlarged.

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Acknowledgment for assistance in preparation of the sections covering mining, milling, uses, and markets is gratefully made to J. N. Gauthier, E. B. McKenna, D. P. R. Smyth, and R. T. Hughes, respectively.

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Properties

Physical

The structures of asbestos fibers have been studied intensively over a number of years. X-ray diffraction patterns have been used as a means of identification and classification. Low angle X-ray scattering techniques have shown that chrysotile fibers are "hexagonally close packed" and parallel to each other, having cross-sectional diameters varying from 180Å to 300Å units, while the amphibole fibers are many times larger in cross section. Electron micrographs of the more common types of asbestos are shown in Figs. 1–4. Fig. 1 illustrates the softness and flexibility of chrysotile which make it suitable for textile-type products.

For a number of years there was considerable controversy over the exact nature of chrysotile fiber, but the photographic evidence in Figs. 5–7 clearly show that it is tubular in structure. The curvature is the result of the mismatch in the dimensions of the silica $[Si_2O_5]$ and brucite $[Mg(OH)_2]$ layers which are on the inside and outside, respectively, of a double sheet. This curvature had been predicted by Pauling (1930) years ago based on the molecular dimensions of the two component structures.

Chemical Composition

The theoretical compositions of the six grades of asbestos are given in Table 1. It can readily be seen that the basic structure of all five minerals in the amphibole series is the same. The only difference is in the amount and type of metallic cations present. Consequently, all the amphiboles are quite similar but do differ substantially from chrysotile.

The idealized formula for the different types of asbestos are given in Table 1, but the actual compositions are different because of various impurities and differences in the chemical com-

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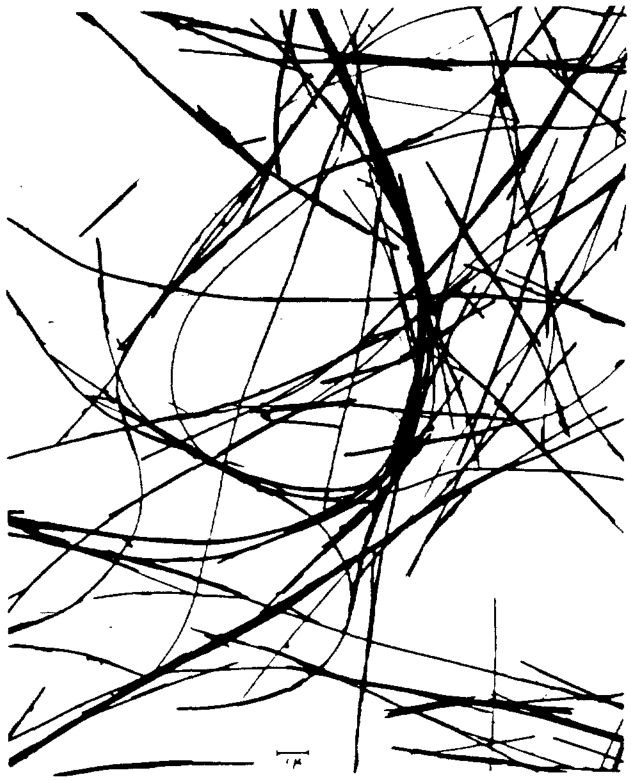

FIG. 1—*Electron micrograph of Jeffrey chrysotile. X8000. Reduced approximately 33% in reproduction.*

position for different deposits. Table 2 shows the range of compositions for the most important components in commercial asbestos. In addition, there will be many trace elements present but these are rarely present in amounts greater than 0.20%.

Chrysotile is the result of hydrothermal reactions under certain conditions within serpentine rock, and it is only natural that there will be imperfections within the crystal structure and the inclusion of impurities between fibers and at the ends of the fibers near the wall rock. It is very difficult to remove these impurities by mechanical means, so they are present in the final product. Generally, they do not have any significant effect on the use of asbestos; but in

TABLE 1—Types of Asbestos

Type	Theoretical Formulae
Chrysotile Hydrated magnesium silicate	$Mg_6[(OH)_4Si_2O_5]_2$
Crocidolite Complex sodium iron silicate commonly called Blue Asbestos	$Na_2Fe_5[(OH)Si_4O_{11}]_2$
Amosite Iron magnesium silicate—same as anthophyllite except for high iron content	$MgFe_6[(OH)Si_4O_{11}]_2$
Anthophyllite Magnesium silicate with varying amounts of iron in the lattice	$(Mg,Fe)_7[(OH)Si_4O_{11}]_2$
Tremolite Calcium magnesium silicate	$Ca_2(Mg,Fe)_5[(OH)Si_4O_{11}]_2$
Actinolite Calcium magnesium silicate with varying amounts of iron	$Ca_2(Mg,Fe)_5[(OH)Si_4O_{11}]_2$

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FIG 2—*Electron micrograph of crocidolite. X8000. Reduced approximately 33% in reproduction.*

a few cases, such as electrical applications or some filtration systems, the amount of impurities has to be limited.

Crocidolite and amosite occur in metamorphosed siliceous-ferruginous sediments. The fibers are often comparatively long, ranging up to several inches. These long lengths have no advantage for most uses and may detract from the value, since the greatest use is in asbestos cement products where fiber lengths of $\frac{1}{8}$ to $\frac{3}{8}$ in. in length are more suitable.

Anthophyllite (Rabbit, 1948) has a low ignition loss comparable to that of tremolite. It is never known to occur with fibers sufficiently flexible to be spun nor with the tensile strength required to make them of value to the asbestos cement industry. Resistance to chemical reaction opens a specialized field for this fibrous

TABLE 2—Approximate Chemical Analysis of Asbestos

	Chrysotile	Crocidolite	Amosite	Anthophyllite	Tremolite
SiO_2, %	37-44	49-53	49-53	56-58	53-62
MgO, %	39-44	0-3	1-7	28-34	0-30
FeO, %	0-6	13-20	34-44	3-12	1.5-5
Fe_2O_3, %	0.1-5	17-20	–	–	–
Al_2O_3, %	0.2-1.5	–	2-9	0.5-1.5	1-4
H_2O, %	12-15	2.5-4.5	2-5	1-6	0-5
CaO, %	tr-5	–	–	–	0-18
Na_2O, %	–	4.0-6.5	–	–	0-9
CaO + Na_2O, %	–	–	0.5-2.5	–	–

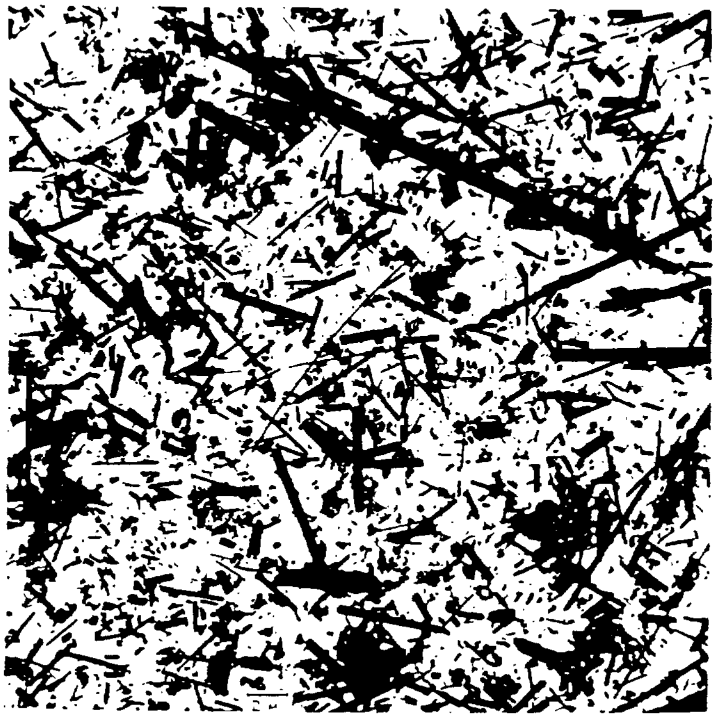

FIG. 3—*Amosite, Penge, South Africa. X5000. Reduced approximately 33% in reproduction*

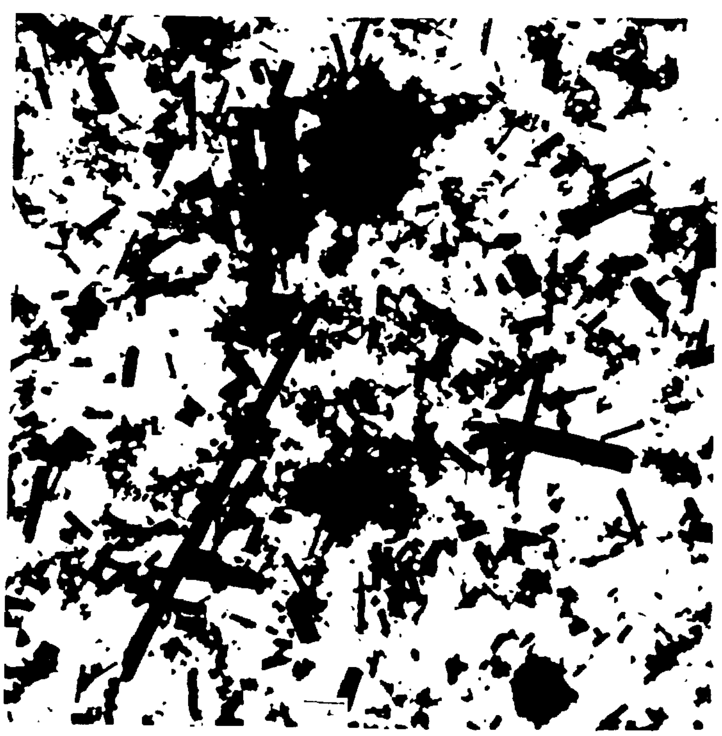

FIG. 4—*Anthophyllite, Georgia X5000 Reduced approximately 33% in reproduction*

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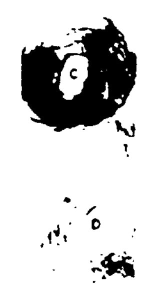

FIG. 6—*H*
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FIG. 5—*Chrysotile. X150.000. Reduced approximately 33% in reproduction.*

mineral as a filter medium and as a filler. A comparison of the general properties (Badollet, 1951) of the six varieties of asbestos is given in Table 3.

Thermal analysis (Pundsack, 1955) of chrysotile shows a broad endothermic peak between 600° and 720°C, which corresponds to the loss of structural water and an exothermic peak at 800°C associated with a phase change to fosterite.

The hydrogen ion concentration of chrysotile has been reported to vary from 9.0 to 10.3, depending on occurrence and method of measurement. A value of 9.7 will be most typical.

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FIG. 6—*High resolution electron micrograph of chrysotile. Reprinted with permission from "Acta Chrystalogica," (Yada, 1967). Reduced approximately 38% in reproduction.*

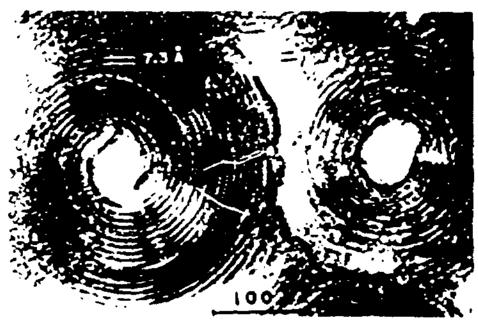

FIG. 7—*High resolution electron micrograph of chrysotile. Reprinted with permission from "Acta Chrystalogica," (Yada, 1967). Reduced approximately 38% in reproduction.*

TABLE 3—Properties of Asbestos Fibers

Property	Actinolite	Amosite	Anthophyllite	Chrysotile	Crocidolite	Tremolite
Structure	Reticulated long prismatic crystals and fibers	Lamellar. Coarse to fine fibrous and asbestiform	Lamellar. Fibrous asbestiform	Usually highly fibrous fibers fine and easily separable	Fibrous in ironstones	Long Prismatic and fibrous aggregates
Mineral association	In limestone and in crystalline schists	In crystalline schists, etc.	In crystalline schists and gneisses	In altered peridotite adjacent to serpentine and limestone near contact with basic igneous rocks	Iron rich silicious agrillite in quartzose schists	In Mg limestones as alteration products of highly magnesian rocks. Metamorphic and igneous rocks
Origin	Results of metamorphism	Metamorphic	Metamorphic. Usually from olivine	Alteration and metamorphism of basic igneous rocks rich in magnesian silicates	Regional metamorphism	Metamorphic
Veining	Slip or mass fiber	Cross fiber	Slip Mass fiber unoriented and interlacing	Cross and slip fibers	Cross fiber	Slip or mass fiber
Essential composition	Ca·Mg·Fe·Silicate water up to 5%	Silicate of Fe and Mg higher iron than anthophyllite	Mg silicate with iron	Hydrosilicate of magnesium	Silicate of Na and Fe with some water	Ca and Mg silicate with some water
Crystal structure	Long and thin columnar to fibrous	Prismatic. Lamellar to fibrous	Prismatic. Lamellar to fibrous	Fibrous and asbestiform	Fibrous	Long and thin columnar to fibrous
Crystal system	Monoclinic	Monoclinic	Orthorhombic	Monoclinic (pseudo-orthorhombic?)	Monoclinic	Monoclinic
Color	Greenish	Ash gray or brown	Grayish white Brown-gray or green	White Gray Green. Yellowish	Lavender-blue. Metallic-blue	Gray-white. Greenish. Yellowish. Bluish
Luster	Silky	Vitreous Somewhat pearly	Vitreous to pearly	Silky	Silky to dull	Silky
Hardness	6±	5.5-6.0	5.5-6.0	2.5-4.0	4	5.5
Specific gravity	3.0-3.2	3.1-3.25	2.85-3.1	2.4-2.6	3.2-3.3	2.9-3.2
Cleavage	110 perfect	110 perfect	110 perfect	010 perfect	110 perfect	110 perfect
Optical properties	Biaxial negative extinction inclined	Biaxial and positive extinction parallel	Biaxial positive extinction parallel	Biaxial positive extinction parallel	Biaxial ± extinction inclined	Biaxial negative extinction inclined
Refractive index	1.63± weakly pleochroic	16.4±	1.61±	1.51-1.55	1.7 pleochroic	1.61±

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Hardness	6±	5.5-6.0	5.5-6.0	2.5-4.0	4	5.5
Specific gravity	3.0-3.2	3.1-3.25	2.85-3.1	2.4-2.6	3.2-3.3	2.9-3.2
Cleavage	110 perfect	110 perfect	110 perfect	010 perfect	110 perfect	110 perfect
Optical properties	Biaxial negative extinction inclined	Biaxial and positive extinction parallel	Biaxial positive extinction parallel	Biaxial positive extinction parallel	Biaxial ± extinction inclined	Biaxial negative extinction inclined
Refractive index	1.63± weakly *pleochroic*	1.64±	1.61±	1.51-1.55	1.7 pleochroic	1.61±
Length	Short to long	2 to 11 in., varies	Short	Short to long	Short to long	Short to long
Texture	Harsh	Coarse but somewhat pliable	Harsh	Soft to harsh. Also silky	Soft to harsh	Generally harsh. Sometimes soft
Specific heat, Btu per lb per °F	0.217	0.193	0.210	0.266	0.201	0.212
Tensile strength, psi	1000 and less	16,000 90,000	4000 and less	80,000 100,000	100,000 300,000	1000 8000
Temperature at maximum ignition loss, °F	–	1600 to 1800	1800	1800	1200	1800
Filtration properties	Medium	Fast	Medium	Slow	Fast	Medium
Electric charge	Negative	Negative	Negative	Positive	Negative	Negative
Fusion point, °F	2540	2550	2675	2770	2180	2400
Spinnability	Poor	Fair	Poor	Very good	Fair	Poor
Resistance to acids and alkalies	Fair	Good	Very good	Poor	Good	Good
Magnetite content	–	0	0	0-6.2	3.0-6.9	0
Mineral impurities present	Lime, iron	Iron	Iron	Iron, chrome, nickel, lime	Iron	Lime
Flexibility	Poor	Good	Poor	High	Good	Poor
Resistance to heat	–	Good. Brittle at high	Very good	Good. Brittle at high	Poor, fuses	Fair to good
Ionizable salts, μmhos (relative electrical conductance)	–	1.34	0.58	1.82	0.84	–

The hydrolysis of chrysotile in distilled water free from carbon dioxide resembles the action of magnesium hydroxide.

Chrysotile is unique as compared to the other types of asbestos and most materials of a similar nature such as clays and talcs, since it carries a positive charge or has a plus zeta potential in a water slurry. The magnitude will vary with chrysotile from different deposits. Similarly, the isoelectric point or pH for zero potential will be different for chrysotiles from various sources. The isoelectric point for chrysotile will vary from 10.5 to 11.3 depending on the source of the fiber and the method of measurement.

Careful density measurements (Pundsack, 1956) of chrysotile have shown values ranging from 2.53 to 2.58 with 2.56 most typical.

The surface area determination of chrysotile depends upon the type of measuring apparatus employed. The industry generally uses an air permeability method (Badollet, 1951) for measuring the degree of openness of the fiber. If the true surface area is desired, it is necessary to employ gas absorption techniques. Specific areas by air permeability will range from about 0.4 to 5 sq m per g, whereas comparable gas adsorption areas will vary by a factor of 10 from 4 to 50 sq m per g, depending on the source of the fiber and the degree of openness.

Effect of Heat on Asbestos

The weight loss for different types of asbestos when heated for 2 hr each at successive temperatures from 400° to 1800°F is shown in Table 4 (Badollet, 1951; Badollet and Streib, 1955). As expected, the weight loss for the amphiboles is considerably less than for chrysotile because of much less available ⁻OH to be driven off as water. In spite of this, the amphiboles after heating at 800°F will still be more brittle than a chrysotile heated at 100° to 1100°F.

TABLE 5—Effect of Heat on Tensile Strength of Canadian Chrysotile Crude

	Tensile Strength, Psi	% of Original Tensile Strength
Original crude, no heat	131,000	–
Heated 3 min at 600°F	120,000	91.6
Heated 3 min at 800°F	96,000	73.3
Heated 3 min at 1000°F	78,000	59.5
Heated 3 min at 1200°F	42,000	32.0

Table 5 shows the effect of heating chrysotile on the tensile strength of the fiber. The fiber bundles tested for tensile strength were very small so heat transfer would be effected in the 3-min heating time. Even after heating at 1200°F chrysotile retains 32% of its strength.

Chemical Resistance

Asbestos is often used in chemical service where resistance to chemicals is of paramount interest. Table 6 gives data on the effect of various acids and caustic soda on asbestos after long exposure at room temperature and for short exposure at boiling temperatures. Because of the basic nature of chrysotile, it is seriously attacked by strong acids and should not be exposed to them. It is resistant to 25% caustic but recent data show that it is attacked by strong caustic (70%) at its boiling temperature.

TABLE 4—Effect of Temperature on Loss in Weight of Asbestos Fibers

°F	Time, Hr	% Loss in Wt				
		Amosite	Anthophyllite	Chrysotile	Crocidolite	Tremolite
400	2	0.23	0.05	0.30	0.08	0.04
600	2	0.57	0.24	0.85	0.25	0.08
700	2	0.80	0.30	1.78	0.49	0.13
800	2	0.98	0.38	2.17	0.73	0.22
900	2	1.07	0.41	2.83	0.83	0.26
1000	2	1.16	0.44	3.99	0.86	0.29
1100	2	1.36	0.52	10.38	1.00	0.37
1200	2	1.39	0.54	12.75	1.04	0.37
1400	2	1.43	0.54	13.43	1.03	0.47
1500	2	–	0.64	–	–	0.56
1600	2	1.52	1.12	13.62	0.93*	0.67
1700	2	–	1.73	–	–	1.40
1800	2	1.53	2.39	13.77	0.77*	2.18

* Iron changing in weight due to oxidation.

TABLE 6—Solubility of Asbestos

	% Loss in Wt, Refluxing 2 Hr, 25% Acid or Caustic				
	HCl	CH_3COOH	H_3PO_4	H_2SO_4	NaOH
Actinolite	20.31	12.28	20.19	20.38	9.25
Amosite	12.84	2.63	11.67	11.35	6.97
Anthophyllite	2.66	0.60	3.16	2.73	1.22
Chrysotile	55.69	23.42	55.18	55.75	0.99
Crocidolite	4.38	0.91	4.37	3.69	1.35
Tremolite	4.77	1.99	4.99	4.58	1.80

	% Loss in Wt, Room Temperature 26°C for 528 Hr, 25% Acid or Caustic				
	HCl	CH_3COOH	H_3PO_4	H_2SO_4	NaOH
Actinolite	22.55	12.14	20.10	20.60	9.43
Amosite	12.00	3.08	11.83	11.71	6.82
Anthophyllite	2.13	1.04	3.29	2.90	1.77
Chrysotile	56.00	24.04	56.45	56.00	1.03
Crocidolite	3.14	1.02	3.81	3.48	1.20
Tremolite	4.22	1.41	4.89	4.74	1.65

Geology

General

Chrysotile constitutes about 94% of the current world production of asbestos and, of this amount, all but a fraction of a percent is derived from deposits whose host rocks are ultrabasic in composition (Berger, 1963; Bateo, 1969; Keith and Bain, 1932). This other fraction of the chrysotile production is derived from serpentinized dolomitic limestone. Among the other varieties of asbestos, amosite and crocidolite are found in certain metamorphosed ferruginous sedimentary formations and, together, account for some 5.3% of world production. Tremolite and anthophyllite make up the balance of the production and are generally found in association with highly metamorphosed ultrabasic rocks.

The bulk of world chrysotile production comes from Canada and the USSR. Southern Africa, including Rhodesia, Swaziland, and Transvaal, is the third largest producer with the balance coming from other parts of the world.

Of the Canadian production, by far the greatest amount comes from the Eastern Townships of Quebec (Fig. 8) with northern British Columbia, the Yukon Territory, Ontario, Ungava, and Newfoundland contributing the balance. Russian production comes mainly from the Bazhenovo district in the central Urals, the Dzhetygara area of northwest Kazakhstan and from Aktovrak near the Yenesei River west of Lake Baikal.

The age of asbestos deposits varies greatly from earliest Precambrian in Rhodesia and Swaziland to Upper Jurassic in California. The Ontario, Ungava, and Brazil deposits are all Precambrian, while those of the Eastern Townships, Vermont, and Newfoundland are all ascribed a Mid-Paleozoic age, associated with early folding in the Appalachian Mountain belt. The deposits of western Canada are connected with mountain building in the Late Paleozoic while the Russian deposits vary from Early Paleozoic to Late Paleozoic or Triassic in age.

Structures

General deformation in the form of faulting, folding, or shearing evidently plays a major role in the localizing of asbestos deposits (Cooke, 1940). The introduction of swarms of small intrusive dikes of acidic to intermediate composition also contributes to the general fracturing and opening up of the rock which, in turn, leads to serpentinization and the formation of chrysotile fiber.

The majority of chrysotile ore deposits tend to occur in serpentinized peridotite rather than dunitic host material. This is probably due to the fact that serpentinized dunite bodies tend to flow when subjected to stress, thereby aiding in the development of fracturing in the surrounding more brittle peridotite.

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continuous zones along highly serpentinized contact zones between massive serpentinized peridotite bands and massive to sheared "clot" peridotite. One of these, the Upper Zone, is economic and contains from 7% to 15% fiber over minimum mining widths. The ore is hand-cobbed and sorted for milling.

Japan: Chrysotile asbestos is mined at two localities in the Yamabe district of Hokkaido, Japan (Rowbotham, 1970). The fiber is generally short and all of the production is utilized locally.

Chrysotile in Dolomite

In addition to the large deposits of chrysotile asbestos found in serpentinized peridotite there are comparatively small tonnages mined from serpentinized dolomitic limestones (duToit, 1946; Hall, 1930; Pelletier, 1964; Rowbotham, 1970; Van Biljon, 1964). Such fiber is often of high quality and is free of the magnetite found associated to a varying degree with deposits where the original host rock is of ultrabasic igneous origin.

Chrysotile of this type has been mined from the Carolina district in the Transvaal and in the Salt River and Sierra Ancha regions in Arizona where it is found in narrow bands associated with diabase sills.

Crocidolite and Amosite

Both crocidolite and amosite occur in South Africa (Cilliers and Genis, 1964; Cilliers et al., 1964; duToit, 1946; Frankel, 1953; Hall, 1930; Keep, 1961; Pelletier, 1964) in bedded metamorphosed sedimentary formations known as banded ironstones, that may be classed as ferruginous quartzite or probably more exactly as an iron-rich silicified argillite. Cross fiber veins are found as closely spaced ribbons roughly conformable with the bedding which in some localities is distorted and steeply dipping. Crocidolite veins are generally less than 2 or 3 in. thick with the bulk of the fiber between ¼–¾ in. in length. Amosite veins on the other hand often range up to 10 or 12 in. thick.

Crocidolite is found over a large area of Cape Province occurring in a belt of the Lower Griquatown series of the Transvaal system. One of the oldest producing areas is in the vicinity of Prieska on the Orange River with notable production coming from Westerberg and Koegas, located a few miles down the river. Another producing area of blue asbestos in the Cape Province is farther north in the Kuruman district, and at Pomfret, just south of the Botswana border.

Approximately 200 miles to the east and north of Johannesburg both crocidolite and amosite are found in similar formations in the vicinity of Pietersburg in northern Transvaal. In some places here the two varieties have been known to occur side by side in the same vein. Such a vein, having fibers composed of crocidolite at one end and amosite at the other, is referred to as a "doublet." It is interesting to note that there is generally no weakening of the fibrils at the point of contact of the two varieties of fiber.

In the Pietersburg area a quite silky-fibered phase of amosite called "montasite" is found which is often a dusty blue in color and has sometimes been contused with crocidolite.

Widespread occurrences of amosite and crocidolite have recently been discovered in the Bababudan Hills north of Chikmagular in Mysore, India. Both varieties of fiber occur in an assemblage of banded ironstones and shales similar to those of northeastern Transvaal but the amosite in particular is noticeably shorter. However, one area of amosite has been intensively investigated for possible production.

Deposits of cro[illegible]dolite are found in the Hammersley rang[illegible]western Australia, as well as in Bolivia and elsewhere.

Amosite-bearing banded ironstone crops out for a distance of over 20 miles near Penge in the Lydenburg district of the Transvaal. The fiber-bearing "reef" is being worked at three points along the strike, at Penge and at the Weltevreden and the Kromellenboog mines. A good cross section of the country rock has been exposed by diamond drilling to 1000 ft in depth. The fiber-bearing banded ironstones and associated sedimentary members dip southwestward at about 20°. This sequence has been intruded by thin persistent sills of dolerite which are conformable with the bedding.

The following column is from a 1200-ft diamond drill hole intersecting the fiber-bearing horizon at a depth of 1000 ft below the surface at the "Amosa" mine which is part of the Penge property

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erally coincides with the earth's major chains of mountain building of all ages. This is particularly true of the Urals, the Appalachians, and Rocky Mountains, but the relationship is more difficult to recognize in Precambrian fold belts.

Production

Of the world's two leading producers, both the USSR and Canada (Hendry, 1972) have vast reserves of chrysotile fiber; though, from the limited information available, it would appear that Russia has more reserves than Canada. Elsewhere in the world, reserves seem to be fairly evenly distributed among those countries presently producing, or those in which potential deposits are known (Table 7).

The production of fiber, including both chrysotile and the various types of amphibole asbestos, has been steadily increasing over the last 10 to 15 years (Fig. 10). Of particular note is the lead taken by the Soviet Union in the mid-sixties. However, it is interesting to note that some authorities consider this figure to be biased by the inclusion of a greater proportion of very short fiber grades not presently recovered in Canada.

Russian production of medium and short fiber chrysotile is concentrated in the Central Urals where the large "Asbest" combine, together with smaller mines and mills at Alypayevsk, Nizhnitagil, Kiyembay, and south of Sverdlovsk, are capable of producing about 1.5 million tpy of fiber. Production has been steadily increasing in the sixties, both at existing mines and at new mills at Dzhetygara in northwest Kazakhstan, Aktovrak in the Tuva SSR, and at Molodezhnoe and Ilchirsk in the Buryat SSR. Other deposits such as that discovered at Bugetsaysk in Kazakhstan await development.

There are no less than six large mills in the "Asbest" combine, the sixth being commissioned recently. Combined capacity of these mills is now thought to exceed 1 million tpy. The first stage of the Dzhetygara combine in Kazakhstan was completed in 1965 but its full productive capacity of 500,000 tons of fiber has probably now been achieved with the completion of a second stage of development and expansion.

The first stage of the "Tuvaasbest" combine at Aktovrak came into operation in 1966. Further expansion has been under construction which, when completed, should give a total capacity of some 500,000 tpy of fiber.

The graph showing Canadian production has been climbing steadily during the period under consideration. This has been brought about by the enlarged capacities of many plants and the opening of new mines such as Advocate, Reeves, Clinton Creek, and Asbestos Hill which have more than compensated for the closing of exhausted properties such as the Munro, Nicolet, and Flintkote mines.

According to the latest statistics, the Eastern Townships of Quebec accounts for over 1.3 million tpy of fiber. This represents approximately 81% of Canadian production, with the balance coming from the Yukon Territory (6.0%), British Columbia (5.3%), Newfoundland (4.7%), and Ontario (2.7%). The Jeffrey mine at Asbestos is the largest single producer, accounting for some 600,000 tpy of fiber. The balance of the production, amounting to approximately 750,000 tons, comes from a number of mines located in and around Thetford Mines.

African production ranks third in world production statistics. It should be remembered, however, that this production comprises 190,000 tons of chrysotile produced in Rhodesia, the Republic of South Africa, and Swaziland, as well as 160,000 tons of crocidolite and 60,000 tons of amosite produced in South Africa. It should also be pointed out that the figures given for Rhodesian chrysotile production are estimates only, as no official production statistics have been issued since the Rhodesian Unilateral Declaration of Independence in 1966. Rhodesian production is anticipated to increase considerably as a large expansion program has been completed at Shabanie.

Recent estimates place China as the fourth major producer of asbestos in the world. Production is estimated at 175,000 tons in 1971 and 220,000 tons in 1972.

European production has shown only minor fluctuations over the past 15 years. Most of the mines are relatively small and production tends to fluctuate. Italy leads European production with 146,000 tons of fiber, most of which is mined at Balangero. French production has all but ceased with the closing of the Corsican asbestos mines.

The United States ranks sixth in world production with 131,000 tons in 1971 and 132,000 tons in 1972. Most of this production comes from California and Vermont with a small amount from chrysotile in dolomites mined in Arizona. Overall production took a noticeable increase in 1963 and 1964 when the Coalinga-New Idria deposits were first developed.

Most other countries show little change in

Geophysical

Owing to the lack of outcrop within areas of ultrabasic rocks, or within a belt in which these rocks are expected to occur, both aeromagnetic and ground magnetic surveys (Conn, 1967; Low, 1951) are often employed in the early stage of exploration for asbestos. Ground magnetic surveys may be used to check and define in more detail anomalies obtained by an airborne survey of a large area, or the ground survey alone may be used for the purpose of exploring a small area.

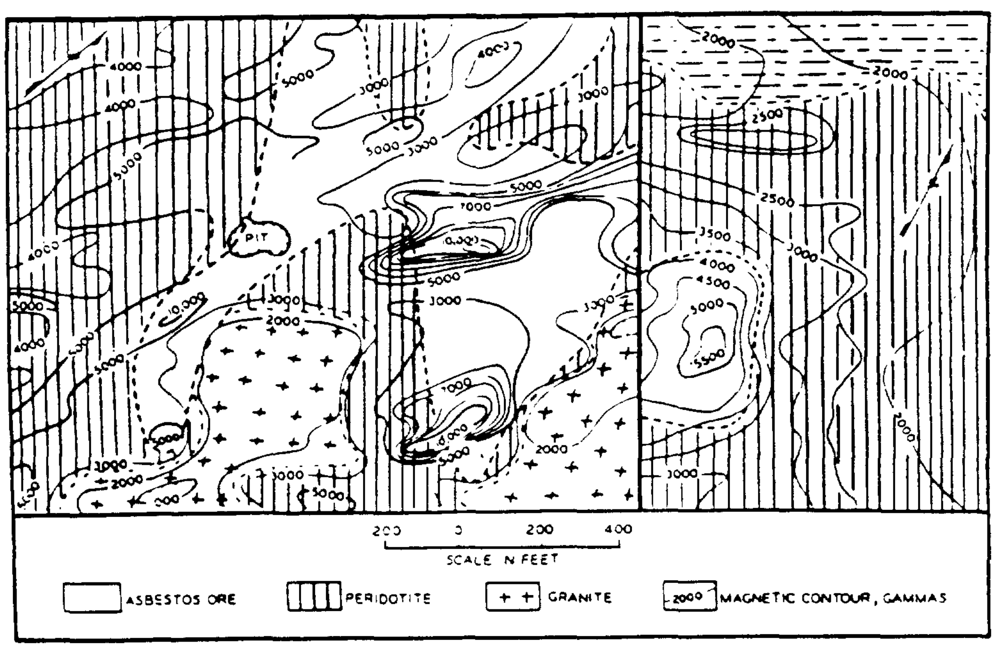
In the case of an airborne survey, flight lines are normally spaced at ¼-mile intervals, and flown as close to 500-ft elevation as possible. Where the terrain is rugged, helicopters are used which are capable of maintaining a constant altitude of 300 ft above ground level. The spacing between profiles on a ground survey is usually 200 or 300 ft and readings are taken at intervals of 50 or 100 ft.

Magnetic surveys are used to locate and define the areas of ultrabasic rocks and, within these, the areas which have been subjected to extensive serpentinization. This is possible because this type of alteration produces a higher content of secondary magnetite. Asbestos deposits in ultrabasic rocks are a result of intensive serpentinization, and for that reason asbestos veining is usually accompanied by a higher concentration of magnetite than is normally found in the barren serpentine. It follows, therefore, that magnetic anomalies obtained over an area of ultrabasic rocks are favorable places to explore for asbestos. Figs. 11 and 12 show the results of ground magnetometer surveys carried out over two known ore bodies.

Modern instrumentation has made great strides in recent years, and it is now possible to conduct precise surveys with small lightweight magnetometers, in contrast to the cumbersome equipment used in the past.

Diamond Drilling

Diamond drilling is normally employed to probe beneath the overburden to assess and define the limits of an asbestos deposit. As asbestos ore bodies are usually large in volume, it is customary to drill vertical holes on a grid pattern. In the initial stages of exploration an interval of 400 ft and sometimes more may be used, filling in to an interval of 100 ft or even less, where an asbestos-bearing zone is encountered. In cases where deposit is elongated in one direction, holes are generally spaced at closer intervals across the strikes. Narrow,



FIGS. 11 and 12—*Results of ground magnetometer surveys of two known ore bodies.*

tabular targets are best explored by angle holes planned to give the attitude and true thickness of the body.

In the past, drill evaluation programs frequently used small diameter, AX ($1\frac{5}{32}$ in.) or EX ($\frac{13}{16}$ in.), core sizes for evaluating any deposits where shearing was minimal and where holes did not exceed 300 ft. Experience has shown, however, that large core sizes such as NX ($2\frac{1}{8}$ in.) or BX ($1\frac{5}{8}$ in.), are preferable for better depth penetration, more geologic data, and to aid in fiber logging and dry milling of the core.

Wire-line drill equipment and the use of nonrotating core barrels are also recommended to minimize fiber loss by grinding of the core during drilling.

Steps are taken to recover the sludge only where core recovery is poor, which is generally the case with a slip fiber occurrence. Because of the tendency of the fiber to fluff up and remain in suspension, much greater settling tank capacity is required than is the case when recovering sludge from other minerals. Care must also be taken to avoid contamination by grease and vegetable matter as these cannot be burned off without damaging the fiber.

In regions where permafrost conditions are expected, every precaution should be taken to avoid freezing the string of drill rods down the hole. The use of suitable low-freezing drill lubricant media such as a concentrated brine solution is adequate to allow drilling in areas of permafrost. However, due to the high percentage of fiber cuttings in the water return, the brine solution has to be renewed at frequent intervals—a factor which considerably increases the cost of drilling asbestos prospects in permafrost areas. A number of successful drill ventures under permafrost conditions have been completed, including some which showed the frozen ground to persist to at least 1000 ft below surface.

In areas where drilling is impractical, exposure by trenching or exploration beneath the surface by adit or shaft and lateral workings may offer the only means of assessing a deposit.

Evaluation

The evaluation (Conn and Mann, 1971; Dean and Mann, 1968; Oughtred, 1952) of any asbestos deposit entails the determination of its size, as well as the grade and quality of its fiber. Dimensions of a mineral zone are established by conventional methods, such as mapping, magnetic surveys, trenching, and diamond drilling. The value of the contained asbestos fiber is dependent on numerous physical properties such as fiber length, strength, flexibility, harshness, and color, besides the actual amount of fiber present.

The determination of grade cannot be based on a simple chemical analysis as both the fiber and the wall rock have essentially the same chemical composition. To avoid the complete crushing of the rock and physical separation of the fiber into different lengths, a method of visual evaluation has been developed which requires careful enumeration of the total number of fiber veins, together with the average length of fiber in each vein. These fiber lengths, if expressed in sixteenths of an inch, give an approximation of the grade, each $\frac{1}{16}$ in. vein of fiber in a 5-ft section being approximately 0.1% fiber.

As the price of fiber varies considerably depending on its length, the use of grade based solely on its percentage fiber content is of little significance. Instead, the product of these two variables, expressed in dollars per ton of rock, offers a far more meaningful value which can be used for direct comparison in the final evaluation.

Drill Core: The method of visual evaluation is ideally suited to the evaluation of drill core.

Each vein of cross fiber is logged and the length carefully measured and recorded in multiples of $\frac{1}{16}$ in. (Adoption of the metric system based on multiples of 1 mm is also acceptable). As veins are often of irregular width, the average width of each vein should be estimated. Some veins are of a composite nature carrying partings, or the fiber may have kinks which cause it to break into shorter lengths. The fiber in some veins may be at right angles to the vein walls, in others sharply inclined. Allowance must be made for these conditions in arriving at the true lengths of fiber.

The more precise determination of fiber content calls for the measurement of each vein angle in the core to permit individual volume corrections. However, in practice it is usually assumed that the random angle is 45° and a factor of 1.414 (inverse of the sine of 45°) is used. However, this can be quite misleading if the average angle is rather small, so logging results should be checked against laboratory recovery and bulk sampling wherever possible.

As a rule, the visual reading gives an indicated lower yield of a higher value fiber than a corresponding mill test. This is to be expected as the visual readings disregard fiber lengths of less than $\frac{1}{16}$ in. which are, of course, recovered in milling and are important in grading. Furthermore, a certain amount of pulverized host rock adheres to the fiber, further reducing the grade and increasing the yield by 20% or more. On the other hand, there may be some loss of veins in the core and the veins themselves contain foreign material such as nonfibrous serpentine, picrolite, and magnetite. There is also a tendency, on the one hand, for some breaking of fibers to occur in the mining and milling process while, on the other hand, the fluffed up milled product tends to remain on a screen which an unopened fiber would pass through. For most practical purposes, the discrepancies are compensating and, when a suitable volume correction factor is used, the ore values found by the two methods are quite close.

Slip fiber is often associated as a minor constituent in deposits made up mainly of cross fiber, and in others the slip fiber may be the predominant type. It is not easy to determine the slip fiber length by the normal visual methods of logging core; however, its presence may be recorded separately by vein widths and the percentage slip fiber determined in the same manner as used for cross fiber. Laboratory assistance is almost essential in evaluating slip fiber deposits.

Regardless of the method used in evaluating asbestos ore the final answer should give the value of the fiber, the yield and, from this, the value of the ore in dollars per ton. A bulk sample properly milled and graded readily supplies the answer, whereas a laboratory test normally gives only the yield of an ungraded fiber and, therefore, of unknown value. The visual method, after due allowance for vein angles, gives the yield only and further calculations are required in order to approximate the fiber and ore value.

In order to place a value on the ungraded fiber resulting from laboratory extraction a graph is used (Fig. 13). The curve on this graph is derived from the Quebec Standard Tests (described elsewhere in this chapter) for average test production of all standard grades by weighting the fractions found in each box to give each grade a "point rating." The prices for Quebec asbestos are based on a minimum shipping test but for practical purposes the average test of production is about 20% higher. Weighting factors for the fractions of 100 for −½ in., 40 for −½ + 4 mesh, 10 for −4 + 10 mesh, and 1 for −10 mesh have no real significance and have been chosen only to control the shape of the curve.

As an example, a fiber testing 5.7 oz on the

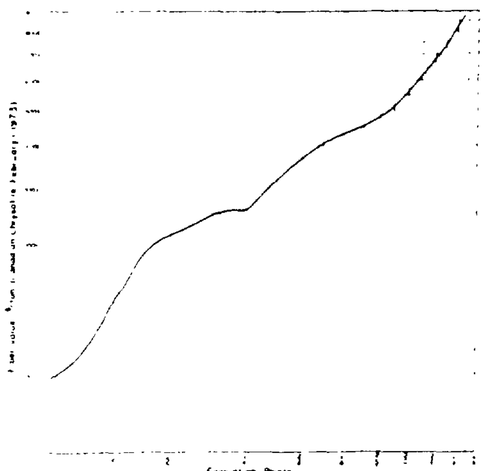


FIG. 13—*Graph for evaluating ungraded fiber. Reproduced by permission of Asbestos Corp. Ltd.*

½ in., 7.5 on the 4 mesh, and 2.3 on the 10 mesh with 0.5 in the pan would have a point rating of:

$$\begin{aligned} 5.7 \times 100 &= 570 \\ 7.5 \times 40 &= 300 \\ 2.3 \times 10 &= 23 \\ 0.5 \times 1 &= — \\ \hline & 893 \text{ points} \end{aligned}$$

and from the curve the fiber value would be about $455 per ton.

In applying this same procedure to the visual method, it is necessary to correlate the observed lengths with the corresponding Quebec Standard Test. In order to do so, it is assumed that fibers of ½ in. length and more will stay on the ½ in. screen, ¼ to 7/16 on the 4-mesh screen, and ⅛ and 3/16 in. on the 10-mesh, whereas the 1/16 is assumed to end up in the pan. A synthetic Standard Test can then be arrived at by simple arithmetic.

To illustrate this procedure, assume that a core length of 85 ft contains four veins of ½ in. length, two of 9/16 in., one of ⅝ in., two of ⅞ in., and one of 1 in.; 16 of ¼ in., three of 5/16 in., two of ⅜ in., and two of 7/16 in., 23 of ⅛ in. and 10 of 3/16 in.; 74 of 1/16 in.

Reducing everything to a common denominator of 1/16th, there would be 104 such sixteenths of ½ in. and over, 105 of ¼ to 7/16 in., 76 of ⅛ and 3/16 in., and 74 of 1/16 in., totaling 359 in all.

In 85 ft there are 85 × 12 × 16 sixteenths; therefore, the uncorrected yield is

$$\frac{359}{85 \times 12 \times 16} \times 100 = 2.2\%.$$

A correction must next be made for the average vein angle which will here be assumed at 45°.

$$\text{Corrected yield} = \frac{2.2}{\sin 45^\circ} = 3.1\%.$$

Next to arrive at the synthetic Standard Test:

½ In.	4 Mesh	10 Mesh	Pan	Total
104	105	76	74	359 sixteenths
104/359 × 100	105/359 × 100	76/359 × 100	74/359 × 100	100%
4.6	4.7	3.4	3.3	16.0 oz

Then to find the fiber value from the graph.

$$\begin{aligned} 4.6 \times 100 &= 460 \\ 4.7 \times 40 &= 188 \\ 3.4 \times 10 &= 34 \\ 3.3 \times 1 &= 3 \\ \hline &\ 685 \text{ points} \end{aligned}$$

From the graph the fiber value is found to be $400 a ton, and from this the indicated ore value is calculated to be 3.1% of $400 or $12.40 per ton.

Face Readings

On the surface or in underground workings, channel sampling may be employed. On the other hand, it is also possible to log these surfaces in a similar manner to that used for drill core. One method is to take a linear reading along either wall of a drift or crosscut and another is to take cross sections at intervals of 5 ft on the back and both walls to ensure that veins running parallel to the drive are not excluded.

An alternative method is to record all the veins in the face, walls, and back after each round. In order to arrive at a percentage, a factor based on the area involved is applied to the reading for each surface, and an average percentage for the round is determined in this manner.

The fact, however, that the rock tends to break along one or more of the numerous fault planes present rather than across the fault bounded blocks to expose the veins within them, makes it difficult to obtain representative results.

Bulk Sampling

The various methods of logging and sampling outlined seldom give entirely dependable results. The visual methods of logging will usually produce dependable results only where there is a relatively low content of shorts. Slip fiber, as already noted, presents a problem in this connection. Even laboratory results which are dependent on complete extraction, usually give an appreciably higher fiber value than that obtained in a conventional mill. It is not easy to simulate in a laboratory the conditions to be found at an operating mine where the fiber from the time of blasting to the final product is subjected to a good deal of handling, some of which is rather severe. The fibers, as a consequence, suffer some breakage in the process.

Bulk sampling is often resorted to as a means to check and to arrive at a suitable factor to be applied to drill core data. This may be done by diamond drilling a block of ground at close intervals prior to mining and milling. The core is then read visually and treated in the laboratory. Provided precautions are taken to avoid contamination and the sample is sufficiently large, results should be reasonably reliable despite the erratic distribution of fiber in the rock.

A 12,000-ton bulk sample from one deposit indicated that a yield factor of two would be necessary to bring the "visual" ore value in line with that found by milling. In this deposit there were approximately equal amounts of slip and cross fiber and it is observed that the visual determined yield is low and the fiber value exaggerated.

	Fiber Value per Ton, $	%	Ore Value per Ton, $	Yield Correction Factor
Mill recovery	111	6.80	$7.53	1.00
Laboratory recovery	164	4.59	7.70	0.98
Visual analysis	202	1.87 [a]	3.78	1.99

[a] No correction for vein angles.

A 50,000-ton sample assessed in the same manner also indicated a factor of two but showed that the fiber value determined visually was fairly close to that found in milling. This is attributed to the absence of slip fiber which, when present, makes the estimation of fiber value more difficult.

may be prepared in this manner to correspond with expected mining level intervals, and these serve as a useful guide to mining. Separate horizontal sections contoured for rock value and fiber value per ton permit the mine operator to produce a more balanced mill feed in respect to both fiber content and grades.

	Fiber Value per Ton, $	%	Ore Value per Ton, $	Yield Correction Factor
Mill recovery	$153	2.75	$4.20	1.00
Laboratory recovery	160	2.52	4.04	1.04
Visual analysis	148	1.37 [a]	2.03	2.07

[a] No correction for vein angles.

Tensile Strength

In considering the preceding paragraphs, it is important to point out that the measurements made and the evaluations so obtained are based entirely on the length of the fiber which is today a secondary factor in fiber value. Most fiber grades sold today are valued for the strength they lend to cement or other mixes and a standard scale of Strength Units has been established. Fibers in groups 4, 5, and 6 are sold at approximately $1.80 per Strength Unit. For example, for use in asbestos cement pipe a fiber regardless of its length distribution must test at more than 100 Strength Units and at that test will sell at approximately $180.00 per ton.

It is imperative then that any evaluation of a chrysotile deposit include Strength Unit evaluations which are laboratory tests involving the testing of an asbestos-cement tile made with the subject fiber. Once the inherent strength of the fiber from a particular ore body has been determined it is usually possible to equate strength to length distribution and dust content measurements.

Tonnage and Grade

To estimate the tonnage and grade of a deposit from diamond drill core data, individual drill holes may be weighted according to their interval using the polygonal method. An alternative procedure is to use cross sections, or groups of cross sections and, by weighting the individual holes in each section, determine the average grade for each section.

A third method employs contoured cross sections, wherein the contouring is based on a reasonable interpolation of the intervening area between drill holes. This method permits the estimator to make use of all available geological information in his interpolation. In open pit operations contoured horizontal sections

Exploitation

Mining

The development of asbestos mining in Canada has been accompanied by a succession of mining practices and equipment. The simplest hand methods were, quite naturally, first employed in shallow open pit workings. During one period, when pits were reaching considerable depth, quite elaborate overhead cableway derricks were popular. Modern power shovels loading into heavy-duty trucks have now supplanted all other loading and transporting equipment where open cast methods are employed. Underground methods which have been used in the past include glory holes, shrinkage and sublevel stoping, and block caving.

In some cases, scraper hoists drag the broken ore from the underground drawpoints and in others it is passed directly through grizzlies. Large primary crushers may be located underground. The trend that prevailed in Canada, in the late 1940s and early 50s when most of asbestos was mined by underground methods, has been reversed and now open pit mining prevails.

It is generally considered that surface mining is more advantageous in recovery, grade control, economy, and safety. The reversing of that trend is mostly due to the technological innovations in mining equipment: shovel size varies from 2½ to 15-cu-yd capacity, truck size goes from 25 to 200-ton payload, rock drilling equipment has improved considerably, and new blasting agents and techniques have been introduced. These innovations permit increased waste to ore ratio up to 3:1 or more, thus lengthening the economic life of open pits.

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ies are generally tabular in shape with a pronounced dip, with the result that the economic limit for quarry mining was reached at a comparatively early stage. Ore widths in the larger mines commonly range from 80 to 200 and up to 400 ft. Some ore bodies, notably in the Shabani district of Rhodesia, are quite extensive in length, in one case, development has extended for three miles along the strike, and is being developed or diamond drilled to over a thousand feet in depth. Several underground methods have been used including cut and fill. Presently, sublevel stoping and caving accounts for most of the tonnage extracted. Caving may be initiated by blasting holes drilled upward from sublevel crosscuts, starting first on the hanging wall side and retreating over a considerable width toward the footwall, or the development and retreat may be along the strike of the ore. In some cases high pressures have developed from an arching effect but these pressures have been largely released by mining a vertical slot which may extend through to surface and toward which the ore is allowed to cave. In the sublevel stoping method a slot may also be opened across the center of the ore body. The long holes which are fanned out from the sublevel drifts are then blasted toward the slot, and mining proceeds as a systematic retreat in two directions away from the opening thus made.

Drilling in the softer portions of these South African chrysotile mines is now frequently accomplished by rotary drills employing bits in which tungsten carbide cutting lugs are set. In drilling long holes, which may be up to 70 ft or more for sublevel mining, short lengths of jointed rods are used. With percussion type drills, which are generally used for harder rock than the rotary drills, flexible ribbon steel with a chisel bit of tungsten carbide has proven useful and efficient.

Much of the amosite and crocidolite in Africa has been mined from small, narrow open cuts or adits following the fiber-bearing band. In the Penge area the operations have been developed for larger scale and deeper mining. The main ironstone "reef" runs quite consistently at around 54 in. thick with a dip of about 20°. A sloping face is advanced along the strike by drilling rounds of about 6 ft with jackhammers. The broken material is shoveled back from the face into temporary pillars for roof support. The remaining material is hand-loaded into small cars, hoisted to a haulage level, and transported to a sorting plant for further removal of waste rock before being sent to the cobbing plant and mill. Formerly the fiber-bearing portion was hand-sorted underground which resulted in excessive values being left behind in the pillars. The ironstone fractures into rectangular blocks which lend themselves well to being built up in this way. The main fiber-bearing reef commonly contains up to 30% asbestos, so that the proportion of waste to barren works out well for the system used. The method is locally referred to as shrinkage stopage but should not be confused because of this nomenclature with the latter system as commonly practiced in other areas.

Milling

Mill flow lines are designed to suit the characteristics of a given ore body. The basic steps are similar for most flow lines. The raw fiber is recovered using the dry process which has been used almost exclusively since the inception of asbestos milling in Canada some 80 years ago. However, in certain cases, wet processing of at least some of the fiber has occurred. This method of processing may be examined more closely in the future.

The previous volumes of this series published in 1949 and 1960 provided a short description of some of the more commonly used equipment peculiar to the industry. The 1960 edition gave a brief description of the essential milling steps. There have been few major changes in the basic process since that time. The major improvements in the past 10 years have evolved around material handling, packaging, and shipping methods. The improved methods developed by the asbestos mining industry have made it possible for both the producer and customer to store, ship, receive, and use asbestos fiber in a relatively dust-free environment.

Apart from relatively modest bulk handling systems for shorts, the major portion of the production is now being packaged in airtight woven polylaminate 100-lb pressure packed bags for export and in paper for domestic markets where fiber handling is not as severe. Both of these packaging methods can be unitized for container and rail shipments. The trend is towards 100% mechanical handling of the asbestos product both at the mines and point of use.

The flowsheet shown in Fig. 14 is a generalization of the essential steps and equipment used in a Canadian chrysotile asbestos mill producing the full range of raw asbestos fiber grades Group 3 to Group 7.

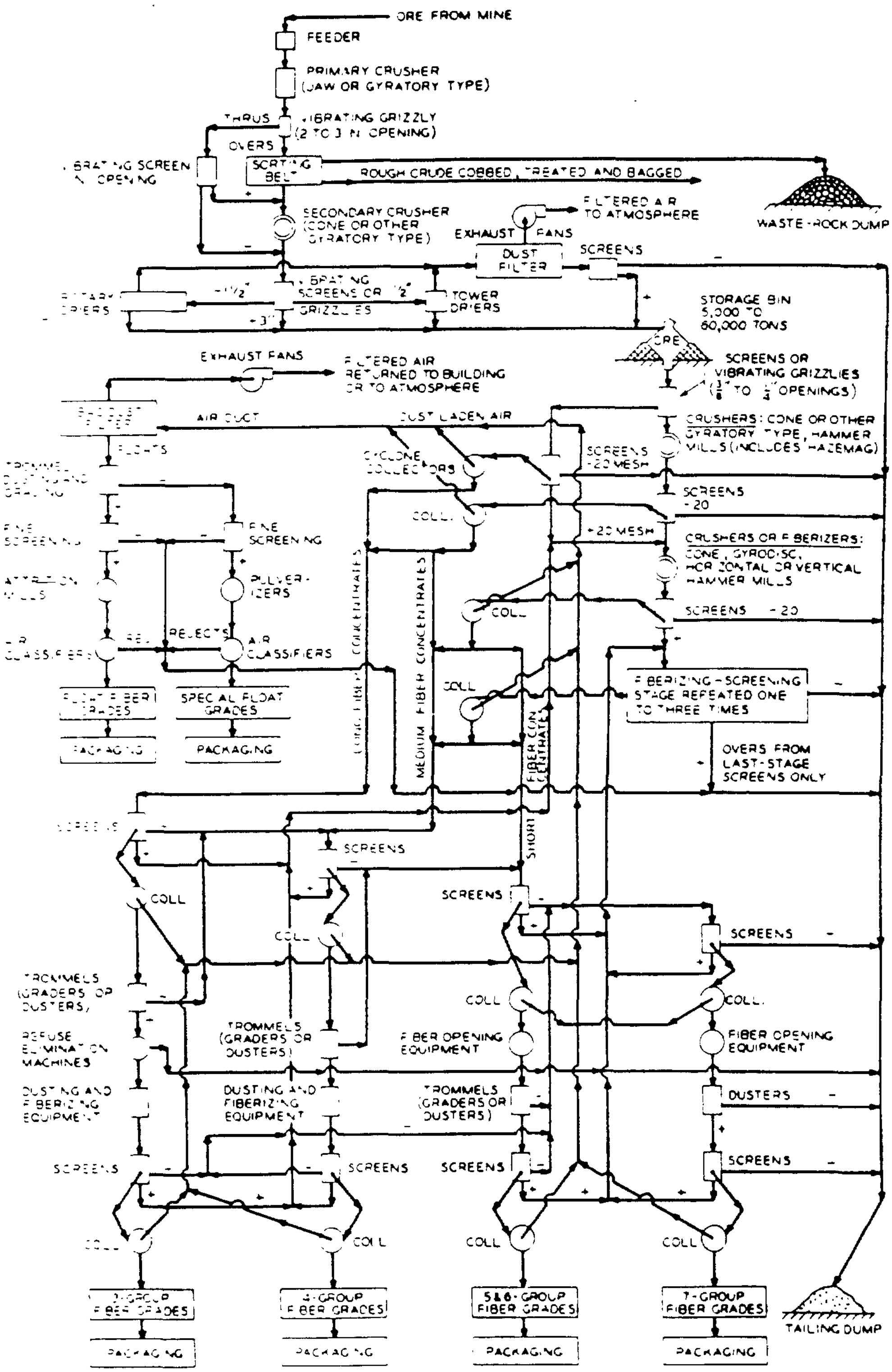

FIG. 14—*Flowsheet of a Canadian asbestos mill.*

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Fig. 15 shows a section of a Canadian asbestos mill primary rock and fiber cleaning circuit.

Fig. 16 illustrates a schematic flow line of a two-product Canadian asbestos mill.

Fig. 17 illustrates a recent Canadian installation of a primary and secondary crushing, drying, and ore concentration system.

The description that follows of the essential steps of a milling operation is based on Figs. 14 and 17.

Mill feed is derived from the underground or pit operation. Primary crushing may be done in underground stations in the case of an underground mine or surface plant when treating open pit ore.

Large jaw crushers (the 48 x 60-in. size is the most popular) are used in the majority of the Canadian plants either underground or on surface. Heavy-duty pan feeders have proven quite practical and comparatively trouble-free, particularly for handling open pit ore containing large unbroken pieces which are likely to cause blockages. Lately the trend has been towards large capacity gyratory crushers which eliminates the need for feeders and bins.

In countries where relatively cheap labor is still available a certain amount of hand sorting continues to be done before or after (or both) primary crushing for the purpose of removing barren rock and also to recover pieces of the larger asbestos veins to be used in the production of No. 1 or No. 2 crudes. Reduction in primary crushers of the size mentioned is normally to about 7 in., and is followed quite commonly by 7-ft or smaller cone crushers with settings ranging from ¾ to 2½ in.

Ore concentration is an important step in the milling of asbestos ore and is particularly important to the lower grade ore bodies. It is not uncommon to discard up to 40% of the mine ore through selective impacting and screening in the primary and secondary crushing circuits. Nearly all producers are able to accomplish beneficiation of this type to some degree. The use of magnetic pulleys is a relatively new approach being used by some producers for

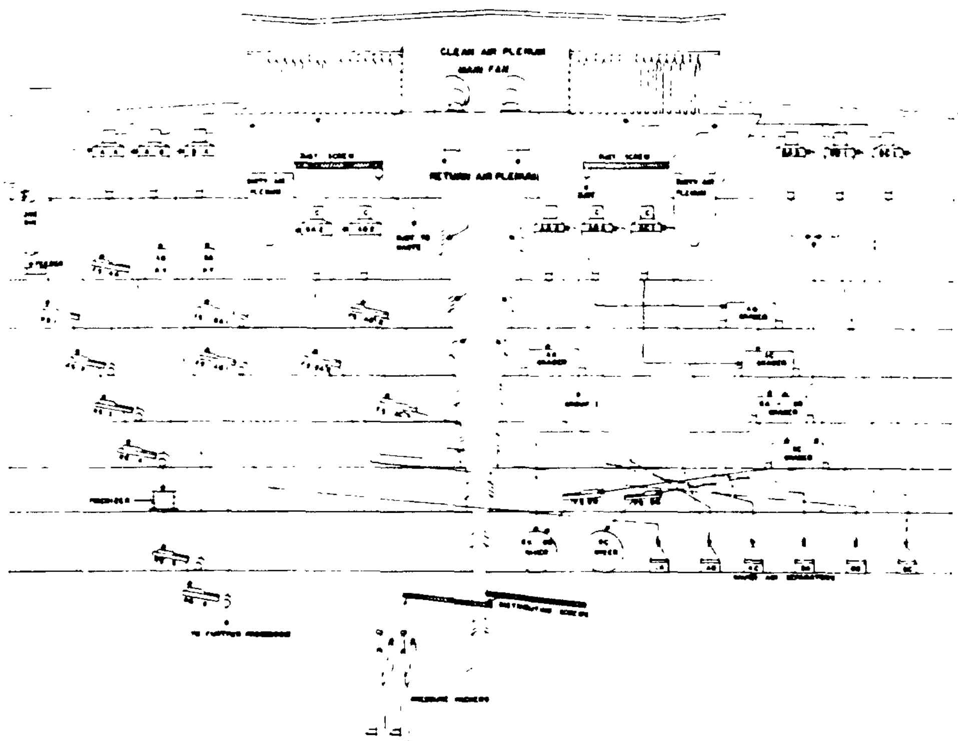
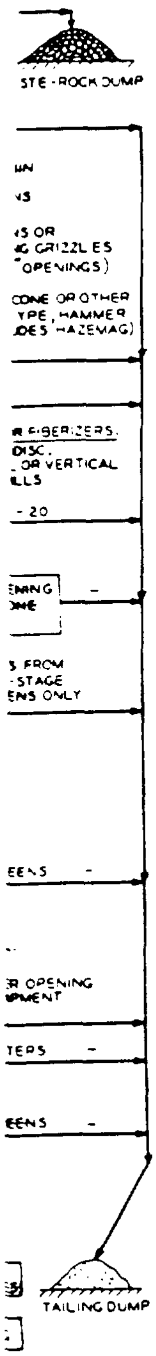


FIG 15—*Section of a Canadian asbestos mill showing the primary rock line and fiber cleaning circuit.*



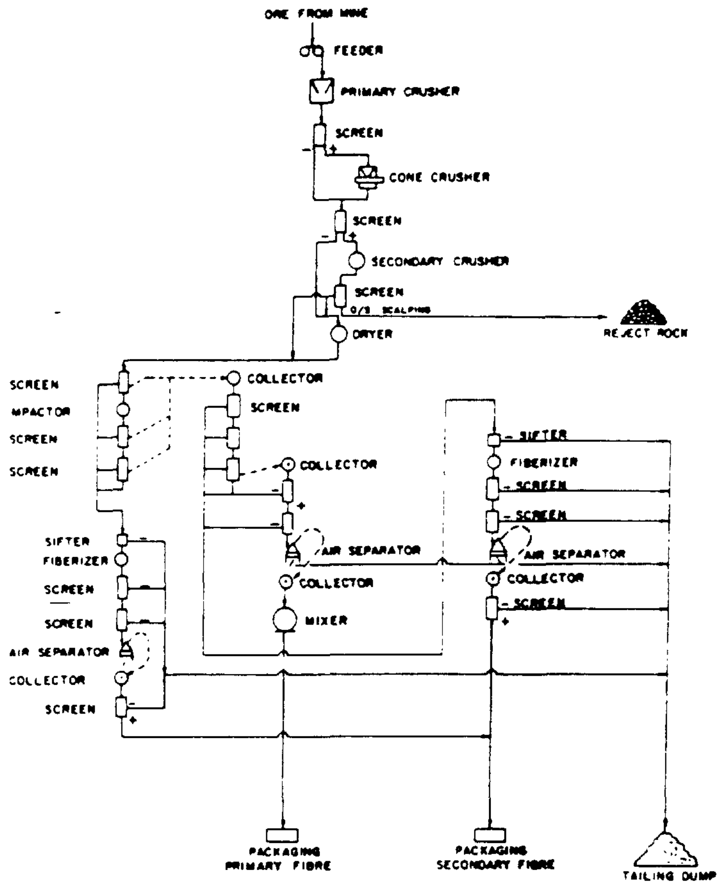


FIG. 16—*Schematic flow of a two-fiber-product Canadian asbestos mill.*

upgrading the mine ore. Not all asbestos ore bodies are amenable to this type of separation.

The next step is to dry the ore. It is considered good practice to provide a storage large enough for one shift's production of mine ore to assist in regulating the flow rate to the dryers.

Most of the moisture is contained in the $-1\frac{1}{2}$ in. fraction. At some plants this fraction is screened and dried separately from the oversize ($1\frac{1}{2}$ to 7 in.).

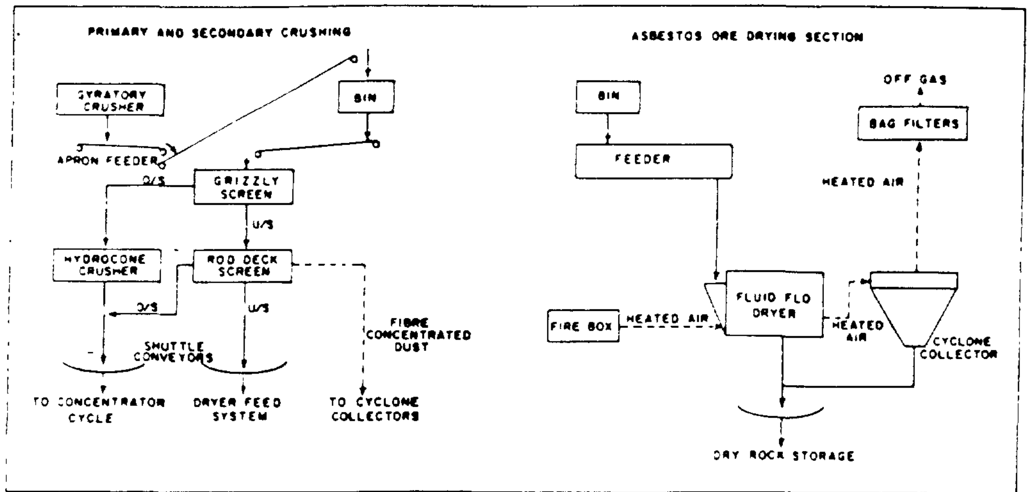
In all stages of beneficiation it is important to minimize abrasion and cutting of the fiber particularly in the earlier stages before the longer and more easily released fiber fractions are separated from the gangue.

The selection of a dryer is largely based on local preference. The two more commonly used are the rotary and vertical dryers. Recently an installation has been made using fluid bed dryers.

The chief advantage of the vertical tower and fluid bed over the rotary kiln-type dryer is normally a lesser degree of mechanical damage to the fiber. On the other hand, the rotary dryer is preferable and is also more effective for open pit ores containing snow and pieces of ice.

Where conditions permit, oversize (say, $+1\frac{1}{2}$ to 3 in.) material may be separated before drying, and bypassed to lessen the pebble-milling action of rotary dryers. Where vertical driers are used the feed should not be much coarser than a $1\frac{1}{2}$ grizzly opening size in order to avoid blockages in the gridwork of arresting bars with which the dryers are fitted.

There is a limit to the air velocity which may be used in the counterflow vertical-type dryer where the products of combustion from an oil or coal-fired furnace rise through the falling ore. Near the bottom of the tower, where the hot gases enter, fluffed particles of fiber may be



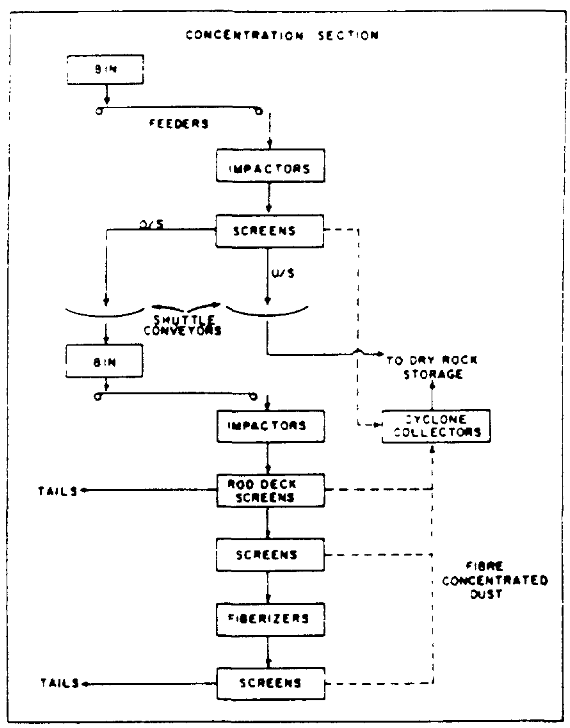


FIG. 17—*Recent Canadian installation of a primary and secondary crushing, drying, and ore concentration system.*

temporarily held in suspension in a damaging temperature environment.

One solution to this objectionable feature is to have at least part of the hot gases introduced at the top of the tower and to be drawn downward with the falling material.

Dryers using the practical application of this principle have the discharge gas takeoff at a point midway up the height of the dryer, this keeping air velocities and temperature within permissible limits toward the bottom of the tower. An after-cooling device may also be used in which cool air is blown through the discharged hot ore to remove further moisture before the ore is discharged onto conveyor belts. The air from this operation may be used as preheated makeup air in the dryers.

The air and products-of-combustion as discharged from the dryers carry a considerable volume of dust. It is desirable, therefore, to provide filtering equipment in order to keep the plant area clean. Bag filters using various fabric have operated successfully and are certainly the most positive means of removing the dust. Care must be exercised, however, to guard against condensation.

An alternative filter which has been used is known as the Impingo. This employs an ever-changing layer of cold moist aggregate, or the ore itself screened to, say, −1-in. size. Some moisture is precipitated from the gases and dust adheres to the surfaces of the crushed stone or pebbles. This system has proven ineffective in most applications.

It has been found desirable to have substantial storage capacity between drying and the main stage of milling. Besides assuring an adequate and more uniform supply of ore to the mill, further drying (up to 1% moisture loss) takes place during the storage. The size of storage facilities will vary with mill capacity.

As will be apparent from the flowsheet (Fig. 14) the release and separation of fiber from gangue is accomplished by successive stages of crushing or comminution by impact. Impactors are designed to release the fiber from the host rock and at the same time produce a minimum of fines.

Fiber in the form of cross-fiber veins or slip fiber thus released is at the same time sufficiently "teased out" so that the portion so freed may be lifted by air suction, leaving most of the rock as a reject to go to the next stage of impacting and eventually to tailings.

Finer fractions are generally screened out prior to air separation. Otherwise a large portion of rock fines would be aspirated with the fiber. Rotary aspirators designed to present a uniform layer of material to the aspirating hood are commonly used to improve the aspirating efficiency. The products of these first stages of separation may be considered as concentrates. They contain a large percentage of rock particles and must be further treated in the fiber grading division of the plant.

Here the concentrates are further graded and undergo a series of cleaning operations for the purpose of removing sand and dust. Screens, trommels, specific gravity air separators, and modified forms of these such as graders and dusters, further clean the fiber and separate it into standard grade lengths.

In the grading mill the fiber is further separated into the approximate quality brackets required for specific grades and is subjected to several stages of screenings using shaking screens, rotating screens, conventional trommels, trommel-like graders, and rotary dusters.

When well opened or fluffed out grades are called for, the fiber is subject to special treatment in one or more of a variety of machines ranging from graders or Willows (fixed shell trommels having a rotating center shaft to which beater arms are attached) to one of several types of high-speed hammer mills, disk grinders, or pulverizers. The type of machine or machines used depends upon the length and type of fiber to be processed and the degree of opening or fluffing up required. This additional treatment is generally given to the shorter fibers.

A large volume of air is used in an asbestos mill, most of which is for the primary purpose of separating fiber from rock, and dust by air suction and classification.

An additional quantity is also required for dust elimination at many points within the building to keep the dust content of air in the building to a minimum. It is estimated that mills having a capacity of, say, 5000 tpd of ore, use from 500,000 to over 800,000 cfm of free air.

The average consumption in Canadian mills is something in the order of 7 to 14 (Kula and Wiser; 1970; Rozovsky, 1957) tons of air per ton of ore treated.

Modern practice requires all this air to be filtered before being discharged from the mill into the open. This has led to extensive bag filter units being installed in nearly all mills in recent years.

In Rhodesia, South Africa, and Swaziland, where there are several modern mills, one finds that the general approach to the beneficiation of chrysotile does not differ greatly from Canadian practice.

One feature of African milling is careful control of moisture content as this may actually fall too low, particularly during the dry season. Fiber may be more easily broken or damaged under extremely dry conditions.

In Rhodesia the small pan crusher or Chilean mill was one in extensive use. This is no longer widely used for general milling but has been adopted to some extent in Canada for the preparation of crudes.

African practice, for the preparation of crocidolite and amosite, is generally very simple, consisting to a large degree in hand sorting, crushing, and screening as with the "crude" grades in Canada. However, in the Penge area of the Transvaal, milling practice is somewhat more elaborate and several milled grades of amosite are produced.

In addition to the more or less conventional sorting and some very difficult cobbing due to the extreme toughness of the rock, the fiber is treated in different mill circuits variously equipped with jaw crushers, cone crushers, rolls, hammer mills, and trommels. As an example the longest grade, *D*, is prepared essentially as follows:

3 x 14 in. grizzly
↓
Reduction to 1½ in. in small jaw crusher
↓
Crushing rolls (24 x 48 in.) to ¾ in
↓
Trommel—1½ in.—undersize to next shorter grade circuit
↓
Crushing rolls (12 x 36 in.) to ½ in
↓
Trommel—¾ in. (as above)
↓
Degritting trommels (2 in parallel)—¼ in.
↓
Bagging

In the circuits for shorter grades, cone crushers, hammer mills, and other fiberizing and cleaning equipment is now used. Trommels have proven effective as a cleaning device for medium as well as the long grades.

For the very short fibers high-speed vibrating screens are found more efficient. Air separation is practiced in various forms such as air traps, suction hoods, and screens, depending on the fiber grade being treated.

Tests and Specifications

The only test that is generally recognized by the government in Canada is the Quebec Asbestos Mining Association classification known as the Quebec Standard (Q.S.) Test. (This test is performed in the Quebec Standard Testing Machine which consists of a nest of three sieve boxes with ½ in. screen, 4-mesh, and 10-mesh screens, respectively, and a bottom box serving as a pan. A test is made with 16 oz of asbestos and the whole mechanically shaken for 600 revolutions at 328 rpm. The equipment is made to exact standard specifications, and can be purchased through the secretary of the Quebec Asbestos Mining Assn., 580 E. Grande Allée, Suite 320, Quebec 4, P.Q., Canada.) The Quebec Asbestos Mining Assn. has set specifications for the various grades of fiber, showing the maximum and minimum limits for the quantities of fiber that should remain on each screen. It is used as a production control and serves as a specification of the grade of fiber for sale.

This type of test has also been partially adopted by other countries, and in some cases the results are expressed in percentages instead of ounces.

Other variations of the Quebec Standard Test at some localities involve the Ro-Tapping of the Q.S. fractions for further evaluating purposes, because it was believed that the Ro-Tap would give a better distribution of the fiber lengths.

The Ro-Tap test is used by many asbestos mill operators to obtain a fiber distribution impossible to get by the Quebec testing machine. The use of the Ro-Tap differs with operators at different plants. It is not a standardized test accepted by the industry, and therefore the type and size of screens vary, as well as the lengths of time of Ro-Tapping and the quantity of fiber used in making a test.

In many cases, a cubic-foot box or a fraction of a cubic-foot box is used for obtaining the density of fibers. When the box is filled with the fiber, it is weighed and the values expressed as pounds per cubic foot. Many customers make density measurements as a guide for the introduction of the fiber in a specific product.

Wet classification and screening have been employed to an increasing extent in recent years. Equipment such as the McNett or the Clark wet testing machine may be used for production purposes permitting the operator a much closer check on fiber lengths, nonfibrous fractions, and dust content.

Many tests are made at the special request of customers who in turn may evolve their own best methods to evaluate the fiber in terms of their finished products. This has resulted in tests such as: viscosity, absorption, grit, troweling, bulk, penetration, soluble salts, magnetite content, compressibility, flexing, tensile strength, color, strength units, surface area, and others being made.

Fiber producers in other countries such as Rhodesia, Russia, Australia, The Cape and Transvaal, South Africa, have evolved their own testing methods for grading and classifying fibers, but do use the Quebec Testing Machine to a certain degree.

The classifications for various grades from the more important producing areas are given in Tables 9–14.

Uses of Asbestos

The uses (Badollet, 1948) of asbestos fibers of all varieties are numerous and only some of the major ones are listed, along with a brief discussion of the products involved.

Crudes No. 1 and No. 2—Chrysotile crudes are usually processed by the customer to produce a long spinning fiber for use in textiles. A desirable fiber for textiles is one that has good flexibility, is soft, low in soluble salts and magnetite, and easily carded without an excess drop in shorts. It should also be free from wood and blasting wire or fuse wire. Fiber of this quality would be desirable for all textile uses, including those for the electrical industry. In some cases, this grade of fiber is used as felts in laminates along with resins to form a strong molded sheet for use in airplanes, boats, etc.

Crocidolite crudes must be carefully processed to produce long fibers which can be used in textiles, gaskets, ropes, or in laminates with resins.

Amosite crudes, after reprocessing, will give a long bulky fiber that is used in blanket insulation or in products requiring a low density and good insulation value. Spinning of amosite can be accomplished, but is difficult.

Group 3 Milled Fibers—Chrysotile fibers that meet this classification are generally used in textiles. Some are used in long fiber asbes-

TABLE 9—Quebec Grading as Set Forth by the Quebec Asbestos Mining Assn.

SPECIFICATION

Group No. 1
No. 1 Crude-cross-fiber veins having 3/4-in. staple and longer

Group No. 2
No. 2 Crude-cross-fiber veins having 3/8-in. staple up to 3/4-in. Run-of-Mine Crude consists of unsorted crudes. Sundry Crudes—consist of crudes other than above specified.

	Guaranteed Minimum Shipping Test			
	1/2 In., Oz	4 Mesh, Oz	10 Mesh, Oz	Pan, Oz
Group No. 3 (Commonly referred to as textile or shipping fibers				
3F	10.5	3.9	1 3	0 3
3K	7	7	1 5	0.5
3R	4	7	4	1
3T	2	8	4	2
3Z	1	9	4	2
Group No. 4 (Commonly referred to as asbestos cement fibers)				
4A	0	8	6	2
4D	0	7.0	6 0	3 0
4H	0	5	8	3
4H	0	5	7	4
4K	0	4	9	3
4M	0	4	8	4
4R	0	3	9	4
4T	0	2	10	4
4Z	0	1.5	9 5	5
Group No. 5 (Often referred to as paper stock grades)				
5D	0	0.5	10 5	5
5K	0	0	12	4
5M	0	0	11	5
5R	0	0	10	6
5Z	0	0	8 6	7 4
Group No. 6 (Paper and shingle fibers)				
6D	0	0	7	9
Group No. 7 (Shorts and floats)				
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
7T	0	0	0	16
7RF and 7TF Floats	0	0	0	16
7W	0	0	0	16
Group No. 8 & 9 (Sands and gravels)				
8S	0	0	0	16
	Minimum 50 lb per cu ft			
8T	0	0	0	16
	Minimum 75 lb per cu ft			
9T	0	0	0	16
	More than 75 lb per cu ft			

TABLE 10—Cassiar Asbestos Grades, Northern British Columbia

C-1	Crude 3/4-in. staple and longer.	
AAA	Extra long spinning fiber	– Canadian Group 3
AA	Long spinning fiber	– Canadian Group 3
A	Spinning fiber	– Canadian Group 3
AC	Spinning fiber	– Canadian Group 3
CC	Spinning fiber	– Canadian Group 3
AK	Asbestos-cement fiber	– Canadian Group 4
CP	Asbestos-cement fiber	– Canadian Group 4
AS	Asbestos-cement fiber	– Canadian Group 4
CT	Asbestos-cement fiber	– Canadian Group 4
AX	Asbestos-cement fiber	– Canadian Group 5
AY	Asbestos-cement fiber	– Canadian Group 5
CY	Asbestos-cement fiber	– Canadian Group 5
AZ	Asbestos-cement fiber	– Canadian Group 6
CZ	Asbestos-cement fiber	– Canadian Group 6

TABLE 11—Classification of African Chrysotile*

C&G1	Long, crudy textile fiber	From mines in the Shabani district of Rhodesia
C&G2	Textile fiber	
C&G3	Long shingle fiber	
C&G4	Shingle fiber	
C&G5	Short shingle fiber or paper stock	
VRA-2	Textile fiber	From the Mashaba district of Rhodesia
VRA-3	Long shingle fiber	
VRA-4	Shingle fiber	
HVL2	Textile fiber	From the Havelock mine in Swaziland
HVL3	Long shingle fiber	
HVL4	Shingle fiber	
HVL5	Short shingle or paper stock	
Msauli – Grade 4 Msauli – Grade 5	Shingle fibers	From the Msauli mine near Swaziland border in the Transvaal
Amianthus 1 and 2	Textile fibers	From the Barberton district of the Transvaal
F	Long shingle fiber	
AA	Shingle fiber	
Munnik-Myburgh M1	Textile fiber	From the Barberton district near Nelspruit of the Transvaal
M3	Shingle fiber	
M4	Short shingle fiber	

* In the absence of a current listing of Rhodesian, South African, and Swaziland grades, this list from the 1960 edition is included to indicate type and source.

tos papers, packings, gaskets, brake linings, clutch facings, electrolytic diaphragms, pipe coverings, and insulating blocks. Some of the fibers of this group are now being used in laminates with resins.

Crocidolite may be used for most of the purposes listed previously, providing color is not an objection. It should generally be carefully prepared in a well-opened condition.

Group 4 Milled Fibers—Many grades of fibers in this classification are used in asbestos-cement processes to produce pipe, jackets, boards, sheets, and a variety of hand-molded articles. Other uses are for papers, pipe coverings, packings, gaskets, millboards, and plastics.

Crocidolite, similar to Group 4 chrysotile, is used in asbestos-cement pipes, in some packings and in some gaskets.

Amosite is used in magnesia blocks, pipe coverings, and other insulation compositions when a light density is desired. It is also used in acetylene cylinders to give strength to the calcium silicate mix during curing.

Group 5 Milled Fibers—Fibers of this group sometimes are used as replacements for Group 4 fibers, and therefore the products made with these fibers would include asbestos-cement sheets, corrugated or flat boards, pipe, electrical panels, papers, millboards, pipe coverings, gaskets, packings, brake linings, and plastics.

Crocidolites of this classification are used in asbestos-cement pipes.

Amosites, similar to Group 5 chrysotile although short in length, are finding use in insulating block of light density, such as Thermobestos or similar products, also in lightweight construction materials such as marinite board.

Group 6 Milled Fibers—Chrysotile fibers of Group 6 are used in asbestos-cement shingles, flat sheets, corrugated sheets, boards, brake lining, papers, millboards, putties, and plastics.

Crocidolite of this grading would be considered as too short in length for use in asbestos-cement products and, therefore, it would be classed as a filler and used whereever its physical properties could be employed to advantage.

Amosite of this classification is considered quite short for most purposes, and would probably be used as a cheap filler to free up asbestos-cement slurries prior to pressing.

Group 7 Milled Fibers—These fibers find usage in certain papers, cements, asphalt roof coatings, putties, paints, welding rods, floor tile, and plastics.

Crocidolite and amosite fibers of a length equivalent to Group 7 chrysotile are not known to be used in commercial products unless as a cheap filler where color is not objectionable.

Floats—Chrysotile floats (Badollet, 1952, 1956) are used extensively in plastics, putties, paints, welding rods, and cements.

The selection of asbestos fiber for a particular application will depend upon the processing

TABLE 12—Classification of Russian Chrysotile (Condensed)

Grade	Type	Texture	Mark according to USSR Standards, 1972
0	Spinning fiber	Harsh, crudy	DV-0 80, DV-0 55
1	Spinning fiber	Harsh, crudy Semi-crudy	J-1-50, J-1-38 PRJ-1-75, PRJ-1-50
2	Spinning fiber	Harsh, crudy Semi-crudy Semi-open	J-2-20 PRJ-2-30, PRJ-2-15 P-2-30, P-2-15
3	Asbestos-cement fiber	Harsh, crudy Semi-open	J-3-40 P-3-70, P-3-60, P-3-50 M-3-70, M-3-60
4	Asbestos-cement fiber	Semi-open Open, soft	P-4-40, P-4-30, P-4-20, P-4 5 M-4-40, M-4-30, M-4-20, M-4-5
5	Paper fiber	Semi-open Open, soft	P-5-67, P-5-65, P-5-52, P-5-50 M-5-65, M-5-50
6	Paper and shingle Fiber and shorts	Semi-open Open, soft	P-6-45, P-6-30 M-6-40, M-6-30 K-6-45, K-6-30, K-6-20, K-6-5
7	Unguaranteed		7-300 7-370 7-450 7-520

method, as well as the desired properties of the end product. The following examples outline some of the major uses for asbestos fiber and illustrate pertinent factors which influence the choice of fiber grade and type.

Asbestos Cement Products—Pressure pipe which must conform to hydrostatic test specifications is produced from high quality Group 4 fiber, usually a blend of chrysotile and crocidolite, to ensure a good modulus of rupture. On the other hand, the flexural and impact strength requirements for asbestos cement sheets can usually be met by using a Group 6 fiber. Formulations for corrugated sheets generally include some Group 5 material to improve adhesion of the wet sheets during the forming process.

In all asbestos cement products made by the wet machine process, drainage is an important fiber characteristic since it has direct bearing on the production rate. For this reason, preference may be given to fast filtering fibers and amosite may be included in the formulation as a filter aid.

The requirements for shingles made by a dry process are not so exacting from either the

TABLE 13—Classification of African Amosite

Grade	Approximate Range Average Fiber Length, In.
S 11	1–1 1/2
W 3	1/2–1 1/2
K 3	1/2–1 1/2
SK	3/16–3/4
S 33	1/8–1/2
S 33/65	1/8–1/2
GW	1/8–1/4
GK	1/8–1/4
S 44	1/8–1/4
RK	1/8–1/4
6605	1/16–1/8

The grades listed above are produced in the Penge area from the Penge mine and the Weltevreden and Kromellenboog mines. The fiber lengths shown are not necessarily exact, but have been included in order to give some indication of the relative lengths of fibers of the different grades.

TABLE 14—Cape Blue (Crocidolite)

Grade	Approximate Range Average Fiber Length, In.	Typical Values Surface Area (Rigden), Sq Cm per G
C	1 1/4–1 3/4	1,500
S	1/4–3/4	5,500
S 80	1/4–3/4	9,500
P 25	1/4–3/4	8,300
H	1/8–1/2	7,500
H 80	1/8–1/2	10,000
713	1/8–1/2	13,000
WDS	1/8–3/8	9,000

Cape Blue Mines (Pty) Ld. produce most of the Blue asbestos. Among other producers grading practice is to refer to "long" and "short" for the bulk of their production.

strength or drainage point of view and can be satisfied with a lower quality 6 or 6–7 blend.

Asbestos Paper—Traditionally asbestos fiber in conjunction with an organic binder has been used for the manufacture of paper and millboard which, in turn, were converted to roofing felt, pipe coverings, electrical insulations, and many other products. Various blends of Groups 4, 5, and 6 fibers are used for this application, depending upon the desired strength and porosity of the paper.

More recently, a latex-asbestos process has been developed in which a long clean Group 7 fiber having a high surface area is coated with latex rubber by a chemical precipitation method and the resulting finish formed into a continuous sheet on a paper machine. A large proportion of this latex asbestos paper is used as an underlayment for vinyl-rolled floor covering. A lesser amount is used in the manufacture of gaskets.

Friction Materials—This product line cannot be related to any particular fiber group, since it spans the complete spectrum from Group 3 spinning grades to the shorter Group 7.

The explanation lies in the wide variety of products, which fall within the general classification of "friction materials," and the equally diversified manufacturing processes involved.

Clutch plates are made from an asbestos open-weave cloth impregnated with resin and bonded to a steel disk. A similar product can be manufactured by molding a dry resin-fiber blend under conditions of high temperature and pressure onto a packing plate. For the first method, a Group 3 fiber is required, whereas the molding process utilizes a Group 5.

Automobile brake linings bonded to a steel shoe are usually made from Group 7 fiber in a semi-wet extrusion process while heavy blocks for railcars and large vehicles use Group 5 or 6 fiber dry-molded and machined to finished dimensions.

Group 5 fiber is also used extensively in disk brake pad formulations.

Sheet Packing—Latex asbestos paper made from Group 7 fiber can be densified and used for gasketing, but most sheet packing material is formed on a sheeter machine by a calendering process. This latter method requires a longer fiber in the Group 4 to 5 range, which has been cleaned and opened. The fiber is blended with natural or synthetic rubber, plasticizers, and other ingredients in a high shear mixer to form a dough which is later calendered into sheets of various thicknesses.

Floor Tile—A large volume of Group 7 fiber is supplied to manufacturers of vinyl floor tile. This product requires a short, clean, well opened Group 7 fiber having a high degree of uniformity in such properties as length distribution, absorption, and color. This latter feature is particularly important to the industry because of the need for matching of shades from different production runs.

Asphalt Products—Group 7 asbestos fiber in combination with asphalt and various solvents form the basis of a wide variety of products often classified under the catchall heading of "Blackline."

These include spray or brush-on roof coatings, sound deadeners for automobile body panels, and caulking components.

In recent years, automobile underbody protective coatings applied by airless spray equipment have provided an outlet for Group 7 fiber. Since the finished compound must pass through an orifice 0.021 to 0.028 in. in diameter under high pressure during application to the automobile, the fiber used must meet strongest specifications on fineness and viscosity building properties.

Short Group 7 chrysotile asbestos added to hot asphalt paving mix helps to improve characteristics of toughness, flexibility, and water permeability. Asbestos modified pavements have proved successful in high traffic density areas, such as busy street intersections, bus stops, and bridge decks.

Caulking Compounds—Combinations of long asbestos with cement and other ingredients, along with waterproofing resins, are used to produce special types of caulking compounds.

In many cases, short asbestos and floats are also combined with various types of resins and other materials to produce a soft plastic caulking compound that remains soft or it may be controlled so as to set up as a hard mass.

Plastics—Structural materials using plastics reinforced by asbestos or as a combination of asbestos and glass are now of considerable importance commercially. The asbestos may be in the form of a mat, or as paper or cloth to form laminates with resins such as polyesters, phenolics, thermosetting silicones, melamines, and furanes.

The use of long fiber chrysotile, crocidolite, and in some cases amosite, in the form of felts or papers and impregnated with resins produces a tough product of high strength and good heat resistance. These products have been used in aeroplane wings in England and in small sailing boats, radar scanner aerials, aircraft tanks, automobile bodies, and other products including rocket tubes, missile nose cones, and other parts.

In some cases, asbestos in the form of cloth or a millboard type is impregnated by resins to obtain a strong sheet for structural use.

Short Group 7 fiber and floats are also used extensively as a fibrous filler for the production of molded phenolic resin and polyester parts, such as automobile heater and air conditioner housings, electric kettle basis, and other appliance parts. In such applications, freedom from abrasive particles is especially important to hold die wear at minimum level.

Joint Filler—Another interesting use for short

TABLE 15—Asbestos Prices—Canada, U.S.

Standard Grade Designation	$ per Ton of 2000 Lb, F.o.b. Mine
Quebec, Canada (As of Jan. 1, 1975)	Canadian Currency
No. 3 Spinning fiber	724.00–1189.00
No. 4 Asbestos-cement fiber	400.00– 614.00
No. 5 Paper fiber	255.00– 301.00
No. 6 Paper and shingle fiber	186.00
No. 7 Shorts	79.00– 152.00
Cassiar, Canada (As of Jan. 1, 1975)	F.o.b. North Vancouver, B.C., Canadian Currency
AAA Grade Nonferrous spinning fiber/Canadian Group 3	1560.00
AA Grade Nonferrous spinning fiber/Canadian Group 3	1240.00
A Grade Nonferrous spinning fiber/Canadian Group 3	945.00
AC Grade Nonferrous spinning fiber/Canadian Group 3	680.00
AK Grade Asbestos-cement fiber/Canadian Group 4	485.00
AS Grade Asbestos-cement fiber/Canadian Group 4	420.00
AX Grade Asbestos-cement fiber/Canadian Group 5	385.00
AY Grade Asbestos-cement fiber/Canadian Group 5	270.00
AZ Grade Asbestos-cement fiber/Canadian Group 6	200.00
Clinton Mine	
CP Grade Asbestos-cement fiber/Canadian Group 4	456.00
CT Grade Asbestos-cement fiber/Canadian Group 4	412.00
CY Grade Asbestos-cement fiber/Canadian Group 5	270.00
CZ Grade Asbestos-cement fiber/Canadian Group 6	200.00
Vermont (As of Sep. 1, 1974)	F.o.b. Morrisville, Vt, U.S. $
Grades 3T and 3Z – Fiber	504.00– 539.00
Grades 4A thru 4T – Fiber	275.00– 466.00
Grades 5D thru 5R – Fiber	198.00– 233.00
Grade 6D Waste	144.00
Grades 7D thru 7T – Shorts	63.00– 125.00
Grade 7TF – Floats (shorts)	55.00
Grade 8S – Shorts	40.00
Hooker No. 1 – packaged in 50-lb woven poly bags	620.00
Hooker No. 2 – packaged in 100-lb woven poly bags	312.00
Arizona (As of Nov. 1, 1974)	F.o.b. Globe, Ariz., U.S. $
No. 1 Crude—soft	1750.00
No. 2 Crude—soft	1000.00
AAA	1000.00
Group No. 3 Nonferrous Filtering-Plastic	660.00
Group No. 4 Nonferrous Filtering-Plastic	660.00
Group No. 7 White Shorts	120.00

TABLE 16—Annual Exports of Asbestos from Canada by Areas*

	1970	1971	1972
United States, St	614,297	663,478	714,669
Value, $ Canadian	71,969,000	76,812,000	82,663,000
Europe including United Kingdom, St	362,711	375,261	481,352
Value, $ Canadian	61,536,000	61,868,000	82,269,000
South and Central America, St	25,628	22,174	106,290
Value, $ Canadian	5,629,000	4,955,000	19,156,000
Africa and Asia, St	219,480	170,697	237,043
Value, $ Canadian	28,096,000	22,160,000	35,141,000
Others, St	340,316	323,953	59,302
Value, $ Canadian	60,018,000	58,130,000	10,585,000

* Figures from "Statistics Canada."

Group 7 fiber and floats is in the manufacture of joint filler cements and texture paints. Here again, fineness and whiteness are critical properties of the fiber. Also, since the viscosity of the mix after the addition of a prescribed amount of water must be consistent from batch to batch, the absorptive capacity of the asbestos must be controlled within very narrow limits.

Canadian prices remained unchanged in 1972. Price increases by the Quebec asbestos producers for Group 7 were announced for January 1973. Cassiar Asbestos Corp. also announced increases for their grades. Prices for fibers from the major Canadian and American producing areas are listed in Table 15.

Russian fiber prices vary with fiber availability, and only certain grades are offered for sale. The following are the approximate prices quoted in 1972, c.i.f. European ports per metric ton in Canadian dollars:

P-3	$275.00
P-4	220.00
P-5	138.00
M-5	138.00
P-6	105.00
M-6	95.00

Markets

Historically, the consumption of asbestos fiber has been increasing at the rate of 3 to 4% yearly. The U.S. and Western Europe have remained the major outlets for asbestos fiber exports; however, in recent years, Japan and other developing countries have become a major factor in the rate of asbestos fiber consumption.

It is estimated that asbestos fiber consumption in the U.S. alone was approximately 811,000 tons in 1972. The major source of

TABLE 17—Russia: Exports of Asbestos to Countries Importing Over 10,000 Tpy in any One Year, 1968-1970*

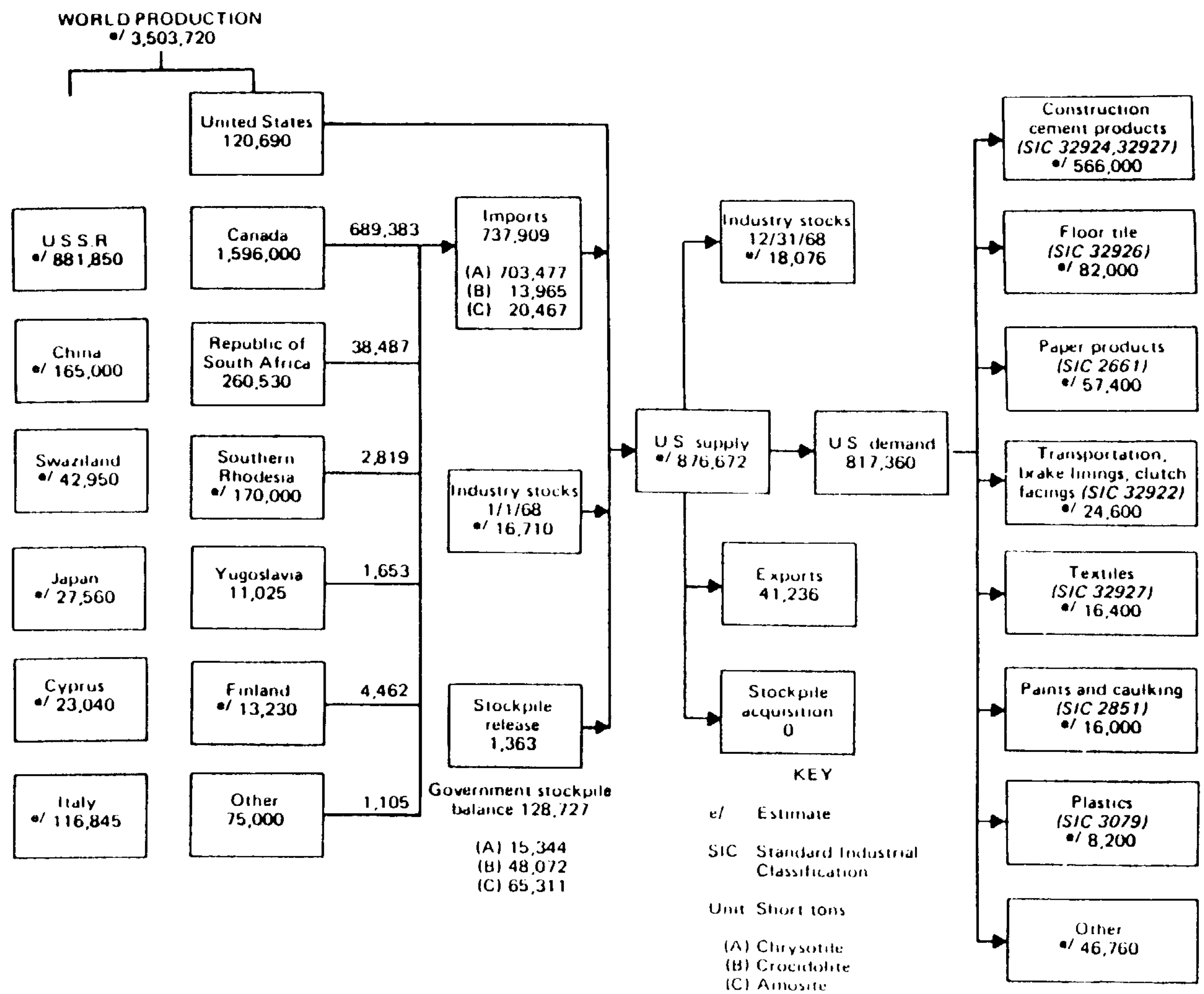
	1968		1969		1970	
	Million Tons	Thousand Roubles	Million Tons	Thousand Roubles	Million Tons	Thousand Roubles
Austria	9,800	1,235	8,500	1,097	11,200	1,411
Belgium	5,600	546	6,300	593	11,100	1,080
Bulgaria	20,600	3,403	24,600	4,237	21,200	3,694
Cuba	9,700	1,374	10,600	1,487	9,500	1,327
Czechoslavakia	19,500	2,853	17,300	2,637	21,000	3,167
France	40,200	3,758	42,400	3,931	53,000	4,865
E. Germany	34,900	4,381	39,600	4,782	43,100	5,155
W. Germany	38,800	3,192	22,900	2,021	9,600	1,011
Hungary	13,800	2,001	14,400	2,027	13,900	1,943
India	1,000	158	18,600	2,658	15,900	2,239
Italy	9,900	1,121	8,800	1,020	11,600	1,212
Poland	25,600	3,352	28,300	3,448	31,500	3,729
Yugoslavia	10,700	1,496	14,800	2,103	20,600	2,935
Other countries	63,500	–	89,400	–	112,100	–
Total	303,600	–	346,500	–	385,300	–

* Figures from Roskill Information Services Ltd.

polyester parts,
air conditioner
and other ap-
itions, freedom
ially important
vel.
ng use for short

an of 2000
b. Mine
n Currency
— 1189.00
— 614 00
— 301.00
186.00
— 152.00
Vancouver, B.C.,
n Currency
1560.00
1240.00
945.00
680.00
485.00
420.00
385.00
270.00
200.00
456.00
412.00
270.00
200.00
orrisville,
U.S. $
– 539.00
– 466.00
– 233.00
144.00
– 125.00
55.00
40.00
620.00
312.00
Globe,
U.S. $
1750.00
1000.00
1000.00
660.00
660.00
120.00

TABLE 18—Supply Demand Relationships for Asbestos, 1968



Source May and Lewis, 1970

supply was Canadian imports which amounted to 719,000 tons or 89% of the total requirements.

On a worldwide basis, estimated consumption is approximately 4 million tons, of which Canada supplies 35% of world requirements. As indicated in Table 16, Western Europe accounts for 30% of total Canadian exports.

The second largest producer is Russia, which exports over 400,000 tpy of asbestos fiber and produces over 2.2 million tons (Table 17).

The major end uses for asbestos fiber continue to be floor tile, asbestos-cement pipe and sheet, brake lining, paper products, and textiles. A breakdown of U.S. 1968 end use consumption shows asbestos-cement products consuming 60% of total fiber, and floor tiles 10% (Table 18).

However, due to the slower increase in consumption for asbestos-cement pipe and shingles, the overall world growth rate will continue to be 2 to 3% yearly.

Health Hazards

In the area of health hazards, the asbestos industry has taken measures to answer statements on the usage and safe application of asbestos by setting up the Asbestos Information Assn. North America, whose basic objectives are to: (1) provide an authoritative channel of communication, (2) rebut irresponsible statements, (3) disseminate information on the uses of asbestos in our modern technological society.

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