Bulletin 552
BUREAU OF MINES

THE ASBESTOS INDUSTRY

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Preface

In 1937 the Bureau of Mines published Bulletin 403, Asbestos, the manuscript of which was compiled by the present author. That report, although containing considerable basic and historic data, is out of date in many respects and has been out of print for several years. As there is wide demand for information on the subject, the need for a revision of the bulletin has become increasingly urgent.

During the years since 1937 several books and numerous articles on asbestos have been written. Some describe deposits scattered in various parts of the world, and others pertain to the technique and equipment of mining and milling, new applications, economic problems, international trade, reserves, and various other aspects of this unique mineral. Accordingly, a vast reservoir of information has become available since the early report was prepared.

A report entitled "Materials Survey—Asbestos," prepared by the author for the National Security Resources Board, was published in 1952. This volume, although paralleling in some respects the present more comprehensive report, was oriented primarily to the strategic grades of asbestos, particularly immediate and future supply.

Supplementing the published information, extensive data have been accumulated by correspondence, by conferring with numerous authorities on production, utilization, and distribution, and by visits to asbestos mines, mills, and undeveloped deposits in the United States and in foreign countries. The writer has drawn freely upon all such accumulated information, as well as upon available literature. He is indebted to numerous individuals for consultation and advice. Valuable comments were supplied from their background of intimate knowledge of the asbestos industry by Herbert Abraham of the Ruberoid Co. and Dudley T. Colton and associates of Johns-Manville International Corp. Special acknowledgment is due to G. W. Josephson, Chief, Construction and Chemical Materials Branch of the Bureau of Mines, for cooperation and assistance on many phases of the subject. The present revision will, it is believed, satisfy a demand for current information on a mineral commodity of unusual interest.

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THE ASBESTOS INDUSTRY [1]

by

Oliver Bowles [2]

Introduction

ASBESTOS is a name applied to a group of naturally fibrous minerals. As indicated in a later section devoted to a detailed discussion of the early history of asbestos, the term may be defined as a fibrous form of serpentine or amphibole. It does not include fibrous forms of other minerals, such as wollastonite, nemalite (fibrous brucite), or the fibrous forms of calcite or gypsum.

A material that has the characteristics of silk or cotton and at the same time will not burn is unique. Because it combines these qualities with other advantageous properties, asbestos has specialized uses for which no substitutes are yet available. Asbestos furnishes a major raw material for a great variety of essential products, and their manufacture constitutes a vast industry. The United States leads all countries in the manufacture of asbestos products. The value of such commodities manufactured in 1952 exceeded $332 million. They are not only of vast importance to building construction and industry but are absolutely essential to certain important fields of use, for example, steam packings and friction materials, such as brake-band linings on automobiles.

UNITED STATES DEPENDENCE UPON FOREIGN SOURCES

This great asbestos-products industry has been built up under conditions of overwhelming dependence upon foreign supplies of raw asbestos. Domestic mines furnish only 6 to 8 percent of the domestic requirements of all grades and not over 1 or 2 percent of the important spinning grades. Canada and Africa are the principal foreign sources. Canada supplies most of the short-fiber demands of the United States and a major part of the longer fibers of textile grade. Africa furnishes a low-iron asbestos essential to important military needs where fireproof electrical insulation is involved and is the only source of an asbestos variety (named amosite) that is of first importance as lightweight insulation on ships and airplanes. Africa is, moreover, the principal source of crocidolite (blue asbestos), which has certain special uses. Bolivia also supplies small amounts and is the only source of crocidolite in the Western Hemisphere. Our striking dependence upon foreign sources of supply makes this report of worldwide scope.

SHORTAGES

Although in the past foreign sources of asbestos have filled United States needs moderately well, the supply has been inadequate at times, notably during World War II and for a few years thereafter. The asbestos-products industries have been expanding to pace the growing industrial activity, therefore the demand for raw asbestos has been increasing steadily. British and continental European needs have also been expanding. Central European asbestos-products industries that stagnated during the war have been revived, and increasing quantities of African and Canadian fibers are being diverted from United States to European markets. Australian demands are also increasing substantially. Asbestos production during recent years has scarcely kept up with these growing needs. This stringency of supply has stimulated an expansion of world production facilities—as indicated in following sections of this report—that tends to bring supply and demand more nearly in balance.

[1] Work on manuscript completed July 1954.
[2] Commodity-industry analyst, Bureau of Mines.

VARIETIES AND COMPOSITION

There are several varieties of asbestos and they differ considerably in composition and physical properties. The most important commercially is chrysotile, which constitutes about 95 percent of the total world production. Its wide use is due to the fact that its fibers are generally strong and flexible and therefore can be applied to many uses, such as textile and steam-packing manufacture, for which weak and brittle fibers are not adapted.

Species of asbestos other than chrysotile fall in the amphibole group of minerals. The principal varieties are anthophyllite, tremolite, actinolite, amosite, and crocidolite. Fibers of anthophyllite, tremolite, and actinolite are generally weak and brittle, and their uses are limited. Sales are small, and very little of the material enters international trade. Amosite and crocidolite are mainly African varieties that are exported to the United States and other countries in considerable quantities for specialized uses. Mountain leather and mountain cork are varieties of amphibole consisting of flexible sheets of interlaced fibers. Mountain wood is a compact, fibrous mass of amphibole resembling dry wood. The last three varieties are mineral curiosities and have no present commercial value.

CHRYSOTILE ASBESTOS

Chrysotile, a fibrous form of the mineral serpentine, is a hydrous magnesium silicate having a composition represented by the chemical formula $3\ MgO.2SiO_2.2H_2O$. Antigorite is a platy form having no present commercial value.

Recent work by Shaw[1] indicates that both OH, the hydroxyl radical or water of constitution, and H_2O, the water of crystallization, are present in chrysotile. To indicate the dual nature of the water content, Shaw writes the chemical formula $(OH)_6Mg_6Si_4O_{11}H_2O$. He claims also that, in fibers from different locations, the proportions of these compounds vary. Thus in Canadian chrysotile a greater part of the hydration is present as water of crystallization, while in Rhodesian chrysotile the hydration is due largely to the presence of the hydroxyl radical. He expresses the view that such a difference in chemical constitution may account in part for the superior electrical resistance of the Rhodesian fiber.

The composition of chrysotile, however, is not rigidly fixed according to either formula given above. Minor quantities of iron, nickel, manganese, or aluminum may replace part of the magnesium. Such small replacements may result in some modifications in the physical properties of the fibers. Furthermore, these properties are influenced to some extent by the presence of impurities; but, in general, chrysotile is more constant and dependable in quality than other varieties of asbestos.

AMPHIBOLE ASBESTOS

The amphibole group of minerals was formerly regarded as consisting of anhydrous silicates of magnesium, calcium, iron, and other elements. When analyses were made, water was always found, but it was regarded as occluded moisture. However, as early as 1916 Schaller,[2] using five exact analyses of tremolite, found, by calculating the molecular ratios, that water was an integral part of the composition, and he derived a formula $2CaO.5MgO.8SiO_2.H_2O$, which is now the recognized composition in contrast with the widely published formula $CaO.3MgO.4SiO_2$. Strange as it may seem, no general recognition was accorded this new concept for many years. When X-ray studies of minerals were begun in the early 1920's, Schaller's findings were confirmed, and it was further learned that all amphiboles contained water of crystallization. It is only in textbooks of mineralogy published since about 1940 that the definite statement appears, "All amphiboles contain hydroxyl." The water content of amphiboles is low—only 1 or 2 percent—whereas chrysotile contains about 14 percent water.

As mentioned previously, the principal varieties of amphibole asbestos are amosite, anthophyllite, tremolite, and crocidolite. Actinolite is of minor importance.

Amosite is not a distinct mineral species. Rabbitt[3] found, by X-ray analysis of two amosite samples from South Africa, that both were monoclinic in crystallization and therefore not anthophyllites. The chemical composition of one indicated that it was probably actinolite, and the other was probably cummingtonite.

Vermaas[4] found by X-ray and differential thermal analysis that amosite is a fibrous modification of the monoclinic amphibole, grunerite, the composition of which is expressed by the formula $(FeMg)_7Si_8O_{22}(OH)_2$ or 7 Fe, MgO, 8 $SiO_2.H_2O$. It is desirable, however, that the name "amosite" be retained, just as the name "crocidolite," as pointed out in a

[1] Shaw, Myril C., The Asbestos Content of Asbestos Textiles: New Jersey Ceramic Research Sta., Rutgers Univ., New Brunswick, N. J., Mar. 27, 1950, 7 pp.

[2] Schaller, W. T., The Chemical Composition of Tremolite: Geol. Survey Bull. 610, Mineralogical Notes, ser. 3, 1916, pp. 133–136.

[3] Rabbitt, John C., A New Study of the Anthophyllite Series: Am. Mineral., vol. 33, May–June 1948, p. 287.

[4] Vermaas, F. H. S., The Amphibole Asbestos of South Africa: Ms. for publication in Trans. Geol. Soc. South Africa in 1953.

later paragraph, is used for the fibrous form of riebeckite.

Amosite may contain as high as 40 percent iron oxide; but, as it is monoclinic in crystallization, it is not a true anthophyllite, although it is commonly classed as a high-iron anthophyllite. Amosite, unlike the true anthophyllites that are almost invariably weak and brittle, consists commonly of long, fairly strong fibers that have certain specialized uses. It is mined only in Africa.

Montasite is a synonym for amosite, but the term is generally restricted to the product of certain mines only.

The composition of anthophyllite is now generally expressed by the formula $Mg_7(Si_4O_{11})_2(OH)_2$, sometimes written $7MgO.8SiO_2.H_2O$. The magnesium may be replaced in part by certain other elements, but complete replacement is not possible because the anthophyllites have only limited isomorphism. Ferrous iron may replace magnesium to a maximum of 26.53 percent, but such an anthophyllite would still contain as much as 11.48 percent MgO. When the ferrous iron content exceeds 26.53 percent, the mineral ceases to be anthophyllite, as it becomes monoclinic in crystallization while all anthophyllites are orthorhombic.

The MgO content of anthophyllite is said to range from 5 to 50 percent. A series of 46 chemical analyses of anthophyllites assembled by Rabbitt [5] shows a maximum of 31.53 percent and a minimum of 11.48 percent. The one with the maximum MgO content contained 5.6 percent FeO. The CaO content of anthophyllites averages about 0.5 percent and rarely exceeds 2 percent.

Aluminum is more important in anthophyllites than is generally supposed. Of Rabbitt's 46 tabulated analyses, 14 show over 10 percent Al_2O_3, and 20 show over 5 percent. The aluminum may replace magnesium or silicon.

As mentioned previously, the composition of tremolite is expressed by the formula $Ca_2Mg_5(Si_4O_{11})_2(OH)_2$ or sometimes is written $2CaO.5MgO.8SiO_2.H_2O$. The calcium may be replaced in small part by sodium. The magnesium is replaceable by iron in considerable quantities and by aluminum to a smaller degree. Also, a small part of the silicon may be replaced by aluminum. Tremolite generally consists of gray to white silky fibers, which are, for the most part, weak and brittle, although fibers of considerable strength and flexibility are found at times. Both tremolite and anthophyllite are superior to chrysotile in resistance to chemical reaction.

[5] Rabbitt, John C., work cited in footnote 5, p. 271.

Actinolite differs from tremolite in that a considerable part of the magnesium is replaced by iron. The fibers are commonly green or greenish gray and quite weak and brittle.

Crocidolite or blue asbestos belongs to the hornblende group of amphiboles. Its simplest chemical formula is $3Na_2O.6FeO.2Fe_2O_3.16SiO_2.H_2O$. Considerable variation in composition has been noted. Sodium may be replaced by potash, ferric and ferrous iron by magnesium or manganese, and ferrous iron by aluminum. Mineralogists now regard crocidolite as identical with riebeckite, being merely a fibrous form of that mineral. Crocidolite, therefore, bears the same relation to riebeckite that chrysotile bears to massive serpentine and amosite to grunerite. Blue asbestos is produced chiefly in South Africa, but several commercial deposits occur in Australia, and a small output is obtained in Bolivia. Except for those in Bolivia, no commercial deposits of blue asbestos are known in the Western Hemisphere. In Bolivian blue a large part of the iron is replaced by magnesium. The magnesium content of African blue asbestos is somewhat lower.

ERRATIC CHARACTER OF AMPHIBOLE FIBERS

It may be observed from the foregoing discussion that the replacement of one element by another in varying proportions is a prevalent characteristic of the several varieties of amphibole asbestos. This variation in composition results in corresponding changes in their physical properties. These properties may also be influenced by the presence of impurities. The somewhat erratic and unpredictable physical characteristics of the amphibole fibers have a profound influence on their use. An anthophyllite from one locality may give satisfactory service for some specific use while one from another deposit, although appearing to be exactly the same, may be unsatisfactory. Thus problems in amphibole-asbestos procurement are much more difficult and complex than the procurement of mineral products like iron and copper which, when pure, have constant properties, no matter where they originate.

ORIGIN

Asbestos originates for the most part from rocks consisting largely of olivine, such as peridotite or dunite, or from pyroxenite. Most chrysotile deposits result from alteration of olivine to serpentine, and subsequent prismatic crystallization provides the fibrous structure. Contact as well as regional metamorphism evidently plays an important part in the process, because in various regions, notably the Quebec, Arizona, and Rhodesian fields, intrusive rocks are associated with the deposits and doubtless definitely influenced their development. However, no closely associated intrusives appear to be present at the McDame Mountain deposit, northern British Columbia, the Munro deposit, Ontario, or some of the African deposits. Prismatic crystallization occurs in fractures. More detailed discussions of origin will be found in later sections describing asbestos deposits by State and country.

Chrysotile occurs in two forms—cross fiber and slip fiber. The former is the characteristic occurrence in all fissure-filled veins, the fibers crossing the veins approximately at right angles to the walls. In some veins the fibers cross from wall to wall, hence the fiber length is governed by the width of the vein. In others the fibers may be broken into two or more lengths by partings that parallel the vein walls. Slip fiber, on the other hand, parallels the vein wall and usually shows the effects of pressure and movement along a fault plane. Figure 1 shows typical cross-fiber veins of Canadian asbestos.

The chrysotile occurring in sedimentary rocks in Arizona, the Carolina district of the Transvaal, and several other localities originated differently. The fiber in these localities was formed by mineralizing solutions derived from intrusive diabase and injected into limestones. It occurs in cross-fiber veins.

Under some conditions peridotites and pyroxenites are altered to fibrous amphiboles, of which the most common is anthophyllite. In some places it occurs as slip fiber in shear zones, but more commonly the altered rock takes the form of pockets or lenses consisting almost entirely of irregularly arranged bundles of fiber. The rock is called amphibolite, and the asbestos is of the mass-fiber type. In the irregular belt of olivine- and pyroxene-bearing rocks that extends from the Gaspé Peninsula in Canada to southern Georgia, the alteration was principally into massive serpentine and chrysotile in the northern part, that is, in the area lying in Quebec, Canada, and in Vermont; but in its southern extension only sporadic occurrences of chrysotile are found because the alteration was more generally to anthophyllite and talc.

The softest and most easily fiberized anthophyllite occurs generally near the surface of the deposits; with increasing depth, the fiber becomes harsher, more brittle, and less easily

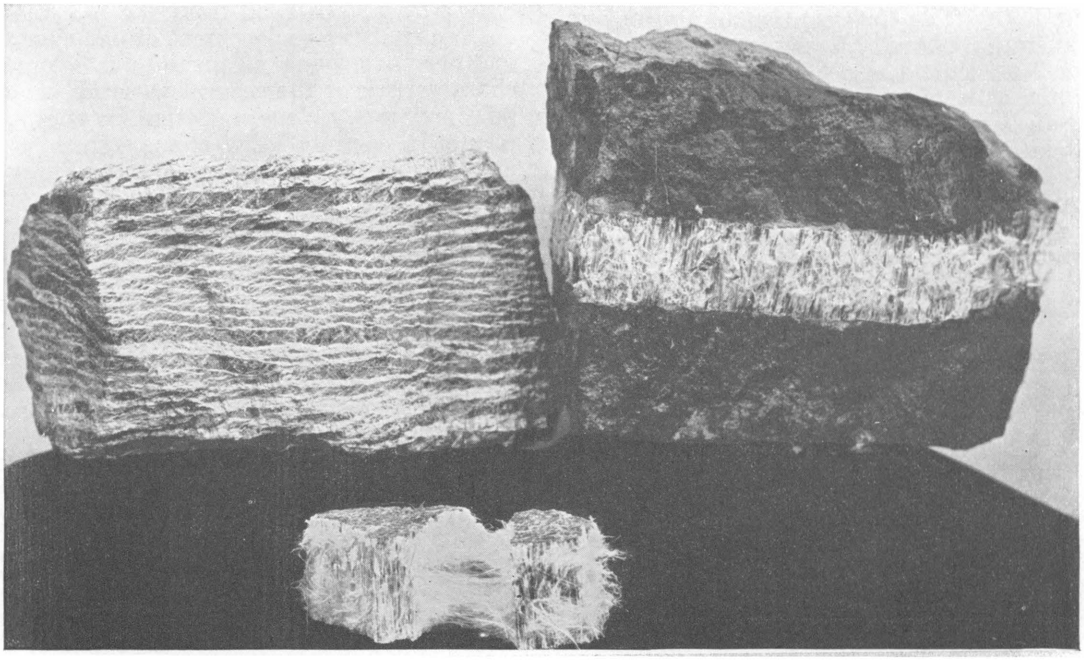

FIGURE 1.—Cross-Fiber Veins of Canadian Chrysotile Asbestos.

worked into a fluffy mass. The development of the best fiber therefore appears to depend upon the action of weathering agencies. Consequently, deposits of soft, easily worked anthophyllite tend to take the form of pockets or lenses of limited depth, and if workings are to be confined to fiber of this character the limitation of reserves must be considered with care. If, however, the harsher, more solid asbestos masses can be fiberized successfully into marketable products, the reserves may be much more extensive. Most of the deposits that have been developed show little promise of large reserves.

The crocidolite and amosite of South Africa originated from rocks quite distinct from peridotite or pyroxenite. They were derived from sediments rich in iron and silica, known as banded ironstones. Prismatic crystallization occurs in cross-fiber veins.

MODE OF OCCURRENCE

From the discussion of origin, it is evident that there are three types of asbestos deposits—cross fiber, slip fiber, and mass fiber. Cross-fiber asbestos consists of innumerable strands extending across veins from wall to wall, except where interrupted by longitudinal seams. Most commercial deposits of chrysotile, amosite, and crocidolite are of this type, but anthophyllite rarely, if ever, occurs in cross-fiber veins. In slip-fiber deposits the strands more or less parallel the vein walls. They frequently show slickensided surfaces because they occupy shear zones where the rock has been subjected to movement and pressure. Slip fiber is common in the chrysotile deposits near Eden, Vt., and predominates in the anthophyllite deposits near Bedford and Rocky Mount, Va.

In mass-fiber deposits there is no definite orientation of fibers. Almost the entire mass of the rock is composed of bundles of fibers or needles that sometimes show a radiating structure. This type of occurrence is confined almost exclusively to the anthophyllite variety and is well exemplified by deposits at Hollywood and Buck Mountain, Ga., and Kamiah, Idaho.

PHYSICAL PROPERTIES

FIBROUS CHARACTER

The outstanding physical characteristic of asbestos is its fibrous structure. Other important fibers found in nature are those of animal origin, such as wool and silk, and those of vegetable origin, examples of which are cotton and flax. Nonflammability is one of the striking differences between asbestos and the fibrous products of animal or vegetable origin. Of perhaps equal importance is the difference in structure. Each filament of cotton, wool, or silk is of measurable and fairly constant diameter and is indivisible into finer sizes. On the other hand, fibers of chrysotile asbestos can be divided and subdivided until a fineness is attained that is limited only by the delicacy of the machinery used and the skill of manipulation. The ultimate fiber size is presumably the size of the ultimate molecule or crystal lattice of asbestos. In other words, fiberization is a cleavage process, and cleavage in minerals is defined as a tendency to split in a certain direction, that is, to separate along and between layers of molecules.

From the standpoint of use, fiber size (diameter) is important, and the diameter will depend upon the degree of fiberization attained in the milling process. Fibers obtained from different deposits vary in the ease with which they may be fiberized. Thus, two samples of chrysotile asbestos, given exactly the same mill treatment, may furnish products differing considerably in fiber diameter, because one of them separates or fiberizes more easily than the other. Such differences may have great practical importance, because an asbestos having difficult cleavage may require such intense milling to reduce the fibers to desirable fineness that they may be broken into undesirable short lengths. Ease or difficulty of fiberization is therefore an important property of asbestos.

Experiments by Raybestos-Manhattan, Inc., in 1952 on samples of Rhodesian chrysotile, one dark with a total iron content of 2.486 percent and one a light type with 1.919 total iron, disclosed that the darker material requires much more time and energy to fiberize than the lower iron type.

The uses to which a chrysotile asbestos may be applied are governed primarily by length of fiber. The longest fibers command the highest prices, and prices are progressively lower for the shorter grades. It is apparent, therefore, that primary attention must be given to milling processes that will separate the fibers from the parent rock and will fiberize them adequately with a minimum of fiber breakage.

COLOR AND LUSTER

Chrysotile occurs in various shades of green or yellowish green. When fiberized into a fluffy mass, all types of chrysotile are virtually white, unless stained by impurities. Amosite ranges from gray or yellowish gray to white and, if relatively pure, is white when fiberized. Crocidolite is lavender blue, and this color is maintained when the fibers are separated. Anthophyllite and tremolite are gray, greenish gray, or white, and the separated fibers are white unless staining impurities are present. The luster of asbestos usually is silky or pearly.

HEAT RESISTANCE

The heat resistance of asbestos is important in many applications. Some users of asbestos tend to confuse nonflammability with refractoriness. Many substances that will not burn will, nevertheless, melt or decompose at relatively low temperatures. The fireproof property of asbestos is one of its chief assets; but, although unburnable, it will decompose and lose its essential physical properties at moderately high temperatures. The concept of asbestos as a highly refractory substance has been created in the minds of some students of the subject by reading the statement made by Cirkel[1] that temperatures of 2,000° to 3,000° F. are easily withstood, while with some varieties a temperature of 5,000° F. has apparently produced no visible effects. With due respect to Dr. Cirkel, who wrote a splendid pioneer volume on a mineral of which little was known at that time, he was in error regarding the heat resistance of chrysotile.

Brandenberger and others[2] who have made a comprehensive study of temperature effects of chrysotile at the Mineralogical Institute of the University of Zurich, state that the so-called adsorbed water of chrysotile is driven off at about 300° C. Between 550° and 600° C. all of the water of crystallization is driven off, and the mineral gradually alters to olivine. A pronounced change in physical properties accompanies this dehydration. At 400° C. there is a notable deterioration in fiber quality; and above 550° C., with more or less complete dehydration, chrysotile is completely decomposed. The amphibole varieties of asbestos will withstand somewhat higher temperatures than chrysotile; however, crocidolite, although having a low water content, is easily fused into a black, magnetic mass.

HEAT CONDUCTIVITY

Asbestos does not have low heat conductivity. Its value for heat insulation is due to its nonflammability and also to its fibrous structure, which adapt it for manufacture into coverings that are nonconductors of heat because of their porous nature.

CHEMICAL RESISTANCE

Tremolite and anthophyllite are highly resistant to chemicals. It is claimed that crocidolite resists chemicals and sea water remarkably well. Chrysotile is affected more readily by acids and other chemicals than are the amphibole varieties.

ELECTRICAL RESISTANCE

Varieties of chrysotile lowest in iron content are most suitable for electrical insulation. Arizona chrysotile is superior for this use. Apparently the iron content of amphibole does not affect its use for this purpose because crocidolite, which upon analysis shows a content of about 35 percent FeO, has high electrical resistance. This seeming contradiction may be explained by the fact that iron is present in crocidolite as a silicate, whereas in chrysotile it commonly appears as iron oxide impurities.

SPECIFIC GRAVITY

The specific gravity of pure chrysotile is 2.22, but that of the commercial fiber is always higher because of the presence of impurities. The specific gravity of Canadian chrysotile ranges from 2.54 to 2.59; and the Arizona fiber, being lower in iron, has a specific gravity of 2.47. Tests recently made by the Bureau of Mines at Tucson, Ariz., on fiber selected with great care to eliminate impurities gave somewhat lower figures—a 2.38 average for Arizona chrysotile and 2.48 for one sample from Quebec, Canada. The specific gravity of anthophyllite ranges from 3.1 to 3.2, and that of crocidolite is still heavier, ranging from 3.2 to 3.3.

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[1] Cirkel, Fritz, Chrysotile Asbestos, Its Occurrence, Exploitation, Milling, and Uses: Canada Dept. Mines, Mines Branch, 2d ed., 1910, p. 30.

[2] Brandenberger, E., Epprecht, W., and Niggli, F., [The Serpentine Minerals and Their Synthesis II]: Helv. chim. acta, vol. 30, 1947, pp. 9-14 (trans. by Frank Riordan, Jr.).

CHEMICAL COMPOSITION

The chemical formulas for the various kinds of asbestos are given in a previous section on varieties. The actual composition cannot be calculated from these formulas because of varying isomorphous replacements of some of the elements and also because of the presence of impurities. Table 1 shows analyses of representative commercial fibers. A wide variation is to be noted, even in the same varieties, but the chrysotiles are in general more consistent in composition than the amphiboles. Iron may be present in the amphibole varieties, except tremolite, combined chemically as an essential constituent of the mineral. Iron may be present in any variety as an impurity, chiefly in the form of an oxide that is detrimental for some electrical uses. The iron impurity in Arizona fiber is considerably lower than that of Canadian, African, or Russian chrysotile.

TABLE 1.—*Analyses of representative asbestos samples, percent*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	H_2O	Total
Chrysotile:									
Canada:									
Bell mine [1]	40.36	0.21	1.35	0.66	43.86	----	----	13.45	99.89
King mine [2]	42.05	----	.96	.39	43.30	0.05	----	12.52	[3] 100.02
United States: Arizona [4]	41.56	1.27	----	.64	42.05	----	----	14.31	99.83
Union of South Africa: Baberton [5]	40.05	1.90	1.60	.40	38.35	.15	[6] 0.40	16.60	99.70
Southern Rhodesia: Shabani [7]	40.96	1.70	----	2.44	38.73	----	[6] .10	16.07	100.00
Russia [8]	39.28	1.75	.40	5.37	40.05	1.74	----	11.52	100.11
Anthophyllite:									
United States:									
Georgia [9]	56.40	1.15	----	11.40	28.68	.50	----	1.63	99.76
Montana [10]	42.80	17.78	1.03	18.32	15.54	----	[6] 1.55	1.94	[11] 99.90
Crocidolite:									
Union of South Africa: Cape Colony [12]	51.10	----	----	35.80	2.30	----	6.90	3.90	100.00
Bolivia [13]	54.68	3.90	13.98	7.40	12.25	1.27	[6] 6.01	.72	[14] 100.42
Amosite: Union of South Africa: Penge [15]	49.72	5.72	----	37.00	3.77	1.65	----	2.29	100.15
Tremolite:									
Union of South Africa: Natal [16]	58.80	[17] 5.32	----	----	22.75	10.65	----	.50	98.02
United States:									
Alaska [18]	58.59	.10	----	----	24.78	13.95	[6] .22	2.31	99.95
New York [18]	58.24	.60	.43	----	25.16	10.85	[6] 1.01	2.50	[19] 100.35

[1] Ross, J. G., Chrysotile Asbestos in Canada: Canada Dept. Mines, Mines Branch, No. 707, 1931, p. 20.
[2] Cooke, H. C., Thetford, Disraeli, and Eastern Half of Warwick Map Areas: Quebec, Canada, Dept of Mines and Resources, Geol. Survey, Mem. 211, 1937, p. 101.
[3] Includes 0.75 percent uncombined water.
[4] Diller, J. S., Mineral Resources of the United States: 1919, pt. 2, p. 302.
[5] Hall, A. L., Asbestos in the Union of South Africa. Union of South Africa Geol. Survey, Mem. 12, 1918, p. 31.
[6] Includes K_2O.
[7] Hall, A. L., work cited in footnote 5, p. 31.
[8] Rukeyser, Walter A., Chrysotile Asbestos in the Bajenova District, U. S. S. R.: Eng. and Min. Jour., vol, 134, No. 8, August 1933, p. 338.
[9] Hopkins, O. B., Asbestos, Talc, and Soapstone Deposits of Georgia: Geol. Survey of Georgia, Bull. 29, 1914, p. 79.
[10] Rabbitt, John C., A New Study of the Anthophyllite Series: Am. Mineral., vol. 33, May-June 1948, p. 270.
[11] Includes 0.94 percent TiO_2, MnO, and F.
[12] Hall, A. L., work cited in footnote 5, p. 35.
[13] Gumucio, Julio F., Memorandum sobre los yacimientos de asbesto del Chapare: Mineria Boloviana, vol. 6, No. 44, May-June 1949, p. 8.
[14] Includes 0.21 percent MnO.
[15] Hall, A. L., work cited in footnote 5, p. 41.
[16] Hall, A. L., work cited in footnote 5, p. 42.
[17] Includes Fe_2O_3.
[18] Schaller, W. T., The Chemical Composition of Tremolite: Geol. Survey Bull. 610, Mineralogical Notes, ser. 3, 1916, p. 134.
[19] Includes 0.04 percent TiO_2, 1.28 percent MnO, and 0.24 percent F.

HISTORY[1]

EARLY RECORDS

The peculiar property of incombustibility combined with a fibrous structure attracted attention to asbestos over 2,000 years ago. Small amounts were used by the Romans for winding sheets to preserve the ashes of the dead when bodies were cremated, but the "immortal linen" was so difficult to weave that only the most distinguished patricians and kings were honored with asbestos shrouds. A specimen of cremation cloth containing ashes was found in 1702 in a Roman sarcophagus and was deposited in the library of the Vatican. According to tradition, the ancient Chinese and Egyptians wove asbestos into mats. In ancient temples asbestos was used for lampwicks and to protect altar fires.

The word "asbestos," evidently first applied by Pliny to the fibrous mineral now known by that name, was employed erroneously, for in both ancient and modern Greek it refers to quicklime. The Greek word "asbestos" means "inextinguishable" or "unquenchable"—words conveying quite the opposite meaning from "incombustible," a characteristic feature of asbestos. Possibly Pliny had in mind Plutarch's

[1] Some of the historical data on this and following pages were obtained from a series of articles on the history of the asbestos-manufacturing industry that appeared in the August, October, and November 1935 and January, May, and August 1936 issues of Asbestos magazine.

reference to the "perpetual" asbestos lampwicks used by the Vestal Virgins. "Lithos amiantos," the original term used by the Greeks for asbestos, meant a rock unstained, untainted, or undefiled and doubtless referred to the cleansing of asbestos cloth by throwing it into the fire.

Another common name applied to asbestos was "Karystios lithos," because a well-known source of flexible mineral fiber was near Karystos, southern Euboea, Greece. Early in the first century Strabo referred to stone from this locality that was carded and woven into handkerchiefs. Solinus and Plutarch also mention a fibrous mineral from this place. These ancient writers evidently knew little of the deposits, but as two exposures of serpentine occur east of Karystos the fiber probably was chrysotile.[2]

Pausanius, who lived in the second century A. D., refers to incombustible "Karpasian flax." Some writers think this term indicates that the source of the fiber was Karpasos, northeastern Cyprus, but no asbestos-bearing rock is known in that vicinity. The reference may have been to the island of Carpathos, the modern Scarpanto of the Dodeconese Islands. Evans points out that the word "Karpasos" means "cotton" and that probably it was applied to the mineral because of its adaptability to textile use.[3] Cyprus, however, was a well-known source of supply of asbestos in ancient times. Although it is difficult to determine, from early references, the exact location of the deposit, probably it was southeast of Mount Troodos in a village known as Amianto, the identity of which is lost. During recent years chrysotile asbestos has been produced in considerable quantities near a town now known as Amiandos. This is probably the site of ancient Amianto, for it is situated near Mount Troodos, 18 miles from the seaport Limasol. William Lithgow, a Scotsman, writing about the minerals of Cyprus early in the 17th century, referred to "the admirable stone Amiante, whereof they make Linnen cloth that will not burn, being cast into the fire, but serveth to make it neat and white."

The asbestos used by the Romans doubtless was a long-fibered variety identified as tremolite and occurring in northern Italy. The use of Italian fiber presumably led to the claim widely made in literature (see definition of asbestos, Webster's New International Dictionary) that the original "amiantos" consisted of fibrous amphibole (tremolite, actinolite, or hornblende). A letter to the author from the chief mineral inspector in Rome, however, casts some doubt as to whether all Italian fiber used by the ancients was tremolite. A significant excerpt from this communication reads as follows:

> For a long time it was believed that the Italian "amianti" were all the tremolite type because the first examinations of the material were based on samples of tremolite. It was only in recent years that, after further studies, the producers recognized that their products were for the most part chrysotile with a long, flexible fiber.

A tremolite asbestos glove examined by the writer in the Museum of Natural History, London, England, in 1935, did not appear to consist of strong fiber. A piece of so-called "asbestos" cloth of unknown origin in this museum is not a fabric; it is a felted sheet that may be a natural mountain leather.

Very little mention of asbestos was made throughout the Middle Ages. According to report, Charlemagne, who reigned from 768 to 814, had an asbestos tablecloth, which he would throw into the fire for cleansing. To mystify his guests was apparently the only reason for its use.

Marco Polo refers to "amiantos" cloth shown to him during his travels through Siberia in 1250. He was told by the superstitious people of that region that it was made of the skin of salamanders, but he was too scientifically minded to accept such statements. After much questioning and search, he learned how the fibers were obtained and prepared. His description of the process of preparation, which consisted of pounding in a mortar to eliminate impurities, suggests that the fiber was chrysotile, and this conclusion is substantiated by the fact that the best known asbestos of Siberia is chrysotile occurring at Minuisinck near the Mongolian border.

Further evidence that the term "amiantos," as used by the ancients, may have applied to chrysotile as well as to amphibole is found in the uses of the material. With the exception of twisted fiber used for lampwicks, virtually all the early references are to textile use. Asbestos was woven into handkerchiefs, tablecloths, winding sheets, and similar fabrics. Most varieties of amphibole asbestos are weak and brittle and cannot be spun or woven. The principal exceptions, aside from the tremolite of Italy, are the crocidolite and amosite of South Africa—varieties unknown until comparatively recent years. Chrysotile, on the other hand, is strong, flexible, silky, and well adapted for textiles. Judging from the probable sources of supply, it seems reasonable to conclude that it was employed in ancient times in the manufacture of incombustible fabrics.

"Asbestos" may therefore be defined as a fibrous form of serpentine or amphibole. It does not include fibrous forms of other minerals.

[2] Evans, John W., The Identity of the Amiantos or Karystian Stone of the Ancients With Chrysotile: Mineral Mag. (London), vol. 14, May 1906, pp. 143–48.
[3] Evans, John W., work cited in footnote 11, p. 143.

The next important reference to asbestos was in 1676, when, at a meeting of the Royal Society, a Chinese merchant exhibited a handkerchief of "salamander's wool" or "linum asbesti." An asbestos napkin belonging to Ferdinand III was exhibited in Vienna in 1679.

Asbestos was discovered in the Ural Mountains of Russia between 1710 and 1720, and the first factory for making asbestos products was operated during the reign of Peter the Great. Textiles, socks, gloves, and handbags were made there for 50 or 60 years, but the enterprise failed through lack of demand and poor transportation facilities.

COMMERCIAL PRODUCTION

The utilization of asbestos on a commercial scale originated in Italy. About 1808 a noblewoman of Valtellina sponsored studies and experiments that brought her many honors and led to the manufacture of asbestos thread, fabrics, and paper of high quality. Several companies were formed between 1860 and 1875. No serious problems were involved in the manufacture of rope packings and heat-insulating board, but much difficulty was encountered in devising suitable machinery for fabricating spun products. Exhibits at the Universal Exposition in Paris in 1878 gave wider publicity to the products then manufactured.

In 1860 asbestos was discovered near St. Joseph, Quebec, Canada, and a specimen of fine, silky fiber from this region was exhibited in London in 1862. The deposits were few and small, and attempts to work them profitably failed. A new era in the asbestos industry began with the discovery, in 1877, of the deposits near Danville, Quebec. Mining was begun in 1878, and 50 tons was produced in that year. The fiber could be worked more easily than Italian asbestos; and its popularity in London, together with the easy availability of a growing market in the United States, led to rapid development near Danville and Thetford Mines. Seven quarries, with an aggregate production of 1,400 tons a year, were reported in 1885. The highest grade fiber sold for only $80 a ton in that year, but by 1900 the price had advanced to $300 a ton. Thereafter, owing to depressed prices and to wasteful and costly hand methods of mining and preparation, the industry languished for several years. Prosperity returned when mechanical methods of fiber recovery were introduced.

An occurrence of blue asbestos on the Orange River of South Africa was discovered in 1815. The name "crocidolite," meaning a stone with a woolly appearance, was proposed by Hausmann in 1831. No development took place, however, until the interest shown by Francis Oats led to the establishment of the Cape Asbestos Co., Ltd., in 1893.

Amosite was discovered in central Transvaal about 1907. The name "amosite," given to the fiber in 1918, was taken from the initial letters of the Asbestos Mines of South Africa, the company chiefly interested in its production. Commercial production was begun about 1916.

Interest in Rhodesian chrysotile was first centered in the Mashaba deposits about 1907. Ground was pegged by a prospector named Gath, and a large mine in the district still bears his name.

Chrysotile was discovered in the Shabani area of Rhodesia about 1906, but no interest was shown in it until 1915. Since that date the growth of the industry has been phenomenal.

ASBESTOS-PRODUCT MANUFACTURE

The spinning and weaving of asbestos for textile manufacture were begun in America over 65 years ago. The early products were chiefly fireproof garments, such as coats, shoes, gloves, and helmets. Disastrous theater fires led to the use of asbestos curtains, but it was not until the advent of the automobile that asbestos fabrics were produced in quantity. Asbestos brake linings for automobiles were made in England in 1896, but 1906 seems to be the earliest date that asbestos was used for this purpose in the United States. A severe test of an asbestos brake band and one made of leather was conducted in 1907. The leather was burned to charcoal, whereas the asbestos was unaffected. Thereafter, woven asbestos brake linings were used almost universally until 1924. The advent about that year of the four-wheel internal brake led to the development of molded brake linings, which were found to be more suitable than woven linings for internal brakes. Molded linings have now become more important than the woven kinds except for heavy-duty industrial uses.

The first asbestos packing employed industrially for steam glands was made in 1871.[4] It consisted of carded Italian fiber enclosed in an outer covering of cotton, but unfortunately gritty grains in the fiber worked through the cotton and scored the piston rods and valve spindles. The next step was to free the asbestos of all gritty impurities.

Another packing made about the same time consisted of cotton wicking saturated with lard oil and coated with powdered anthophyllite, then known as "southern" asbestos. Although scarcely falling within the category of asbestos packings, it at least helped to emphasize the value of asbestos for such use.

Soon thereafter packings of much better quality were made by using asbestos rope covered with a cotton "sock." Between 1877

[4] Asbestos, The History of the Asbestos-Manufacturing Industry: Vol. 17, No. 5, November 1935, pp. 2–6.

and 1880, when high-grade spinning asbestos became available from Canada, the cotton covering was replaced by one of asbestos cloth. With the addition of rubber cores to give strength and resilience, these packings began to assume a modern form. With the advent of high pressures and temperatures, the requirements as to quality, shape, and size became more exacting, and today the manufacture of packings is a highly specialized and complicated process.

Asbestos paper was known as early as 1700, when a certain Prof. Bruckmann used it for his writings, but the objective of obtaining an imperishable document was defeated because, although the paper would withstand the fire, the printing would not. The same result is recorded by Pontoppidian, Bishop of Bergen, in his Natural History of Norway, published in 1750. About the middle of the last century asbestos boards were used for book covers in Italy, and soon thereafter a vain effort was made to induce the Italian Government to manufacture asbestos banknotes. Other early uses of asbestos paper were for ornamental wallpaper and carpet linings.

Asbestos paper is now a very important product, but its present uses as a fireproofing and heat-insulating material were not contemplated by the pioneer investigators or manufacturers. It was first made in America at Waltham, Mass., about 1878. Italian fiber was used until 1879, when the shorter grades of Canadian asbestos were tried and found to be satisfactory. Its principal use at that time was to protect hair-felt insulation from the heat of steam pipes. The value of asbestos paper for heat insulation was speedily recognized, and the industry grew rapidly. At present a number of large factories make, in all, more asbestos paper in a day than was made in an entire year 40 years ago.

An important development of recent years is the manufacture of preshrunk paper. It does not absorb moisture and, therefore, when used as a pipe covering does not shrink under the influence of heat. Thus, gaps in the covering through which heat might escape do not appear. Special papers designed for electric insulation where high temperatures are encountered are now made by the Johns-Manville Co. at Tilton, N. H. Further details on this product are given in a later section devoted to the beneficiation of asbestos.

The heavier and thicker product, known as millboard, was also made in the early days of paper manufacture.

Heat insulators constitute an important branch of the asbestos-products industries. Asbestos, in the form of a mixture of fiber and silicate of soda, was first used for heat insulation in 1866. Asbestos insulation containing 15 percent fiber was tried first as a boiler covering about 1870. Canvas-covered sectional magnesia pipe covering appeared in 1885. Shredded rope and silk noils were first used as binders, and just when the change was made to asbestos fiber is not known. Modern sectional pipe coverings have painted or lacquered surfaces instead of canvas, which improves the appearance and gives better insulation. The first air-cell covering was produced in Brooklyn in 1898.

The manufacture of asbestos-cement products is comparatively recent. Asbestos-cement roofing was first made in Austria about 1896 by the "wet" process, known as the Hatschek process after Ludwig Hatschek, its inventor. A pressure-filtration or "dry" process was developed by C. L. Norton at Nashua, N. H., about 1905. He first produced 36- by 48-inch sheets several inches thick. Much larger sheets were made later. In 1908 a second process was developed for making thin sheets suitable for roofing shingles. However, asbestos-cement shingles were first introduced in the United States by Dr. R. V. Mattison at Ambler, Pa., in 1903. Within recent years the coloring of shingles has attained higher refinement, and asbestos-cement siding shingles have been developed. Flat sheeting for siding and roofs came into use shortly after 1903, and corrugated sheeting was first made in 1905. Production of this great group of building materials has attained large proportions during the past 30 to 35 years.

Asbestos-cement pipes were first manufactured at Genoa, Italy, in 1913 by the Mazza process. Their manufacture began in America in 1929, and the first shipment was made in 1930.

USES

The uses of asbestos are so numerous and important that one could write a book on that subject alone. On the basis of use, asbestos falls into two principal classes—spinning and nonspinning fiber. Spinning fiber comprises the longer grades of chrysotile and crocidolite. Nonspinning fiber comprises the shorter grades of these varieties and both the long and short grades of amosite, anthophyllite, and related amphibole varieties.

SPINNING FIBERS

Spinning asbestos is used for weaving into textiles, but under the general classification of textile uses are included prepared yarns, listing, tape, rope, cord, wick, and thread. The longer fibers, such as Canadian Groups 1, 2, and 3; Arizona No. 1 and 2 soft types; Rhodesian C & G1, C & G2, and to some extent C & G3, and VRA2; Swaziland HVL1 and HVL2; the longer African and Australian blue fibers; and Russian C–1, C–2, and I–2 are adaptable for making textile products, such as cloth, yarn, tape, rovings, etc. The asbestos is spun and woven in much the same way as cotton, silk, or wool.

An outstanding characteristic of asbestos fabrics is their fireproof quality. They also have superior heat-insulating properties but lower tensile strength than products made from other fibers. The low tensile strength is not due to lack of strength of the individual fibers, which in many instances are as strong as or stronger than silk; it is due to their shortness, because fiber lengths range generally from ¼ to ¾ inch. Because of the shortness and smoothness of the fibers, it is difficult to make a 100-percent asbestos cloth; and only small quantities, applied to specialized uses, as in electrolytic cells, are now manufactured.

To give adequate strength to asbestos fabrics cotton, rayon, or other organic fibers are blended with the asbestos in varying proportions. As the organic fiber content is increased, the strength increases, but the resistance to heat decreases. Accordingly, the proportion of organic fiber is adjusted to suit the conditions of end use. The higher the asbestos content the more difficult are the manufacturing processes, but these difficulties may be overcome to some extent by making a heavier cloth. Table 2 presents the standard code under which asbestos fabrics are classified and the heat resistance of each grade.[1]

A very important use of asbestos fabrics is for the manufacture of friction materials.

TABLE 2.—*Asbestos content and heat resistance of asbestos fabrics*

Grade	Asbestos content, percent	Maximum temperature for end use, °F.
Commercial	75 to, but not including 80	350 to 400
Underwriters'	80 to, but not including 85	400 to 450
A	85 to, but not including 90	450 to 550
AA	90 to, but not including 95	550 to 600
AAA	95 to, but not including 99	600 to 750
AAAA	99 to and including 100	750 to 900

Such materials are brought into contact with moving members (brakedrum, flywheel, or other rotating equipment) in such a manner as to retard the free motion of the rotating part. The effect of the friction is to convert the kinetic energy of the moving member into heat. The best braking materials are those that convert the kinetic energy into heat the most rapidly and dissipate the heat as quickly as possible. The friction material must also be heat resistant and nonflammable. Asbestos is regarded as indispensable in most types of friction materials.

Brake linings are of three principal types. In early days virtually all brake bands were of woven-asbestos fabrics, but at the close of World War I the molded type was invented and is now used extensively. Molded linings are of several types, but all consist primarily of asbestos fibers bonded with an organic matrix. Metallic reinforcing, such as brass, zinc, or lead, is commonly added, and the shaped products are thoroughly cured. The asbestos required is chrysotile, ranging in length from fibers just under spinning grades to those as short as 7–F in the Canadian classification. A preponderance of the shorter fibers is used because of the price advantage.

A second type of friction materials is rubberized fabric lining. It consists of multilayer woven structures held together with wire-inserted asbestos yarn. The asbestos used is of spinning grades.

The third type is woven brake lining. It is made in roll form in a variety of widths and thicknesses. It permits a wide range of service with a relatively small inventory. Its general utility popularizes it, particularly in industrial applications. As such linings are woven fabrics, chrysotile of spinning grades is required. The largest use of asbestos textiles is for the manufacture of automobile brake linings and clutch facings. As much as 70,000,000 linear feet of brake-band lining has been made in a single year in the United States, but this figure has been considerably reduced during recent years

[1] Tucker, J. L., Blending Fibers for Fabrication of Asbestos Textiles: Asbestos, vol. 32, No. 12, June 1951, pp. 4–11.

because of the substitution of molded linings. This is a fortunate circumstance, because spinning fibers are in increasing demand and constitute a relatively small proportion of the asbestos recovered. More detailed information on friction materials has been published.[2]

Asbestos cloth treated with rubber is made into gaskets for use between the abutting or flange ends of pipes or between adjoining surfaces, such as manhole and handhole plates, to make the joints tight enough to prevent passage of air, steam, or oil. Asbestos cloth is used also for manufacturing fireproof theater curtains and scenery; blankets; draperies; mattresses; safety clothing, such as firemen's suits, gloves, shoes, aprons, mittens, leggings, and helmets; awnings; conveyor belts for carrying hot materials; woven sheet packings; and lagging cloth to protect packings on shipboard. Braided and twisted packings are closely related to textiles.

Spinning-grade fibers are also employed for certain nonspinning uses, such as compressed sheet packings and gaskets. Another important nontextile use is the manufacture of low-iron fibers of spinning grade into strong asbestos paper. When used in tape form for wrapping electric wires, it is said to make a covering superior to that obtained by wrapping the wire with asbestos roving. Because of their low iron content, Rhodesian spinning finers are used for electric cable coverings and for primary electrical insulating on magnet wire. A small tonnage of the longer Vermont fiber is used for filters in electrochemical cells.

NONSPINNING USES

An important use for nonspinning asbestos is for compressed packings consisting of felted masses of fiber combined with rubber or other binders. They are of various forms, known as compressed sheet, coil, spiral, and high-pressure packings.

Another large group of uses is for heat insulation; in fact, asbestos is one of the most important fireproofing and heat-insulating materials known. Among the best-known products is 85-percent magnesia pipe covering, which consists approximately of 85 to 90 percent basic magnesium carbonate and 10 to 15 percent asbestos. Asbestos paper is used for making 3-ply air-cell and similar pipe covering; as sheeting between floors; as lining for stoves, heaters, filing cabinets, soldiers' helmets, muffiers for automobiles, drum controllers in sulfite mills, and automobile radiator covers; in tubes for electric wires, table mats, pads, stove mats, and other household appliances; and in many other ways. Asbestos paper is also used extensively in manufacturing asbestos felt roofing and builtup roofs and in making asbestos-protected metal roofing. Millboard is used not only as a building material but as a packing for joints of steam pipes and as a lining for safes, stoves, electric switchboxes, automobile hoods, and ovens, where a material thicker than paper is required. An important use of millboard is for gaskets on automobiles and steam machinery. Asbestos is used for lagging steam boilers to prevent heat radiation. Large quantities of the shorter fibers are used in plastic fireproof cements for boiler, pipe, and furnace covering. An asbestos-cement coating is sometimes applied to the surface of wallboard for both heat insulation and fireproofing. Numerous household appliances, such as pot holders, mats, and table covers, may be classed in the group of heat-insulating materials.

Large quantities of the shorter grades of asbestos are used in manufacturing building materials. Portland-cement and asbestos roofing shingles are used extensively. Compressed sheets of asbestos combined with cement are used for corrugated sheeting, wallboard, millboard, and lumber. Corrugated asbestos sheets have special merit in the construction of chemical plants or other buildings exposed to a corrosive atmosphere. Asbestos-cement wall tiles in a wide range of colors were introduced about 1930. Asbestos-cement products are used increasingly in Europe as roofing, ceilings, partitions, paneling, linings of interior and exterior walls, water pipes, and gutters. The pipes and gutters require no painting and compare favorably in strength with cast iron. It has been found that wooden flooring may be nailed to a subflooring consisting of concrete to which about 10 percent of asbestos has been added. Asbestos-resin-composition products are becoming popular for floor tile in homes, offices, and ships.

There is a marked tendency toward more extensive use of molded brake bands in automobiles. Of the brake bands made in 1929, about 84 percent were woven and 16 percent molded. In 1931, 70 percent were woven and 30 percent molded, and in 1933 these percentages were, respectively, 59 and 41. In 1947 the value of molded brake linings was over four times as great as that of the woven, and the number of pieces of molded clutch facings sold was twice as great as the number of woven clutch facings. This trend indicates a relatively wider use of nonspinning asbestos and consequent conservation of the spinning grades for other uses.

Asbestos-cement pipes are being used increasingly for water and sewer pipes and to some extent for gas mains. They are moderately resistant to chemicals, noncorrosive, relatively nonconductive of heat and electricity,

[2] Halstead, R. T., Brake Linings of Various Types and Their Manufacture: Asbestos, vol. 31, No. 2, August 1949, pp. 6–12; No. 3, September 1949, pp. 8–13; No. 4, October 1949, pp. 3–6.

light in weight, and, when laid with the usual flexible joints, so elastic that traffic vibrations are unlikely to cause leakage. Moreover, they are easily placed and joined. They are particularly advantageous for carrying solutions that must be kept free from iron rust. A standard pipe may contain 15 to 30 percent of asbestos fiber, depending upon the type and use. Lightweight tubes are used as electrical conduits and ducts of various types and for some venting applications in homes and industrial buildings.

Asbestos is used in fireproof paints, in arc welding, for protecting the surface of metal sheeting, as a constituent of plastic floor tiles and asphalt roof coatings, for covering fire hose, and in the manufacture of gas burners. A process has been developed whereby asbestos may be cemented to steel by means of metallic adhesives. This process promotes wider use of asbestos-protected metals.

Asbestos paper and millboard are used for electrical insulation. Short-fiber asbestos mixed in proportions of 4 to 6 percent with asphalt improves the surface of roads.

Asbestos is used as a polishing agent. A rough asbestos cloth is suitable for common scouring and an acid-refined asbestos cloth for imparting a high luster.

In chemical laboratories asbestos is used for acid filters, for stoppings in combustion tubes, for fireproof supports and protectors, and for wicks which, when saturated with various mineral salts, will produce colored flames. A filter cloth in which noncorrosive wires are combined with the fiber has an advantage of greater strength over the all-asbestos cloth and also of lower cost because the wire reinforcement permits the use of lower grades of asbestos. Metals such as iron, Monel, nickel, and lead-coated steel are used for the wires, the choice depending on the nature of the solution to be filtered and operating conditions. An important use of filter asbestos is removal of oil from condensate (condensed steam).

An important development in use during recent years is the employment of the very short grades, chiefly Group 7 of the Canadian classification, as a component of asphalt and plastic floor tiles and as a reinforcing constituent of molded plastics. As floor tiles may contain 35 percent or more of asbestos, this use consumes large quantities of fiber, much of which was formerly discarded as waste.[3]

ANTHOPHYLLITE

The uses of anthophyllite are limited because of its lack of strength. It is, with few exceptions, too weak for spinning purposes and cannot be used for asbestos-cement shingles or other products to which a high tensile strength of the fiber imparts essential qualities. However, because of its superior resistance to acids, it is well suited for use in chemical laboratories. The stronger grades of both anthophyllite and tremolite are used for chemical filters. Anthophyllite and tremolite may be employed for other chemical-laboratory uses mentioned in a previous paragraph.

The principal uses known for anthophyllite are for making plastic cements to cover boilers, pipes, and furnaces, as a filler in rubber, battery boxes, and molded electric insulation products, for welding-rod coatings, and as an admixture in cement and plastic flooring, acoustical and other wall plasters, and stucco. No large, consistent market for it has yet been developed, and production has never exceeded a few hundred tons a year.

Many industries use asbestos in hundreds of minor ways. The catalogs of some asbestos-product companies contain lists of several hundred articles in which asbestos is a more or less essential ingredient.

AMOSITE

The uses of amosite, in order of importance, are:

(1) Lagging in felted form for high-temperature insulation up to 900° F. It is commonly used as a protective covering over 85-percent magnesia or other kinds.

(2) Felted, loosely compacted covering for marine turbines, jet engines, and similar applications. It is especially well adapted for this use because it does not pack under vibration, and if it becomes wet it retains its resiliency and dries without detriment to the product.

(3) As a constituent of 85-percent magnesia and calcium silicate insulation. For the asbestos content of 85-percent magnesia, some manufacturers use 40 to 60 percent amosite and the remainder of Canadian Groups 4 or 5. When fibers of fair length are used, the proportion of fiber may be reduced, possibly as low as 11 percent. If shorter fibers are used the percentage must be increased, possibly to 15 percent or more. The shorter the fibers that are used the greater the breakage loss in the finished product. Amosite furnishes long fibers at lower cost than those obtained by employing Canadian chrysotile. The 85-percent magnesia is used for temperatures up to about 550° F., above which the magnesia disintegrates. Some products consist of amosite or other asbestos with a siliceous binder. They will withstand temperatures from 550° to as high as 1,200° F.

An important special use for amosite is for insulating underground steam pipes. Its qual-

[3] Asbestos, Asbestos and the Asphalt-Tile Industry: Vol. 31, No. 3, September 1949, pp. 16–23.

ity of moisture resistance prevents or reduces corrosion and electrolytic reaction detrimental to the pipes.

Another special use for amosite is for making a lightweight, fireproof wallboard used for partitions on ships. It is even lighter than wood, and the weight per cubic foot would be increased considerably if other fibers were substituted for amosite.

CROCIDOLITE

Crocidolite (blue asbestos) is characterized by high tensile strength, acid resistance, and harshness in wet mix. The longer fibers are used for spinning and weaving. It is reported that, during World War II, one United States firm manufactured yarn from crocidolite in a small way, and this yarn was woven into fabrics for chemically resistant packing. According to current information, no spinning or weaving of blue fiber is carried on in the United States at this time. These processes are conducted in Europe. Blue-asbestos fabrics for acid-resistant packings or for other uses in the United States are now imported; Canadian fiber cannot be substituted for blue asbestos in such packings. The shorter blue fibers are used extensively in the manufacture of asbestos-cement pipe on the North American Continent, as their high tensile strength and harshness in wet mix adapt them well for such use. The new Munro mine in Ontario furnishes a harsh type of chrysotile that may, after further experimentation, replace blue fiber to some extent. Long blue fibers are exceptionally well adapted for gas filters. Bolivian blue is preferred for this use.

The uses of asbestos have been listed in some detail in the magazine Asbestos.[4]

TRENDS IN FIBER UTILIZATION

A striking feature of asbestos utilization is the very small proportion of the fiber that is sold directly to the consumer trade. With few exceptions, asbestos products are sold to other industries for manufacture into finished products. In other words, they constitute a class of raw materials used in many manufacturing industries. Accordingly, the consumption of asbestos is closely related to industrial activity. X

An important field of utilization is for heat insulation, roofing, siding, millboard, wallboard, lumber, paper, and roof coatings, all of which are employed extensively in the building trades. Asbestos consumption, therefore, is influenced greatly by the volume of building construction. The relationships between the consumption of asbestos and activity in its major markets—construction and industry in general—during the past 30 years, are shown graphically in figure 2.

RECOVERY OF SCRAP

Recovery of scrap is an important element in some metal industries, notably iron, steel, copper, and lead. On the other hand, asbestos once used is rarely recovered for reuse. In manufactured products asbestos is usually combined with other materials; and its separation from such materials and its reprocessing into usable form are so difficult and costly that they are generally regarded as uneconomic. However, recent research indicates that recovery for reuse is feasible under certain conditions.

During the early post-World War II period there was a shortage of spinning-quality asbestos, and the Bureau of Ships of the United States Navy Department requested the National Bureau of Standards to study the possibility of reclaiming asbestos from insulation discarded during the repair and refitting of ships. The materials were of three general types—asbestos cloth, asbestos-cotton cloth, and molded pipe insulation, consisting of about 15 percent asbestos and 85 percent magnesia cement. Some of the products were painted or covered with magnesia compounds. It was found that the cement could be removed by treatment with a 5-percent hydrochloric acid solution and the paint with a sodium hydroxide solution. The cotton was removed by burning in a muffle furnance, but great care had to be exercised to keep the temperature down to 400° or 450° C., because high temperatures will damage the fibers by driving off the water of constitution. The cleaned cloth was reduced to fiber form in a paper-pulp beater. Fibers recovered from the cloth were satisfactory for reuse. Asbestos mixed with strands of fiber glass or with a large proportion of magnesia cement were recovered with greater difficulty and had limited use.[5]

[4] Asbestos, The Uses of Asbestos and Asbestos Products: Vol. 24, No. 3, pp. 4–10; No. 4, pp. 4–8, 1942.

[5] Zimmerman, E. W., Reclamation of Asbestos: Nat. Bureau of Standards, Tech. News Bull., vol. 37, No. 9, September 1953, p. 139; see also Asbestos, vol. 35, No. 3, September 1953, pp. 16–18.

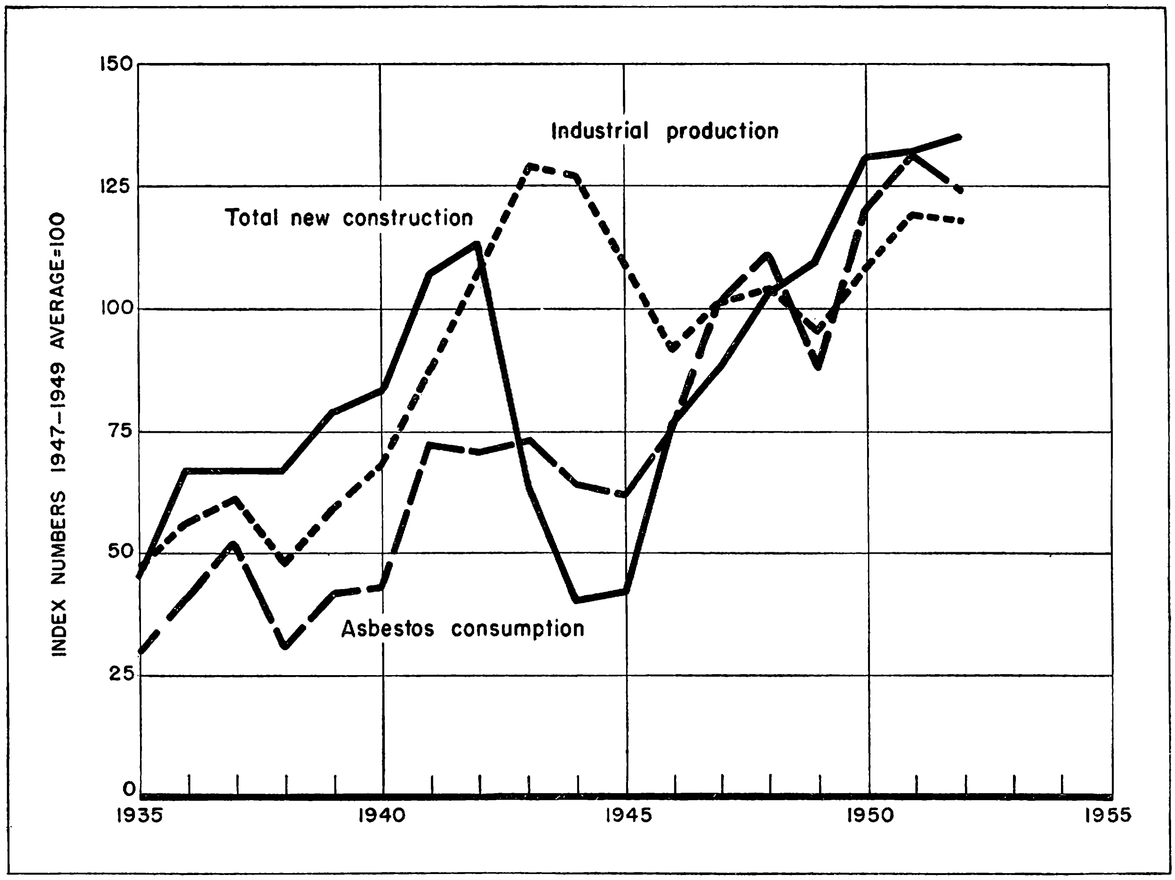

FIGURE 2.—Consumption of Asbestos Compared With Total New Construction and Industrial Production 1935–52.

(Statistics on value of construction from Bureau of Foreign and Domestic Commerce, and on industrial production from Federal Reserve Board.)

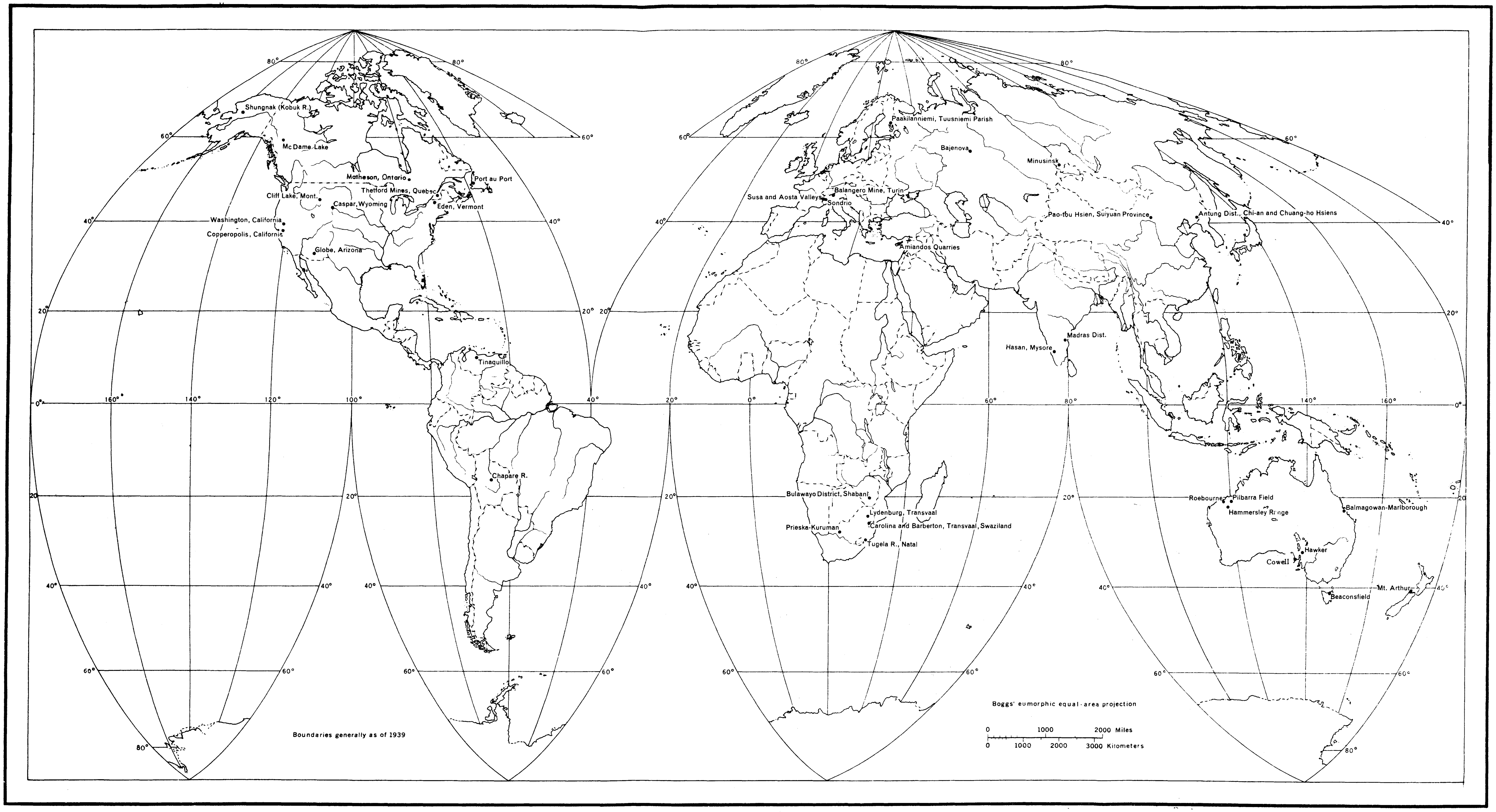

FIGURE 3.—Map of World Deposits of Asbestos.

(Courtesy of Prentice-Hall, Inc. NOTE.—The Hammersley Range in Australia should be spelled Hamersley Ranges.)

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DISTRIBUTION

The United States has never been a large producer of asbestos. Production is centered in four principal countries—Canada, Rhodesia, Union of South Africa, and the Soviet Union. Since asbestos first became an important commercial commodity the Province of Quebec, Canada, has led in tonnage produced, but a large proportion of the output of this Province is of the shorter, nonspinning grades. Since 1916 the Union of South Africa and Southern Rhodesia have become increasingly important as sources of high-grade spinning fibers and certain special types of asbestos found only in small quantities elsewhere in the world. Before World War I the U. S. S. R. ranked next to Canada as a producer of asbestos, but during the revolutionary period there the industry in that country was almost at a standstill. In 1926, however, activity was revived, and both production and exports increased greatly. The Russian industry probably is again second only to Canada on a quantity basis. Smaller quantities of asbestos are produced in Cyprus, Australia, Finland, Italy, and many other countries. The location of asbestos deposits throughout the world is indicated in figure 3.

Chrysotile is the leading variety of commerce, and most of the occurrences throughout the world are of this type; however, substantial quantities of crocidolite (blue asbestos) are produced in the Union of South Africa and Australia and amosite in the Union of South Africa. Minor quantities of anthophyllite and similar amphibole varieties are mined in the United States, Italy, Finland, the Union of South Africa, and several other countries.

DOMESTIC DEPOSITS

CHRYSOTILE

Alaska

Chrysotile has been found near Shungnak and in the Jade Hills in far northwestern Alaska; several attempts have been made to develop the deposits.

The Shungnak occurrences are close to the Kobuk River, 150 to 200 miles from its mouth. According to Smith and Mertie,[1] the chrysotile occurs in small veins closely associated with greenstone and serpentine. The veins, which are most abundant on the east side of Dahl Creek, consist mostly of short fiber, although some long fiber has been found. Samples of the latter were submitted to manufacturers some years ago; they reported that the color was good, but the fibers were too weak for high-grade uses. However, samples of strong, flexible chrysotile, over 6 inches long and apparently of high grade, were obtained in 1932 from a deposit in this locality. The asbestos appears to be of the slip-fiber type; therefore, it may be confined to shear zones. Stewart [2] states that 3 thin veins, the largest of which is about 3 inches wide, were uncovered at one point, and that some veins have been traced for at least a quarter of a mile. The deposit is undeveloped. Water transportation is available in summer.

Asbestos deposits occur in the Jade Hills, which lie north of the Kobuk River not far from its mouth. These deposits were worked in a small way for a short time many years ago; in 1925 and 1926, interest in them was revived, and a trader at Kotzebue financed some new prospecting in the region. No definite information is available as to the kind or quality of asbestos found, but it probably is similar to that occurring at Shungnak.

Additional prospecting in the Cosmos Hills was undertaken in 1931 and 1932 by Michael Garland under the Territorial Department of Mines prospecting program. The asbestos deposits in the serpentine at the head of Dahl Creek were discovered, and samples containing slip fiber 1 foot in length were submitted to the Bureau of Mines for analysis. Garland staked several claims. Although the sample of slip fiber was identified as chrysotile asbestos of good quality, no development was attempted, and the claims were allowed to lapse.

Between 1944 and 1946 the Bureau of Mines conducted exploration work on asbestos deposits on Bismarck Mountain on the Shungnak River in the neighborhood of Cosmos Creek and Dahl Creek. Samples were taken, and tests were made at the Bureau of Mines Experiment Station at Rolla, Mo. Tests were also made by several companies that mine asbestos and manufacture its products. The asbestos of the Dahl Creek area is chiefly tremolite, while chrysotile is the chief product of the other deposits explored. The results of tests on the chrysotile were disappointing both as to length and quality of the fiber. The following conclusions were reached by Bureau of Mines investigators:[3]

(1) Recovery of the higher grades of asbestos is so low that these deposits cannot be considered a source of spinnable asbestos.

(2) The material might be used in the manufacture of asbestos shingles and asbestos board,

[1] Smith, Philip S., and Mertie, J. B., Jr., Geology and Mineral Resources of Northwestern Alaska: Geol. Survey Bull. 815, 1930, pp. 344–345.

[2] Stewart, B. D., Mining Investigations and Mine Inspection in Alaska: Rept. for Biennium Ended March 31, 1933, pp. 21, 22.

[3] Heide, H. E., Wright, W. S., and Rutledge, F. A., Investigations of the Kobuk River Asbestos Deposits, Kobuk District, Northwestern Alaska: Bureau of Mines Rept. of Investigations 4414, 1949, 25 pp.

although the fiber is more brittle than the Canadian product.

(3) This asbestos might also be used as a filter medium because of the rapidity with which water passes through the finer sizes.

Arizona

Asbestos was first discovered in Arizona by Charley Newton in 1872. He, with a small force of pioneers, fought a band of Indians and during the engagement came upon an asbestos outcrop 3 or 4 miles northeast of Chrysotile on Ash Creek, Gila County. No interest was taken in the deposit for many years. About 1900 chrysotile asbestos was discovered in the Grand Canyon, and small quantities were mined on the north side opposite Grand View, about 20 miles west of Grand View, and at other points. After these discoveries interest reverted to the Gila County occurrences, and in 1912 and 1913 many claims were staked. Asbestos was found in numerous localities over an area 60 miles long and 25 miles wide, most of which lies west of the San Carlos and Fort Apache Indian Reservations.

The asbestos occurs in the Apache geological group, which, in the Salt River region, is represented chiefly by beds of quartzite and limestone. It apparently was formed by mineralizing solutions derived from intrusive diabase dikes and sills which replaced the Mescal (pre-Cambrian) limestone by serpentine. Possibly there was some reaction with the limestone or its impurities. It is associated with greenish and mottled serpentine. It occurs in cross-fiber veins, which are most abundant throughout the limestone in proximity to the diabase intrusions. Places where the limestone is much broken by the diabase are particularly favorable for the formation of asbestos. The veins reach a maximum thickness of about 6 inches. The fibers may extend across the full width of the vein or be broken into two or more lengths. The veins are erratic and do not persist for long distances. Conditions are most favorable for mining where several veins are close enough to each other to be worked from one drift. Usually much barren rock must be mined to recover the fiber-bearing seams. The occurrences are quite different from the Canadian deposits, where fiber veins traverse massive serpentine irregularly.

The highest grade fiber, shown in figure 4, is soft and silky, has high tensile strength, and is excellent for spinning purposes. A harsher, less desirable fiber, however, occurs in many places. Arizona chrysotile is very low in iron, therefore it is more suitable for electrical insulation than chrysotile from other regions. According to

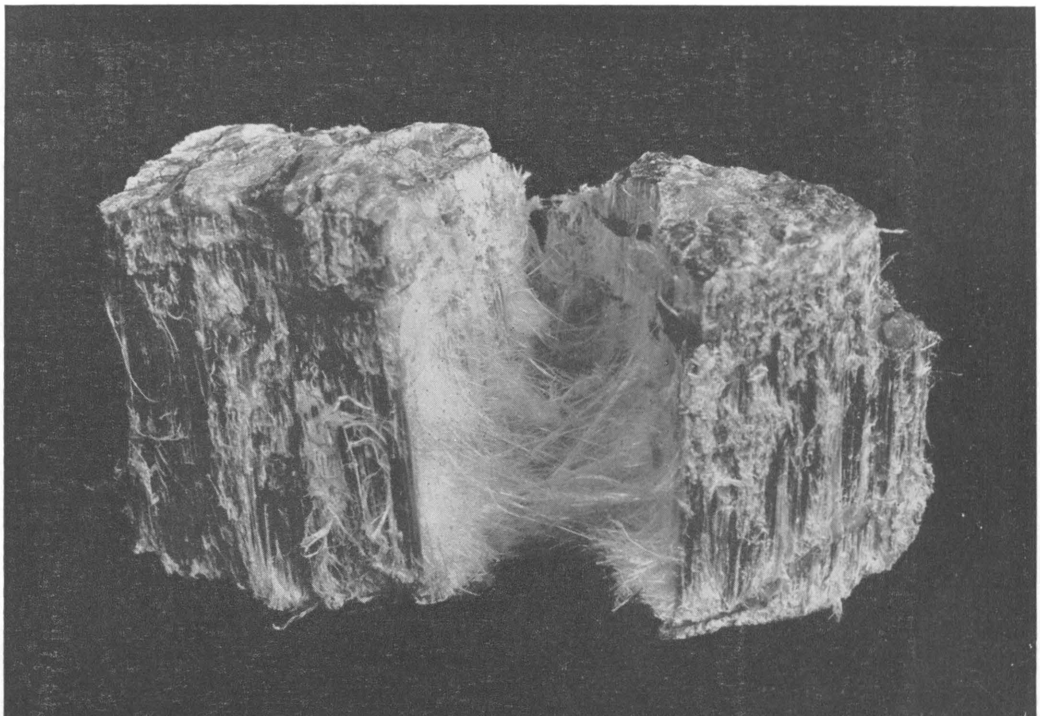

FIGURE 4.—Crude Chrysotile Asbestos From Arizona.

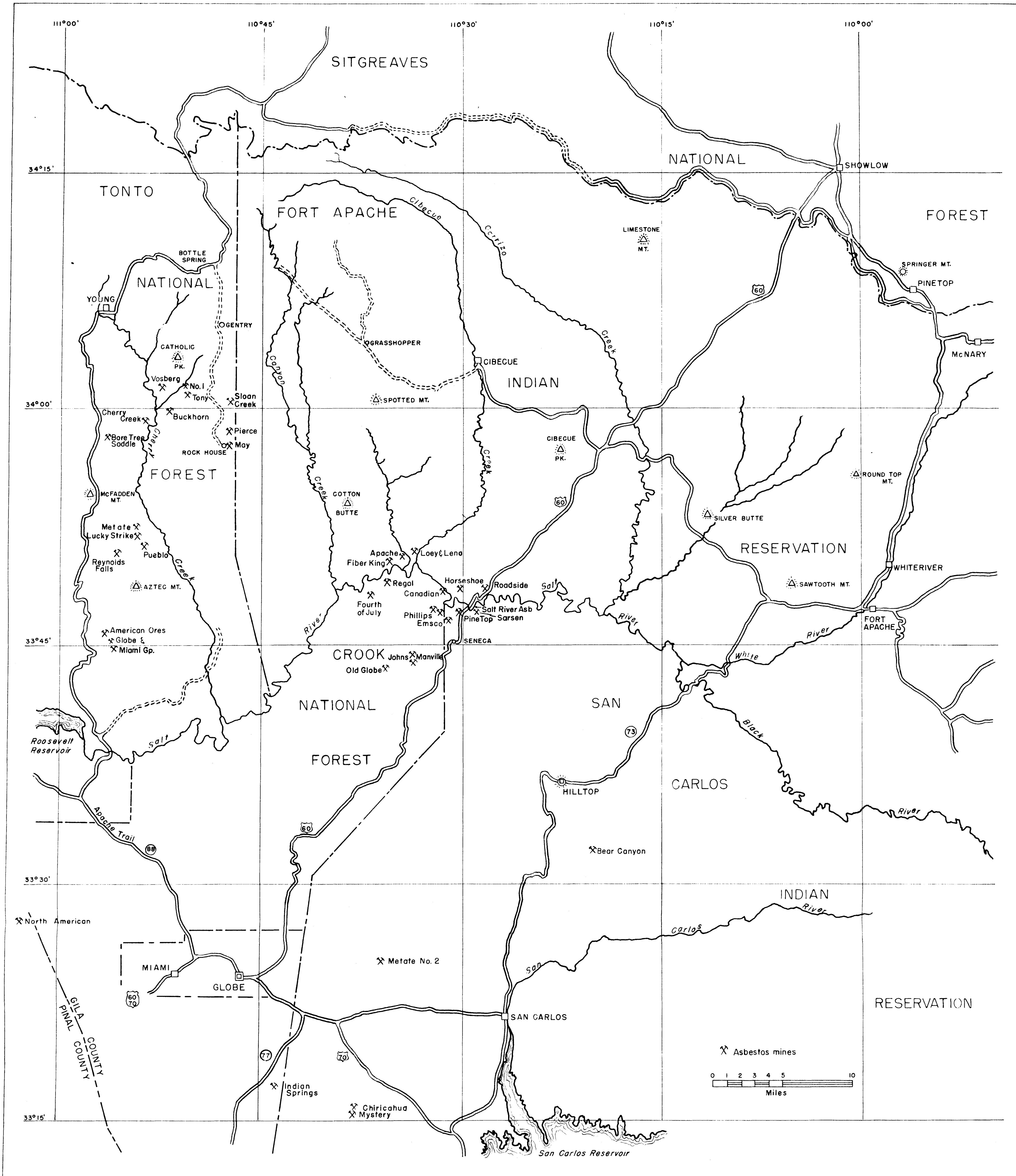

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FIGURE 5.—Location Map of Asbestos Deposits in Gila County, Ariz.

(Index map of aerial photo sheets)

Compiled by Lincoln A. Stewart, Bureau of Mines

Melhase,[4] the asbestos deposits of Gila County were grouped in five districts, but Wilson [5] later grouped them into two regions—the Chrysotile-Salt River and the Sierra Ancha. The former extends from a few miles north of Salt River south to the latitude of Globe. North of the river it includes part of the Fort Apache Reservation and south of the river a part of the San Carlos Reservation. The area south of the river is sometimes called the McMillan mining district. The Chrysotile-Salt River region contains the most productive mines. Asbestos deposits also occur south and east of Globe in areas beyond the limits of the region as originally defined. The region is a plateau of nearly horizontal strata, capped in places by lava and intruded by sills of diabase. It is deeply dissected by the Salt River and its tributaries.

The Sierra Ancha region includes an area extending north of Salt River to the latitude of Young and west of Canyon Creek to longitude 111°. It is made up of strata that generally dip eastward and are intruded by large and small diabase sills. It is deeply dissected by the canyons of Cherry Creek and other streams.

The early history of developments in Arizona is given in some detail in the Wilson report cited above (footnote 5).

The geology of the deposits has been reviewed by Badollet.[6]

The region is accessible more easily than in earlier years. The nearest railway station is Globe, which is 40 or more miles from most of the deposits. Hard-surface roads from Globe reach the vicinity of the deposits, and good access roads connect the main highways with most of the mines. Access to some of the undeveloped claims is difficult. The scattered character of the fiber veins, the high cost of mining, the presence in places of harsh fiber, and the long distance from markets have tended to discourage production. Table 3 shows production, by years, from 1914 to 1944. Figures for production for the years since 1945 are confidential, but the average for the period since 1945 was a little higher than the average for the preceding 6 years.

A detailed description of nearly all of the Arizona deposits has recently been published.[7]

As discussed elsewhere in this report, low-iron chrysotile has great strategic importance for electric insulation products, such as electrical tapes and cable coverings. The C & G grades of Rhodesian chrysotile constituted virtually our sole source of supply of these highly important fibers up to 1953. The Arizona fiber, however, is low in iron, and the soft varieties are eminently suitable for electric insulation uses; the Arizona deposits are, in fact, the only low-iron chrysotile occurrences known at present in the United States.

During the early stages of World War II, it seemed desirable to stimulate production in Arizona as a safeguard against shortage of supply from Rhodesia. To determine the possibilities of the Arizona area, the Bureau of Mines undertook an exploratory project in 1943, the results of which have been published.[8] Mining was conducted in four locations that were regarded as most favorable. "Commercial ore" that could presumably be mined at a profit was found in two of these locations, but the exploratory work failed to indicate reserves of any considerable magnitude. In the other two locations, "commercial ore" was not found; the rock was, in fact, too lean to justify sampling. In general, the occurrences were found to be erratic, discontinuous, and limited in area by rather exacting geologic conditions, such as small folds and bedding-plane faults in limestone in proximity to diabase sills and dikes. The tunnels driven as a result of one of these projects were driven farther by Phillips Asbestos Mines, and the Grand View mine, which includes these workings, has produced considerable quantities of soft fiber. One of the handicaps facing the Arizona asbestos industry is the limited market for the shorter grades, the disposal of which is discouraged by the relatively low price they will bring in the market and by the high cost of transportation. Activity is interrupted at times through lack of working capital. A profitable market for the shorter grades would stimulate the industry considerably, but because of the scattered nature of the occurrences and the high cost of mining, only a relatively small output is to be expected during future years.

TABLE 3.—*Sales of asbestos in Arizona, 1914–44* [1]

Year	Short tons	Year	Short tons
1914	50	1930	683
1915–18 (inclusive)	[2] 1,900	1931	184
1919	423	1932–34 (inclusive)	[2] 34
1920	1,200	1935	------------
1921	413	1936	464
1922	93	1937	648
1923	4	1938	942
1924	[2] 132	1939	904
1925	[2] 80	1940	1,197
1926	100	1941	2,574
1927	[2] 1,250	1942	1,742
1928	[2] 1,500	1943	1,459
1929	934	1944	696

[1] Data compiled by Arizona Bureau of Mines.
[2] Estimated.

[4] Melhase, John, Asbestos Deposits in Arizona: Eng. and Min. Jour. Press, vol. 120, No. 21, Nov. 21, 1925, pp. 805–810.
[5] Wilson, Eldred D., Asbestos Deposits of Arizona: Univ. of Arizona, Bull. 126, Mineral Technol. Ser. 31, 1928, 97 pp.
[6] Badollet, Kay, Geology of Asbestos Deposits, II. Arizona: Asbestos, vol. 30, No. 3, September 1948, pp. 4–10.
[7] Stewart, Lincoln A., Chrysotile Asbestos Deposits of Arizona: Bureau of Mines Inf. Circ. 7706, 1955, 124 pp.
[8] Stewart, Lincoln A., and Haury, P. S., Arizona Asbestos Deposits, Gila County, Ariz.: Bureau of Mines Rept. of Investigations 4100, 1947, 28 pp.

The location of the Gila County, Ariz., mines is indicated in figure 5.

An interesting occurrence of asbestos was discovered in a new locality in Arizona in 1953. A ¼- to ½-inch-thick band of soft, spinning-quality chrysotile was found in a narrow fault fissure in the Abril zinc mine, about 15 miles northeast of Tombstone, Cochise County. The vein is in Permian limestone at least 40 feet from a basic dike, and therefore the deposit differs considerably from those in Gila County, which are found only in pre-Cambrian limestone close to diabase intrusions. The occurrence is too local in extent to justify commercial development.

California

Asbestos occurrences in California are numerous, but the history of their development has been disappointing. The first reference to chrysotile in the Mineral Resources chapters of the Federal Geological Survey was in 1901. In that year a small ouput was reported in Riverside County, and an occurrence was mentioned in Calaveras County. A small output was reported from Placer County in 1905; but, although several new deposits were recorded between 1906 and 1911, none bore promise of a large supply. Slip fiber was found in Sierra County in 1912. Samples of chrysotile obtained in Shasta and Napa Counties in 1913 were not of promising quality. Up to 1914 asbestos had been reported in 12 counties. Production in Shasta, Placer, Calaveras, and Alameda Counties aggregated 65 tons in 1914. In 1915 a manufacturer of asbestos pipe covering and shingles at Oakland reported purchase of 80 tons of fiber in Placer, Alameda, and Contra Costa Counties. Three carlots of nonspinning fiber were shipped to Oakland from near Sims in Shasta County in 1916. The asbestos is said to occur in cross-fiber veins, in serpentine, which would indicate that it is chrysotile, but shipments from this locality in 1922 were reported as amphibole.

An asbestos deposit 2½ miles northwest of Washington, Nevada County, occurs in a large area of serpentine. Mining was begun about 1917. A 300-foot tunnel was driven into a serpentine hill on a 6-percent upgrade, and a 150-foot raise was put through to the surface. The rock was mined by a gloryhole method, dropped through the raise, and trammed through the tunnel. A mill having a capacity of 100 tons a day was equipped with stamps, screens, fiberizers, and air-suction pipes. Short fiber and a small quantity of spinning fiber were produced, but activity ceased with the sale in 1923 of a small tonnage of fiber milled in 1921. Much of the output was used in manufacturing flooring in San Francisco. A deposit that promises to have commercial importance was reported in the Chicago Park district in 1937.

Another property that attained some prominence is about 6 miles east of Copperopolis, Calaveras County, in a serpentine belt having a maximum width of 2,700 feet. The serpentine area is cut by andesite dikes up to 20 feet thick, which, it is believed, were factors in fiber development. Prospecting and developing conducted in 1920 and 1921 revealed a mineralized area about 1,400 feet long and 400 feet wide. A 5-percent recovery is recorded for one period of mill operation. A small crushing and fiberizing mill, capable of handling about 30 tons of rock a day, began operation in 1921. Underground workings consist of several tunnels, the longest of which was driven 278 feet into the hill. Very little fiber was produced. It is reported that an experimental mill was operated on this property for about 6 months during 1927.

About 1944, 16 core-drill prospect holes were sunk to depths of 225 to over 400 feet. Although no further development work was done at that time as a result of the findings, exploitation of the deposit was seriously considered in 1953. Reserves are said to be extensive; and the fiber, which is similar to the Canadian, appears to be of good quality.

A deposit was developed about 1920 and a mill built in 1921 on a property 2½ miles from Hernandez in southern San Benito County. A small tonnage of fiber was produced from 1923 to 1926; thereafter activity ceased.

In 1931 asbestos occurring in irregular veins in dark-green serpentine was mined in an open-cut near Carrville, Trinity County. Several tons of good-quality chrysotile averaging three-fourths inch in length were obtained.

A large asbestos deposit was reported in Napa County as early as 1908, and a company was formed to develop it in 1922, but no progress was made. Plans were underway for a $20,000 mill in 1931, but the project did not materialize. The deposit is between Napa and Monticello. A serpentine area shows asbestos fiber over a length of about 1,000 feet and a width of 300 feet. Short-fiber chrysotile only is available, and the percentage in the rock appears to be low. Kochler & Chase built a mill on the property in 1941 and produced a small tonnage for several years, but no activity has been noted since 1945. The company used the very finest material, consisting chiefly of serpentine, for making a type of wall plaster.

In 1928, 7 or 8 tons of asbestos was obtained 10 miles from Middletown, Lake County.

Good-quality asbestos was reported from a deposit 27 miles northwest of Coalinga, Fresno

County, in 1918. A small tonnage, produced in 1918 and 1919, was sold in 1925.

Small quantities were produced 2½ miles east of Ione, Amador County, in 1917 and near Valley Springs, Calaveras County, and in Alameda County in 1918.

About 4 miles from Bryon, Monterey County, occurrences of chrysotile fiber of good quality up to 1½ inches long were reported by the State mining bureau in 1925. Fiber has been found in several widely separated spots; but, although claims have been made that a large deposit exists, no factual evidence at this time indicates continuity of a large area of commercial-grade rock.

Asbestos deposits have been reported at Towle, Iowa Hill, and 3½ miles from Cisco, Placer County; at Goodyears Bar, Sierra County; and at Edgewood and Coffee Creek Bridge, Siskiyou County.

During 1950 several promising deposits of chrysotile of textile quality were found in Shasta, Trinity, and Siskiyou Counties in an extensive serpentine belt. Milling and processing tests on a large sample from one of these deposits gave such encouraging results that further exploration would be justified.

In 1951 an asbestos deposit was discovered in the Panamint Range, Death Valley National Monument, about the center of Inyo County. The location is about 7 miles north of Goldbelt Springs. Chrysotile asbestos occurs at a contact zone of syenite with dolomite. Samples taken from shallow pits show cross-fiber veins of chrysotile, of which some is of good quality. A small proportion of spinning grade appears. Most of the formation has been eroded away. The asbestos-bearing rock occupies an area about 450 feet in diameter on the top of the mountain. Accordingly, the reserves are limited. Other remnants of the same horizon may be present in other sections of the mountains, but they have not yet been found. The nearest railway is at Keeler about 62 miles distant. The deposit is in an uninhabited, arid region served by a poor mountain road. During 1952 the Defense Minerals Exploration Administration advanced a small cooperative loan for exploration of the property, but no following development work has been recorded.

An unusual deposit occurs about 2 miles northwest of Jamestown, Tuolumne County. Preliminary work has uncovered a mass of rock about 4,000 feet long and 1,300 feet wide, said to consist chiefly of antigorite, a platy form of asbestos closely related to chrysotile. It occurs in a serpentine area intruded by dikes and sills of metadiorite and related rocks. According to a press report a carlot of antigorite was shipped from the deposit in 1952. No commercial use for antigorite has yet been recorded.

Some exploratory work was done in 1953 on a short-fiber chrysotile deposit 4 miles from Jacksonville and 10 miles from railhead at Chinese Camp, Tuolumne County.

Table 4 [8a] shows production in California, by years, since 1887. For the years omitted there was no output. In certain instances, the figures are grouped in periods of 2 or 3 years to avoid disclosure of the output of individual companies. The figures in this table include both chrysotile and amphibole. The entire output before 1900 was classed as amphibole.

[8a] State of California, Division of Mines, California Mineral Production for 1946: Bull. 139, 1948, p. 60.

TABLE 4.—*Asbestos production in California, 1887–1951*

Year	Short tons	Value	Year	Short tons	Value	Year	Short tons	Value
1887	30	$1,800	1909	65	$6,500	1927	13	$1,160
1888	30	1,800	1910	200	20,000	1928		
1889	30	1,800	1911	125	500	1929	219	6,175
1890	71	4,260	1912	90	3,700	1930		
1891	66	3,960	1913	47	1,175	1932	309	3,274
1892	30	1,830	1914	51	1,530	1933		
1893	50	2,500	1915	143	2,860	1934		
1894	50	2,250	1916	145	2,380	1941	16	2,867
1895	25	1,000	1917	136	10,225	1942	4	836
1898	10	200	1918	229	9,903	1943	723	15,000
1899	30	750	1919	131	6,240	1944		
1900	50	1,250	1920			1945	37	3,605
1901	110	4,400	1921	410	19,275	1946		
1904	10	162	1922	50	1,800	1947	[1]	[1]
1905	112	2,625	1923	20	200	1948	[1]	[1]
1906	70	3,500	1924	70	4,750	1949	[1]	[1]
1907	70	3,500	1925	25	1,650	1950	[1]	[1]
1908	70	6,100	1926			1951	[1]	[1]

[1] Data not available.

Maine

A sample of chrysotile asbestos was submitted to the Bureau of Mines in 1940 from a deposit said to be in T. 2 or 3, R. 5, Somerset County. The sample consisted of slip fiber, apparently of good quality, on slickensided surfaces of dark-green serpentine. It resembled the asbestos-bearing rock mined near Eden, Vt. Some exploration work has been done in the Little Spencer Stream area, probably the same locality from which the 1940 sample was obtained. Johnson's Co., of Thetford Mines, Quebec, Canada, drilled a few holes in the serpentine some years ago, and the cores indicate the presence of narrow cross-fiber asbestos veins. The Bureau of Mines conducted a drilling program in this area in 1954.

Montana

A deposit of asbestos near Cliff Lake, Madison County, close to the Idaho line, was developed to some extent between 1917 and 1923. The chrysotile occurs with serpentine in limestone, an association similar to that found in Arizona. The asbestos-bearing zone is closely associated with diabase intrusions. Samples sent to the Federal Bureau of Mines in 1929 were found to be weaker and more brittle than fiber from Canada or Arizona. A mill was begun in 1923, and additional machinery was delivered in 1926, but production has been almost negligible. Small quantities were mined and milled by the Montbestos Co. in 1935, but there has been no subsequent activity. Samples examined by the Bureau of Mines in 1951 were found to have fair strength and flexibility. A small proportion of the fiber is over three-eighths inch long. The veinlets of cross-fiber chrysotile occur within or adjacent to narrow stringers and small lenses of serpentine within and between carbonate beds close to the basic intrusion. DMEA authorized a loan under which exploratory work was conducted in 1952, but no following development work has been recorded.

A small deposit of chrysotile asbestos, said to be of good quality, with fibers ½ to 1 inch long, has been located about 27 miles west of Red Lodge, Carbon County. It occurs in a mass of serpentine about 100 feet in diameter, entirely surrounded by granite.

New York

A deposit of chrysotile was found many years ago near Thurman, 7 miles west of Thurman station on the Delaware & Hudson Railway, Warren County. It was worked in a small way in 1910, and a sample of selected crude fiber was submitted to asbestos users. According to report, it was found to be of excellent quality. The veins are said to be small and probably too widely spaced to have commercial value. The maximum fiber length is about 1 inch, and most of the asbestos is one-fourth inch or less in length. A sample received by the Bureau of Mines in 1951 consisted of serpentinized crystalline limestone containing one cross-fiber chrysotile vein about three-fourths inch wide and several small veins. The fiber is weak and brittle; but, as the sample was taken at an exposed surface, its quality has doubtless been impaired by weathering. The region has not been adequately explored. This deposit is in no way related to those of Vermont or Quebec, Canada, inasmuch as the Warren County occurrences are, like the Arizona deposits, associated with limestone.

Samples of chrysotile of good spinning quality have been obtained in the Lake George area, but the location and extent of the deposit have not been recorded.

Oregon

A deposit of chrysotile asbestos has been reported in Malheur County. In 1918 an asbestos mine, a few miles north of Mount Vernon, Grant County, was operated for a short time. The product was a short-fiber chrysotile.

A deposit of serpentinized peridotite containing cross-fiber veins of chrysotile $\frac{1}{32}$ to ¾ inch in width was located by Ray Stitham et al. in 1942. Exploration under a purchase option was begun in 1952 by the Johns-Manville Sales Corp. The deposit is near Bates, eastern Grant County, on the southwest bank of Big Butte Creek. A zone of fiberized serpentine 250 to 350 feet wide and 1,200 feet long was uncovered by bulldozing, and some core drilling was done. No further development was undertaken at that time.

It was reported in the press in 1953 that Canadian Johns-Manville Corp., Ltd., had optioned chrysotile asbestos claims in an abandoned gold mine on Josephine Creek, southwestern Josephine County. An asbestos-bearing zone about 6 feet wide was found in a tunnel at the contact of gravel and serpentine.

Vermont

Although asbestos was discovered in Vermont in 1824, no interest was taken in it until M. E. Tucker found a chrysotile vein while felling trees on the eastern side of Belvidere Mountain in 1892 or 1893. Its resemblance to the

Canadian fiber was recognized immediately, and it was later found to occur over a considerable area in Lamoille and Orleans Counties.

The Vermont fiber is chrysotile similar in character and occurrence to that found at Thetford mines, Quebec; the deposit is regarded as a southward extension of the well-known Canadian belt. The asbestos is of two kinds—cross-fiber veins passing irregularly through serpentine and slip fiber lying parallel to slickensided surfaces. Most of the cross-fiber veins are narrow, those over three-fourths inch in width being uncommon. After detailed study of the veins, Keith and Bain[9] decided that the asbestos had been introduced as a vein-filling material in torsion cracks and crush fractures. Matched structures on opposite walls of the veins are common. They found little evidence in support of a replacement theory. The slip fiber ranges from a fraction of an inch to several inches in length, is similar in quality to the cross fiber, and is adapted to certain spinning and textile uses. Fiber recovery ranges from 5 to 6 percent.

Asbestos-bearing rocks occur in four prominent localities in Lamoille and Orleans Counties. The first occurrence, which is undeveloped, is about 2 miles northeast of Lowell. It consists of numerous cross-fiber veins and some slip fiber in serpentine. The second deposit, northwest of Lowell in the vicinity of Westfield, is in the form of a belt several miles long and a mile wide. Considerable slip fiber and cross fiber occur in places, but none has been mined.

In the third locality, southwest of Lowell at the foot of Mount Belvidere, both slip fiber and cross fiber occur. The latter provides a small quantity of crude asbestos. On this property in 1907 the Lowell Lumber & Asbestos Co. erected a mill with a daily capacity of about 200 tons of rock. Production was first recorded in 1908, and in 1909 the industry was so active that Vermont became the chief asbestos-producing State. In 1910 the output increased 24 percent over that in 1909. In 1911 the total production of the United States, 7,604 tons, was largely from Vermont. During that year considerable No. 2 crude was obtained. In 1912 Vermont, with an output of 4,403 tons, had the distinction of being the only asbestos-producing State in the Union, but for several years thereafter no activity was noted.

The fourth serpentine area, extending about 2 miles eastward from the third, occupies a prominent bluff on the shoulder of Belvidere Mountain. Slip fiber predominates. A mill was erected in this district in 1902 by the New England Asbestos Mining & Milling Co. but was operated only 6 months. The industry was revived in 1920 by the Asbestos Corp. of America but not in the locality formerly most productive. Operations were confined to the opposite side of the deposit at the former quarry site of the New England Asbestos Mining & Milling Co. Slip fiber predominates in this region; there is little or no spinning fiber. A mill was built, and experimental runs were made, but there was no commercial production until 1929. In 1928 the company was reorganized under new ownership as the Vermont Asbestos Corp. of America. The new company quickly put the plant in operation, producing 1,049 tons of mill fiber in 1929, and more than doubled that quantity in 1930. Although depressed markets led to some reduction in output thereafter, production increased substantially after 1936. In February 1936 the properties were acquired by Vermont Production Co., Inc., subsequently named the Vermont Asbestos Corp., a subsidiary of the Ruberoid Co. In 1939 the name was changed to Vermont Asbestos Mines Division of the Ruberoid Co.

In 1944 a new quarry opening was made at the former location of the Lowell Lumber & Asbestos Co. The fiber-bearing rock was conveyed over the mountain to the mill by means of an overhead cableway about 1 mile long. In 1949 a new mill was built about one-fourth mile from the quarry, and the cableway was abandoned.

The first large blast fired in the new quarry, about June 1944, uncovered substantial quantities of slip-fiber chrysotile of unusual length. Some masses consisted of fibers over 6 inches long. As it was difficult to process as a spinning fiber, it was milled to Group 3 or to the better grades of Group 4 (Canadian classification). As greater depth was attained in the quarry, the proportion of long slip fiber became smaller. The quarry is predominantly a medium to short-fiber operation. The output of Group 3 fibers is approximately 4 percent of total production. These fibers are used for spinning and for filters in electrochemical cells. The remaining groups in order of abundance are 6D, Group 5, Group 7, and Group 4.

The geology of the Vermont deposits has been described in some detail.[10]

Wisconsin

An asbestos deposit known as the Herriman property, in sec. 24, T. 36 N., R. 21 E., Marinette County, was explored in 1952 under a Defense Minerals Exploration Administration (DMEA) loan to the Star Mining Co. Chrysotile occurs in scattered, cross-fiber veins in peridotite. Most of the veins are less than

[9] Keith, Stanton B., and Bain, George W., Chrysotile Asbestos, I, Chrysotile Veins: Econ. Geol., vol. 27, No. 2, 1932, pp. 169–188.

[10] Badollet, Kay, The Geology of Asbestos Deposits, I. Vermont: Asbestos, vol. 29, No. 9, March 1948, pp. 4–10.

three-eighths inch across. The peridotite occurs in a pluglike mass, which, as indicated by a magnetometer survey, is about 300 feet long and 150 to 200 feet wide. No development work following exploration has been recorded.

Wyoming

Several deposits of chrysotile have been found in Wyoming. The Brown Bear deposit lies in northwestern Lincoln County near the Idaho border, 7 miles south of Yellowstone Park. The nearest rail point is Lamont Siding, Idaho, 25 miles west. Greenish-yellow chrysotile fiber occurs in veinlets, most of which are less than one-fourth inch wide. Both slip and cross fiber occurs. Both have been described as harsh, but the slip fiber is most likely to be of commercial grade.[11] It is estimated that the rock contains less than 5 percent fiber. The property was acquired by the American Asbestos Milling & Mining Co. of Idaho Falls, Idaho, in 1917. It was developed with tunnels and opencuts, and 13 miles of access road were built. No production has been recorded, and there appears to have been no mining activity in the area since 1921.

The Fire King asbestos deposit, about 28 miles south of Lander, Fremont County, in T. 30 N., R. 100 W., consists of cross-fiber veins in serpentine associated with chlorite schist and granite intrusions. A shaft 72 feet deep was sunk many years ago, and a drift from the bottom of the shaft was projected for 400 feet. The fiber-bearing rock is well exposed in a cut 125 feet long, 25 feet wide, and 20 feet deep in places. Most of the fiber is short, but Diller[12] states that some long fiber of good spinning quality was obtained. The yield of all grades would probably be under 5 percent. The property was acquired by the American Fireproofing & Mining Co. in 1917. A mill was built in 1919, and it is reported that several carlots of fiber were shipped to Lander. In 1920, however, the output consisted of shaped sectional blocks of serpentine used in chimney construction. No activity has been noted since 1920.

Cross-fiber chrysotile veins occur in serpentine at Beaver Creek, T. 30 N., R. 96 W., about 38 miles southeast of Lander, Fremont County. The fiber is short, and the deposit is evidently small.

Asbestos deposits that have received considerable attention are situated in the Casper Mountain and Smith Creek areas, Natrona County. The Casper Mountain area is in T. 32 N., R. 79 W., about 8 miles south of Casper. The rocks of the district, comprising about 4½ square miles, consist of hornblende schist, diorite, granite, and serpentine. In places the serpentine is cut by granite dikes. The asbestos occurs as cross-fiber veins in the serpentine. Veins ⅛ to ¼ inch wide are the most common; they rarely exceed 1 inch across. Most of the small quantity of asbestos mined came from a lens 1,400 feet long and 500 feet wide. The old workings indicate that considerable short fiber is available. Small quantities of long fiber obtained many years ago were said to be of good spinning quality.

The Smith Creek asbestos area, of about 7 square miles, lies in T. 31 N., R. 78 W., about 27 miles by road from Casper. Masses of serpentine are surrounded by granite-gneiss and are cut by metadiabase dikes. A lens of serpentine 650 feet long and 300 feet wide is exposed by a cut 25 feet wide, 50 feet long, and 20 feet deep in places. Vertical cross-fiber veins of chrysotile appear in the serpentine. Maximum fiber length is about three-fourths inch, and most of it is under one-half inch. The veins are scattered, and there is no evidence of an extensive workable deposit.

In 1908 the North American Asbestos Co. held the Casper Mountain property and the Wyoming Consolidated Asbestos Co. the Smith Creek area. Two other companies—the United Asbestos Co. and the International Asbestos Mill & Power Co.—apparently had holdings in these areas. The latter company leased the Casper Mountain and Smith Creek properties about 1909 and built a small mill on each of them. The Smith Creek mill was completed in 1910 and the Casper Mountain mill in 1911. A small output of asbestos was reported from one or both of these mills in 1911, but activity was restricted by transportation difficulties. Small shipments for flooring manufacture were made in 1912. Thereafter no activity was indicated until 1934, when the Patee Asbestos Shingle Co. reported production of 200 tons from the Casper Mountain property. A small occurrence of harsh chrysotile in serpentine has been noted 3 miles east of the Smith Creek mill. Further details of the Wyoming deposits have been given by Beckwith.[13]

AMPHIBOLE

Alaska

In 1943 Arctic Circle Exploration, Inc., of Candle, Alaska, submitted to the Territorial Department of Mines at Fairbanks, Alaska, a sample that was identified as tremolite asbestos. Mining was begun in a deposit near the summit

[11] Sampson, Edward, Asbestos: Geol. Survey Mineral Resources of the United States, 1920, pt. 2, p. 317.

[12] Diller, J. S., Asbestos: Geol. Survey Mineral Resources of the United States, 1917, pt. II, p. 201.

[13] Beckwith, R. H., Asbestos and Chromite Deposits of Wyoming: Wyoming Geol. Survey, Bull. 29, 1939, 32 pp.

of Asbestos Mountain in the Dahl Creek area, Kobuk River district. Up to November 1945 the company had produced a few tons, but no subsequent production has been reported. The material is suitable for making chemical filters. Occurrences of amphibole fiber have been reported on Admiralty Island and at Chitina on the Copper River.

A peculiar asbestos of the mountain-leather type occurs on Lemesurier Island in the northern part of southeastern Alaska. It is a fibrous, lightweight, matted material resembling buckskin. Three occurrences have been noted, all paralleling the strike and dip of associated limestone beds. About one-half ton of the material was obtained from an opencut. Beds 6 to 10 inches thick were observed. Its identity as paligorskite was established by X-ray analysis. Following is its chemical composition, in percent: MgO 8.11, Al_2O_3 14.27, SiO_2 49.50, Fe_2O_3 2.62, TiO_2 0.32, CaO 3.34, K_2O 0.06, Na_2O 0.34, ignition loss 21.43, H_2O-7.05, H_2O+10.85. It appears to have qualities that would adapt it to the manufacture of asbestos paper. The deposit may be large enough for commercial exploitation. It has been described in some detail in a Bureau of Mines report.[14]

California

As early as 1882, asbestos deposits were worked in San Bernardino, San Diego, Calaveras, and Placer Counties; and in 1883 and 1884 occurrences in Butte, Fresno, Los Angeles, Tulare, Mariposa, and Inyo Counties were noted and some of them developed. Production in 1882 was 1,200 tons; in 1883, 1,000 tons; and in 1884, 1,000 tons. In 1885 a small mine was opened at Windsor in Sonoma County, and fiber of good quality was reported from Del Norte and Yolo Counties. Sales of asbestos in the United States of 30 tons in 1889, 71 tons in 1890, and 66 tons in 1891 were credited entirely to California. In 1892 most of the production was from Wyoming, with small quantities from Oregon and California, but again in 1893 California, with an output of 50 tons, was the only producing State. The mines were idle in 1894 but produced 90 tons in 1895. A small and gradually decreasing output was noted from 1897 to 1900. All the production up to the latter year was classed as amphibole asbestos. Evidently it was used chiefly in San Francisco and Oakland for making pipe and boiler coverings, packings, and roofing.

Deposits of tremolite asbestos of good quality have been worked to a limited extent by Ray J. Sylvester in sec. 1, T. 37 N., R. 5 W., Shasta County. The asbestos occurs in greenish black peridotite. An adit driven 88 feet encountered a tremolite lens that furnished marketable fiber. A small output was recorded in the late 1940's. Homer E. Fenn operated a similar deposit, the Stark property, in the same region. A small tonnage was shipped east for filter use in the late 1940's. A slip-fiber anthophyllite was mined for several years near Sims, Shasta County, but no activity has been noted since 1923. Amphibole asbestos deposits have been reported also at Castellia and Hazel Creek in this county.

A deposit of amphibole asbestos associated with serpentine near Chandlers, Kern County, was developed in 1928. Several short tunnels and opencuts were made, but evidently the operation has not passed the development stage.

A deposit of tremolite 2½ miles north-northeast of Keeler, Inyo County, known as the McIlroy property, has been developed and operated at times. Both long slip-fiber and short cross-fiber asbestos are present. Soft, white fiber occurs near the surface. Small shipments were made to eastern United States for filter use in 1940 and 1941.

A deposit of tremolite asbestos about 1 mile southeast of Iowa Hill, Placer County, was worked in a small way in 1944, 1946, and 1948. It is 9 miles by road from Colfax on the Southern Pacific Railroad. A production of 35 tons over a period of 40 years before 1948 has been reported. The fiber occurs in a faulted contact zone associated with amphibolite schist. A shallow overburden has been removed by a series of trenches about 100 feet long. Tremolite appears in various places throughout the area, but only one vein large enough to work commercially appears.

In 1952 steps were taken to develop a property known as the Golconda asbestos deposit situated in sec. 36, T. 9 N., R. 4 W., about 20 miles north of Victorville, San Bernardino County. The fiber is a tremolite occurring in both slip- and cross-fiber veins in a belt of green schist.

An occurrence of amphibole asbestos, probably tremolite, was reported in 1949 at a point 4 miles northeast from Burro Springs in the Panamint Range, Death Valley Monument. Commercial deposits of amphibole asbestos have been reported also near Quincy, Plumas County, and Hemet, Riverside County.

An experimental mill for preparing amphibole fiber for market was operated for a time in the late 1940's near Paradise, Butte County.

Georgia

Many deposits of anthophyllite are known in Georgia, mostly of the mass-fiber type. Georgia

[14] Fisher, Robert B., Thorne, Robert L., and Van Cott, H. Corbin, Paligorskite, a Possible Asbestos Substitute: Bureau of Mines Inf. Circ. 7313, 1945, 5 pp.

has been the most consistent producer of amphibole asbestos of any of the States. The largest quantity has been obtained from deposits on or near Sall Mountain in the vicinity of Helen, Santee, Cleveland, and Nacoochee, White County. These deposits produced with some interruptions from 1894 until 1930 and possibly in a small way during earlier years. The asbestos is of the mass-fiber anthophyllite type. It is claimed that 90 to 95 percent of the rock quarried was fiber. The best asbestos was near the surface, where weathering had made it soft and flexible. The solid, unweathered rock was less desirable and required different treatment. Resources of the best fiber, therefore, were relatively limited, and most of the available high-grade material was exhausted. The fiber was prepared for use some years ago in a mill at Gainesville about 27 miles from the deposits. It was employed principally for fireproofing, for insulation, and in paint manufacture.

A deposit of considerable extent, described many years ago as the John Martin property, is situated at the top of Mack Mountain about 11 miles north of Clarkesville, Habersham County, in the Chattahoochee National Forest Reserve. Access to the deposit is over about 3 miles of good to passable dirt road, suitable for truck haulage, connected with a paved road. The deposit consists of a potato-shaped pod or lens, about 150 feet long from north to south and about 50 feet wide. Bulldozer cuts have uncovered the deposit enough to permit a fair estimate of a reserve of about 10,000 tons of asbestos-bearing rock which would yield about 50 percent fiber. Associated minerals are talc, chlorite, mica, and clay. No sales have been reported. Two other deposits occur about 7 miles west of Clarkesville.

Another location of some importance, particularly from 1924 to 1927, is at Hollywood, Habersham County. The mass fiber is harsher and less silky than that at Sall Mountain. The deposits are of considerable size. They are said to comprise 5 separate lenses 50 to 250 feet long and 20 to 50 feet wide. The Tallulah Falls Railroad passes within 100 feet of the deposits. During the 3-year period mentioned previously, a small mill was operated. Its equipment consisted of a gyratory crusher, an elevator, a hammer mill, a double cage mill, a vibratory screen, air suction, bin storage, and bagger. The rock was hauled from quarry to mill in small, narrow-gage cars. The fiber produced was used in making battery boxes, for boiler covering, as a constituent in concrete, and as rubber filler. No activity has been reported since 1927. The mill was dismantled and later destroyed by fire. Discontinuance of operation was evidently due to inability to develop sustained markets for the fiber.

The L. M. Arnold asbestos deposit is about 1 mile from Statham, Barrow County, in a flat farming country. Small quantities of fiber have been mined intermittently. Shipments made from 1923 to 1927 were used principally for chemical filters. In 1948 a small tonnage of asbestos was excavated from an open pit, which at that time was about 150 by 100 feet in area and about 35 feet deep. A soft, easily disintegrated anthophyllite appeared in the bottom of the pit. The size of the deposit cannot be easily determined.

Asbestos was mined about 1880, 2 miles northwest of Burton, Rabun County. The mineral was said to be long fibered and woody. It resulted from alteration along fracture zones of an extensive peridotite intrusion. Fiber 6 to 7 inches long occurs in an 18-inch vein in soapstone about 2 miles southeast of Moreland, Corveta County. Long slip fiber occurs in talcose rock north of Luthersville, Meriwether County. A large deposit of anthophyllite was reported in 1949 in Cherokee County, about 45 miles from Atlanta. Other deposits have been noted 2½ miles west of Cleveland and between Cleveland and Nacoochee, White County; near Dillard and Clayton, Rabun County; 10 miles west of Greenville, Meriwether County; southeast of Highlands, Jackson County; and in several localities in Coweta and Troup Counties. Many other undeveloped deposits in the State have been described by Hopkins.[15]

Idaho

The only asbestos deposit in Idaho that has been developed commercially is in Idaho County about 14 miles southeast of Kamiah. The deposit consists of brittle mass-fiber anthophyllite occurring in lenticular masses, some 200 feet long and 25 feet thick. It is regarded as an alteration product of dunite. The Kamiah Asbestos Manufacturing Co. produced in a small way for a number of years before 1918. In September 1921 the property was purchased by the Western Mineral Co. of Kamiah, but no output was reported by this company. The Panhandle Asbestos Co. of Lewiston, Idaho, acquired the property in 1923 and reported small shipments in 1925. No sales have been recorded since that year. According to a press report in 1930 the Diatom Products Co. of Seattle, Wash., purchased the plant. The mill, which was apparently last operated in 1925, had a daily capacity of 240 tons of rock and was equipped with crusher, rolls, screens, and air

[15] Hopkins, Oliver B., Asbestos, Talc, and Soapstone Deposits of Georgia: Georgia Geol. Survey, Bull. 29, 1914, pp. 142–189.

separators. The fiber was used for pipe and boiler covering, in wall plaster and paint, and as a binder in cements and asphalts. In 1922 equipment was installed for sawing fire blocks and insulating brick, but the project did not materialize. Later the property was leased on a royalty basis by Roy Randall and C. H. Bryson, but there is no record of commercial operation. A more complete description of the deposit has been published.[16]

Maryland

Asbestos occurrences were noted in western Maryland as early as 1883, but no production worthy of mention was recorded until 1917. In that year a slip-fiber asbestos deposit was developed near Pylesville, Harford County. For many years this material was designated anthophyllite but was later identified definitely as tremolite. The asbestos occurred in gneissoid schist that had been softened by weathering. The veins generally were small, and the usable fiber was confined to a zone near the surface. The good asbestos extended to greatest depths along shear zones where movement and pressure had been greatest. Mining was conducted to a depth of about 50 feet. The fiber was unusually strong and tough and especially well adapted for making chemical filters. It was processed by the Powhatan Mining Co. at Woodlawn, a suburb of Baltimore. Unfortunately the deposit was worked out and the mine abandoned in 1941. A small quantity of long fiber said to be similar to that occurring at Pylesville has been found in a talc quarry near Dublin, Harford County.

Montana

A deposit of anthophyllite said to be extensive is about 17 miles south of Gallatin Gateway, Gallatin County. The fiber occurs in a dense, hard form but fiberizes to a soft, fluffy mass. Peter F. Karst operated the property for several years, but in 1936 it was acquired by the Karstolite Co. For a time the fiber was manufactured into a wall and ceiling insulation sold under the trade name "Karstolite." The Montana Asbestos Co. controlled the deposit for a time and was succeeded by the Interstate Products Co., the present owner. During the late 1940's the latter company reconditioned the mine, built new roads, stockpiled a considerable tonnage of fiber-bearing rock, and planned to erect a processing plant at Bozeman about 35 miles from the deposit. No production has been reported during recent years.

A small shipment of anthophyllite was recorded in 1928 from a property on Rainey Creek, 7 miles northeast of Libby, Lincoln County.

New Mexico

In 1951 the Bureau of Mines received a sample of a tough, matted mountain leather from a deposit near Deming, Luna County. According to report, the deposit is of considerable extent.

North Carolina

The Bluerock mine, owned by Industrial Minerals Corp., Asheville, N. C., is on an anthophyllite deposit of considerable size on the South Toe River, about 2 miles southeast of Micaville, Yancey County. The original rock was probably a dunite, which evidently had been altered by a granite intrusion into a bluish to greenish-gray amphibole asbestos. The exposure is about 400 feet wide. The chief constituents of the rock are asbestos and talc. Serpentine and magnetite occur in minor quantities. Development reported in 1943 consisted of 2 shallow pits, 1 about 100 feet long and the other considerably smaller. Asbestos, which forms the major part of the rock in the vicinity of the larger pit, is in radiating fibers ranging from ¼ inch to nearly 4 inches in length. Near the surface much of the fiber is altered by weathering to an undesirable brownish color. Further details concerning the occurrence are given in a press release of the Federal Geological Survey.[17] During 1942 and 1943 the mine was an active producer. Sales of amphibole asbestos amounting to 2,214 tons in 1943 were chiefly from the Bluerock mine. The principal use of the fiber was for welding-rod coatings. No sales have been recorded since 1943.

In 1952 a mill was equipped at Spruce Pine, N. C., for processing anthophyllite obtained chiefly at the Bluerock deposit. The mill was designed to prepare Group 7 fibers to be used in conjunction with Canadian 7R chrysotile in asphalt and vinyl tile manufacture. Other actual or proposed uses include welding-rod coatings, molded compounds, paints, insulating cements, filtration materials, and underbody coatings.[18]

About 1928 a mill that would handle 35 tons of rock a day was built at Minneapolis, Avery

[16] Anderson, Alfred L., The Geology and Mineral Resources of the Region About Orifino, Idaho: Idaho State Bureau of Mines and Geol., Pamph. 34, 1930, 63 pp.

[17] Geological Survey, Asbestos Mine Near Bluerock Knob, Yancey County, N. C.: Press release, May 19, 1943, 2 pp.

[18] Rukeyser, Walter A., Mining & Milling Corp. of America to Begin Production in November 1952: Asbestos, vol. 34, No. 5, November 1952, pp. 26–29.

County, for treating mass-fiber anthophyllite occurring in that region. The mill equipment was improved considerably in 1935, and steps were taken to develop a market for prepared asbestos to be used in home insulation and in many other ways. The mill has been idle for many years. A deposit near Plumtree, in this county, was developed some years ago, but very little fiber has been produced.

A mill was built near Otto, Macon County, in 1928 but has not produced. A small output was reported in 1919 from a deposit of mass-fiber anthophyllite at Cane River, Yancey County. Deposits of anthophyllite occur also near Warlick, Burke County; on the Nantahala River, Macon County; near Bakersville, Mitchell County; near Todd, Ashe County; Brevard, Transylvania County; and on Davis Mountain near the old Baker gold mine, Caldwell County.

Oregon

Sixty-four tons of amphibole asbestos produced in Oregon was sold in 1892. Asbestos occurring in the Pine Creek district, Baker County, was described in 1922 as a soft, long-fiber tremolite. Development work on the property was reported in 1925, and in 1926 a 310-foot tunnel was driven. A small production for experimental purposes was reported in 1929. White, iron-free tremolite occurs near Azalea, Jackson County, a slip-fiber asbestos developed along fracture planes. Small quantities were sold between 1941 and 1944. A tremolite deposit has been reported on Cedar Springs Mountain, northern Jackson County. An undeveloped tremolite deposit is situated about 5 miles from Agness, Curry County.

Texas

Amphibole asbestos approaching tremolite in composition occurs in cross-fiber veins traversing serpentine in four localities in Llano and Gillespie Counties. The veins are very irregular, but there is promise of a considerable supply. The occurrence of cross-fiber veins is unusual in amphibole asbestos deposits. Further information is supplied by Sellards and Baker.[19]

Virginia

Anthophyllite asbestos occurs about 12 miles south of Bedford, Bedford County. The prevailing associated minerals are hornblende and olivine. Unlike the mass-fiber deposits of Georgia and Idaho, the best asbestos is the slip-fiber type, occurring in veinlike masses occupying shear zones. Several veins have been noted, and one 18 inches thick supplied considerable fiber from 1904 to 1911. A mill for treating the asbestos was erected in Bedford in 1903. Very little has been produced since 1911. A small quantity has been used in the manufacture of Tenax, a preparation used by dentists.

A deposit of slip-fiber amphibole occurs also at Rockymount, Franklin County. A shaft was sunk to a depth of 40 feet, and 40 tons was obtained from this mine in 1907. Deposits have been noted also near Boyce, Clarke County, and 8 miles from Roanoke, Roanoke County.

Washington

The Asbestos-Talc Products Co. developed a property near Burlington, Skagit County, and produced a small tonnage of mixed talc, serpentine, and asbestos about 1930. The milled product was used in boiler coverings, roofing, and acoustic plaster. The company also manufactured "Asbesto-fill," a heat-insulating building material, and "Asbestocite," a compound of asbestos fiber and talc used in roofing paints and plastics. No production has been recorded during recent years.

Asbestos has been mined near Pateros, Okanogan County, for use in paints. Deposits have been reported near Leavenworth, Chelan County, near Hamilton, Lyman, and at other points in Skagit County; and 8 miles north of Chewelah, Stevens County.

Other Occurrences

Many other occurrences of amphibole asbestos were known from 1880 to 1905. The following localities, mentioned in early records, evidently had small importance as sources of supply: Staten Island and Long Island, N. Y.; New Brunswick, N. J.; Median and Colerain, Pa.; Lawrence County, S. Dak.; Stevens Point, Wood County, Wis.; Six Mile and Pickens, S. C.; Baraga County, Mich.; and New Hartford, Conn., where a small mill was operated in 1903. From 1901 to 1906 a small output of asbestos was reported near Dalton, Mass. It was first thought to be chrysotile but was identified definitely as anthophyllite in 1906. Blue asbestos (crocidolite) occurs at Beacon Pole Hill near Manville, Providence County, R. I., but not in commercial quantities.

FOREIGN DEPOSITS

The deposits of the major producing countries—those of Canada, Southern Rhodesia, Union of South Africa, Swaziland, and Soviet Russia—will first be described and thereafter those of less importance.

[19] Sellards, E. H., and Baker, Charles Laurence, Economic Geology of Texas: Part 3, 1935, p. 252.

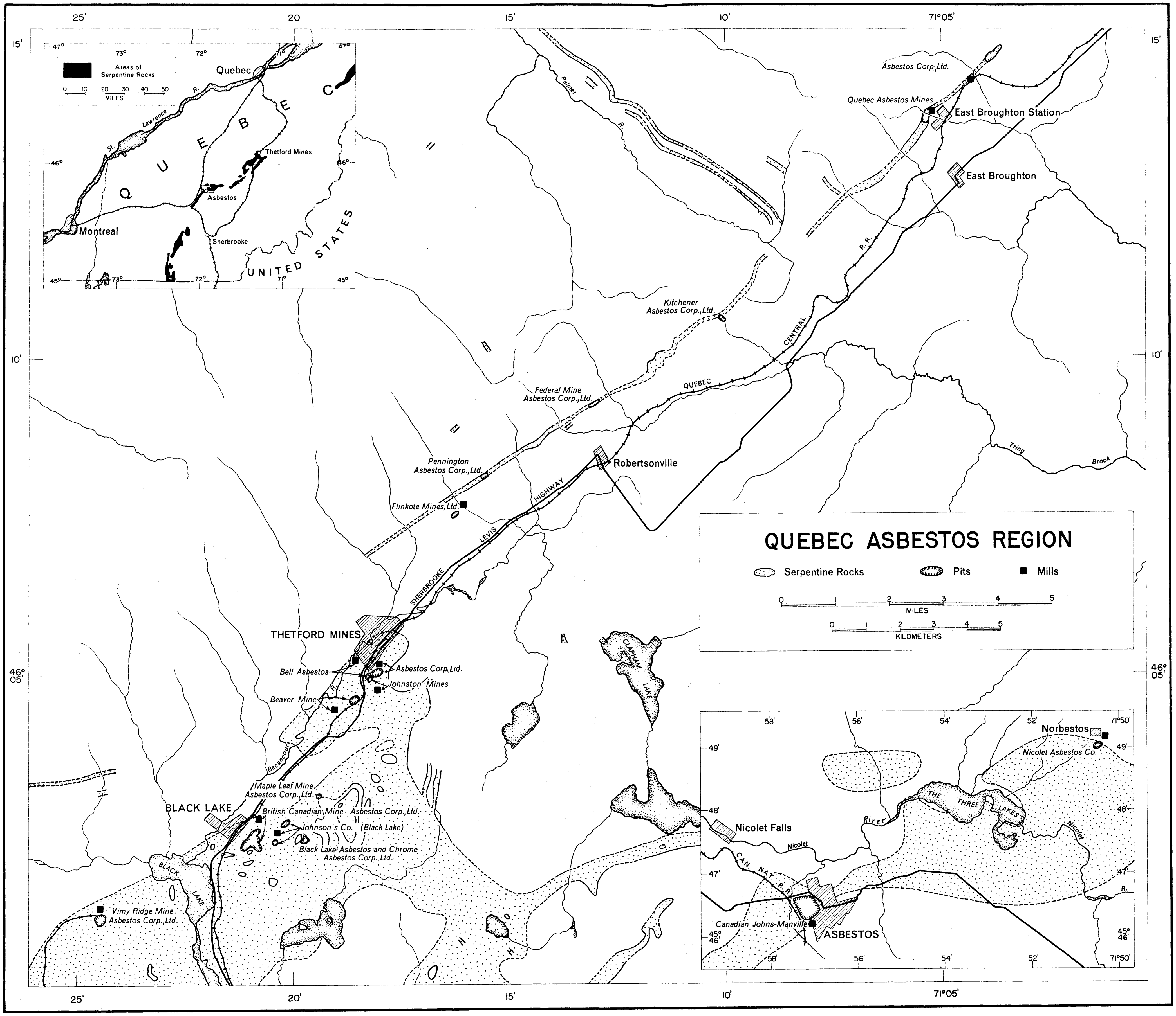

FIGURE 6.—Map of Asbestos Region in Quebec, Canada.

MAJOR PRODUCING COUNTRIES

CANADA

Quebec

The asbestos deposits in the eastern townships of the Province of Quebec, Canada, have been famous since 1878. They are situated 100 to 175 miles from Montreal and somewhat nearer Quebec, occupying a stretch of high ground known as the Notre Dame Hills—an extension into Canada of the Green Mountains of Vermont. The hills continue northeastward to the Gaspé Peninsula, and serpentine is exposed in many places throughout their length. An asbestos deposit was developed at Port Daniel on the Gaspé Peninsula in 1919. Commercial asbestos occurs in two areas along this serpentine zone—the Asbestos and Thetford Mines district described later and the Eden (Vt.) district, which has been described in the discussion of domestic deposits.

The Quebec area, about 70 miles long and a maximum of 5 or 6 miles wide, lies between Danville and East Broughton. Within this section are six producing centers—East Broughton, Robertson, Thetford Mines, Black Lake, Coleraine, and Asbestos. The asbestos, a chrysotile of exceptionally high quality, occurs in a very extensive serpentine and peridotite formation of post-Ordovician age appearing in places as mountain masses rising 700 to 1,000 feet above the surrounding country. It is said to be the largest area of serpentine near the eastern coast of North America. In the accompanying map (fig. 6) of the Quebec asbestos region the areas indicated as consisting of serpentine include also areas of gabbro and pyroxenite, hence the areas of host rock are not as extensive as the map would indicate. Cirkel [20] attributed the origin of the chrysotile to columnar crystallization of serpentine in cracks and fissures. The process is somewhat obscure; but he presumed that the serpentine, which thus takes the form of bundles of extraordinarily fine filaments, crystallized from aqueous solutions acting upon the vein walls.

Cooke,[21] who has made a comprehensive study of the origin of Quebec asbestos, states that folding and deformation toward the close of the Ordovician period were accompanied by the injection of masses of peridotite and pyroxenite. Further folding, probably in the Devonian period, was accompanied by injection of granites and related rocks.

The peridotites and pyroxenites have suffered a general alteration, in consequence of which most of the original olivine and pyroxene have been converted to serpentine. This serpentinization is presumed to have been caused by water present in the peridotite magma reacting with the mineral constituents during the later stages of crystallization.

A second more local alteration was caused by injection of heated waters into fault fissures, from which they penetrated all the pores of the rock; wherever they encountered incipient fissures they reacted with the peridotite, converting it into serpentine, some of which was deposited as the fibrous form of chrysotile. The high temperature that induced or assisted the reaction is attributed to intrusion into the peridotite of the granitic dikes and plugs already mentioned. Deformation and faulting were contributory factors assisting the alteration and recrystallization. Cooke summarizes his conclusions as follows: Three conditions were necessary for the formation of chrysotile fiber veins:

(1) Faulting to break up the rock and permit ingress of solutions.

(2) An adequate supply of the necessary solutions.

(3) Injection of acid dikes in sufficient numbers to raise the temperature of the serpentine to a point where it would react readily with the solution.

Lack of any one of these conditions would prevent formation of fiber veins, even if the other two were present. Cooke claims that the asbestos deposits are localized along the northwest side of the main peridotite mass, therefore the asbestos-forming agents must have entered from that side.

In some places the Quebec fiber is soft and flexible, while in others it tends to be harsh and brittle. Cooke [22] concluded, from careful analyses, that the harshness was due primarily to the presence of talc. Keep [23] reached a similar conclusion regarding Rhodesian chrysotile.

Most of the output of the Black Lake, Thetford, and Danville areas is derived from cross-fiber veins ranging in width from hairlines to 4 or 5 inches and, rarely, even wider. The bulk of the production is obtained from veins less than one-quarter inch across. The width of veins is important because it governs largely the length of fiber. Fortunately the fiber as a rule breaks easily from the wall rock. Figure 7 shows a typical occurrence of asbestos veins in the Quebec district.

Slip fiber originating along slickensided

[20] Cirkel, Fritz, Chrysotile Asbestos—Its Occurrence, Exploitation, Milling, and Uses: Canada Dept. of Mines, Mines Branch, 2d ed., 1910, pp. 92–95.

[21] Cooke, H. C., Thetford, Disraeli, and Eastern Half of Warwick Map-Areas, Quebec: Canada Dept. of Mines and Resources, Geol. Survey, Mem. 211, 1937, pp. 139–140.

[22] Cooke, H. C., The Composition of Asbestos and Other Fibers of Thetford District, Quebec: Trans. Roy. Soc. Canada, ser. 3, vol. 29, sec. 4, May 1935, pp. 7–19.

[23] Keep, F. E., Geology of the Shabani Mineral Belt, Belingwe District: Southern Rhodesia Geol. Survey, Bull. 12, 1929.

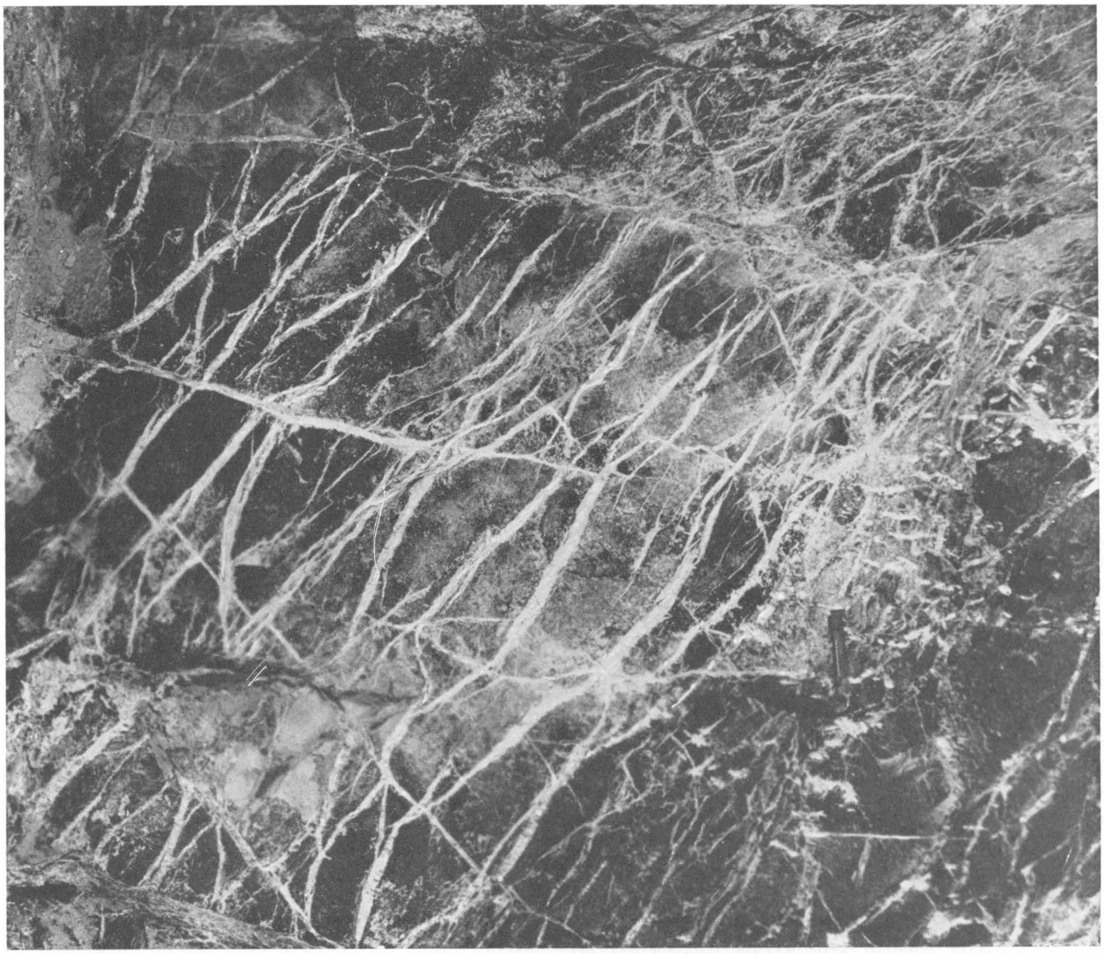

FIGURE 7.—Veins of Asbestos on Drift Face 500 Feet Below Surface, Thetford Mines, Quebec.

fault planes as a result of slow readjustment of the rock masses at a later time forms the chief product of the East Broughton area. The fibers are matted together, more or less in parallel position, and therefore appear to be longer than they really are. Slip fiber, as a rule, is less valuable than cross fiber.

The percentage of fiber in the rock is low; however, because of the wider utilization of the very short fibers during recent years, the percentage of recovery is now considerably higher than it was 20 or more years ago. In 1929 the yield was 5 percent of the total rock mined and 7.7 percent of the rock milled. In 1951 these percentages were 7.7 and 9.5 and in 1952, 7.2 and 8.5, respectively.

Although Canada produces substantial quantities of spinning fiber, considerably more than 90 percent of its production consists of the shorter grades, for which, fortunately, an extensive market exists in the United States.

Table 5 shows the annual production and value of asbestos in Quebec since the industry was first established.

Until 1891 virtually the entire Canadian output was crude fiber, but thereafter both crude and milled asbestos were produced. This change in the character of products is reflected in the sharp drop in average value in 1892 compared with the previous year. The exceptionally high average values from 1918 to 1920 may be attributed to the abnormally high prices obtained for fiber on account of war conditions. Crude No. 1, for example, sold for more than $3,000 a ton during part of this period. The remarkable gains in output during and since World War II are noteworthy.

The following companies operate in the Quebec area: Asbestos Corp., Ltd., operates four mines, the King, Beaver, British Canadian, and Vimy Ridge. Work is underway on a new mill that will bring the Normandie

TABLE 5.—*Asbestos production (shipments and sales) in Quebec, 1878–1953* [1]

Year	Production, short tons	Total value	Average value per ton	Year	Production, short tons	Total value	Average value per ton
1878	50			1916	133,339	$5,182,905	$38.87
1879	300	$19,500	$65.00	1917	137,242	7,198,558	52.45
1880	380	24,700	65.00	1918	142,375	9,019,899	63.35
1881	540	35,100	65.00	1919	135,862	10,932,289	80.47
1882	810	52,650	65.00	1920	179,891	14,749,048	81.99
1883	955	68,750	72.00	1921	87,475	5,199,789	59.44
1884	1,141	75,097	65.81	1922	160,339	6,053,068	37.75
1885	2,440	142,441	58.37	1923	216,804	7,364,260	33.97
1886	3,458	206,251	59.65	1924	208,762	6,561,659	31.37
1887	4,619	226,976	49.55	1925	273,522	8,976,645	32.82
1888	4,404	255,007	57.90	1926	278,689	10,095,487	36.22
1889	6,113	426,554	69.77	1927	274,798	10,621,571	38.65
1890	9,860	1,270,240	128.82	1928	273,033	11,238,361	41.16
1891	9,279	999,878	107.75	1929	306,055	13,172,581	43.04
1892	6,082	390,462	64.16	1930	242,113	8,390,164	34.65
1893	6,331	310,156	48.99	1931	164,297	4,812,886	29.29
1894	7,630	420,825	55.15	1932	122,977	3,039,721	24.72
1895	8,756	368,175	42.04	1933	158,367	5,211,177	32.90
1896	10,892	423,066	38.84	1934	155,980	4,936,326	31.65
1897	13,202	399,528	30.26	1935	210,467	7,054,614	33.52
1898	15,893	496,340	31.23	1936	301,287	9,958,183	33.05
1899	15,571	581,667	37.36	1937	410,026	14,505,791	35.38
1900	21,408	719,416	33.60	1938	289,793	12,890,195	44.48
1901	33,466	1,274,315	38.70	1939	364,472	15,859,212	43.51
1902	30,634	1,161,870	37.92	1940	345,581	15,620,000	45.20
1903	29,261	916,970	31.94	1941	477,846	21,468,840	44.93
1904	35,479	1,186,970	33.43	1942	439,460	22,663,283	51.57
1905	48,960	1,476,450	30.16	1943	467,196	23,169,505	49.59
1906	61,675	2,143,653	34.76	1944	419,265	20,619,516	49.18
1907	61,985	2,455,919	39.62	1945	466,896	22,805,157	48.84
1908	65,157	2,551,596	39.16	1946	558,181	25,240,562	45.22
1909	64,965	2,296,584	35.35	1947	661,821	33,005,748	49.87
1910	80,605	2,667,829	33.10	1948	716,769	42,231,475	58.92
1911	102,224	3,026,306	29.60	1949	574,906	39,746,072	69.13
1912	111,175	3,059,084	27.52	1950	875,344	65,854,568	75.23
1913	136,609	3,830,504	28.04	1951	973,198	81,584,345	83.83
1914	107,401	2,895,935	26.96	1952	929,339	89,254,913	96.04
1915	113,115	3,544,362	31.34	1953	911,226	86,052,895	94.44

[1] Figures for 1878–1922 from Fisher, Norman R., The Quebec Asbestos Industry: Canadian Min. Jour., Aug. 17, 1923, p. 651. Figures for 1923–53 published by the Quebec Dept. of Colonization, Mines, and Fisheries, Bureau of Mines.

mine into production. Johnson's Co., a pioneer producer, has operated a mill for many years, and an additional new mill has recently been completed. Canadian Johns-Manville Corp., Ltd., operates the largest asbestos mine and mill in the world at Asbestos. Other operators are Bell Asbestos Mines, Nicolet Asbestos Mines, Ltd., Quebec Asbestos Corp., Ltd., and Flintkote Mines, Ltd. The Dominion Asbestos Co. produced, on a more or less experimental basis, in its new mill near St. Adrian, Quebec, during part of 1953, but operation was suspended at the end of the year for financial readjustment. Continental Asbestos Co. operated for a short time only. Provincial Asbestos Co., Ltd., began production on a small scale in 1953. The rock was being milled at the Continental Asbestos Co. plant. Extensive development work has been done on the United Asbestos Co. property, most of which underlies Black Lake. The work has been done by Lake Asbestos Co., a subsidiary of American Smelting & Refining Co.; and it was reported in 1954 that the former company had exercised its option to take over the property, erect a new mill, and drain the lake preparatory to open-pit operation. The Lafayette Asbestos Co., Ltd., successor to St. Lawrence Asbestos Co., Ltd., is planning development of its property in Cranberry Township, Dorchester County, Quebec. Development and exploratory work has been done on several other properties.

The Canadian deposits occupy an exceptionally favorable position, as they are within easy reach of extensive markets in the United States. The Quebec industry doubtless will maintain its advantage indefinitely in the short-fiber market, because high freight charges on relatively low-priced products discourage transoceanic competition. For spinning, pipe, and shingle fibers, however, the price per ton is high enough to provide a worldwide market range, and Canada must compete with Southern Rhodesia, South Africa, and Soviet Russia.

In the 1920's, when demand did not exceed supply, foreign competition posed a serious threat to the Canadian spinning-fiber industry. About 1924 the industry took active steps to meet this competition by consolidating companies and exercising economies in mining, manufacture, and marketing. Since then the industry has operated on a better competitive basis, particularly with establishment in 1931 of a uniform fiber classification. The threatened inroads of foreign competition were obviated in the years following the late 1930's, when demand gradually increased until it reached a point where all world sources were unable to meet it.

Recognizing the trend toward wider use of the shorter fibers, shipping companies have recently reduced rates on these grades. Consequently, the market range of the short fibers has been expanding.

Asbestos deposits in Quebec are not confined to the productive area already discussed. The pre-Cambrian Grenville limestone in the Ottawa River Valley has been altered in places to dolomite and magnesite, and in some localities serpentine has been formed by reaction with magnesia- and silica-bearing solutions that emanated from invading gabbros or other intrusive rocks. Locally the massive serpentine is traversed by veins of cross-fiber chrysotile similar to the occurrences in Arizona. Such veins have been found on lot 15, range IX, Grenville Township, Quebec, but their extent has not yet been determined. A few tons of asbestos were recovered in 1942 and 1943 in connection with the mining of refractory magnesite-dolomite rock near Kilmar.[24]

A similar deposit held by Eastern Asbestos Co., Ltd., occurs about 40 miles to the west, 24 miles from Buckingham, Papineau County. Some development work has been done in this area. One band of serpentine 18 inches wide, visible for a length of 40 feet, shows veins of asbestos of the ribbon type ⅛ to ½ inch wide. Another band containing asbestos veins up to ¾ inch thick is said to be continuous for 250 feet. Further exploration is contemplated.

A deposit of good-quality tremolite has been discovered in Quebec on the south side of the St. Lawrence River about 30 miles from Quebec City. Attempts were made in 1949 and 1950 to find a market for the fiber. It is said to be well suited for filter uses, but demands were too small to justify commercial operation.

It was reported late in 1953 that asbestos had been discovered along the new Quebec-Labrador Railway. It is said to be crocidolite (blue asbestos). If so, it is the first discovery of this type of deposit in North America. A Canadian asbestos company is investigating its possibilities.

Ontario

From 1916 to 1924, some interest was aroused in the development of an asbestos industry in Ontario. Small quantities of chrysotile have been obtained at two points in Doloro Township south of the gold-producing area of Porcupine—the Slade-Forbes mine and the Bowman mine. Production was reported at intervals from 1917 to 1926. Thereafter there was no activity, except mining of test samples under option by prospective operators until 1950, when Taegana Mines, Ltd., Shumacher, Ontario, reopened the Slade-Forbes mine and produced a small tonnage. In 1951 the property was optioned to Van Packer Mines of Canada, Ltd., and some exploratory drilling was conducted.

In 1935 considerable development work was done by the Rahn Lake Mines Corp., Ltd., of North Bay, Ontario, on a chrysotile deposit near Matachewan, Ontario, Bannockburn Township, about 30 miles southeast of Timmins in the Porcupine gold area. There has been no significant production.

The most important recent event in the Ontario asbestos industry is development by the Johns-Manville Corp. of a new property—the Munro mine—12 miles east of Matheson, Munro Township, district of Cochrane, Ontario. The deposit is about 55 miles east of Timmins. The chrysotile asbestos occurs in cross-fiber veins in a nearly vertical serpentinized sill having a width of 500 to 900 feet. The sill is cut by later dikes and displaced by cross faults. The veins have a maximum width of about 1 inch. It is anticipated that the deposit will furnish considerable quantities of the longer Group 4 grades, but little or no fibers of spinning grade. Drilling indicates that fiber persists to a depth of several hundred feet. The rock is mined by open-pit methods. Initial milling capacity is 50 tons of rock per hour, with provisions for adding a second 50-ton-an-hour unit. Production began in April 1950. It is stated that much of the output will be used for asbestos-cement products. Development and operation of the Munro mine and mill have been described.[25] Other prospective producers hold adjoining properties. The asbestos-bearing rock has been traced eastward to the Quebec boundary and may extend through several townships to the west. This deposit may prove to be an important supplementary source of asbestos, but

[24] Dresser, John A., and Denis, T. C., Geology of Quebec: Province of Quebec, Dept. of Mines, Economic Geology, vol. 3, 1949, p. 456.

[25] Baker, R. D., Asbestos Production in Ontario: Western Miner and Oil Review (Vancouver, B. C.), vol. 26, No. 12, December 1953, pp. 35–37.

it will probably furnish limited quantities of fibers long enough for textile use. The geology of the area has been described in detail by Hendry.[26]

It was reported in 1953 that the Johns-Manville Corp. had acquired an asbestos property in Reeves Township about 80 miles west of Matheson. Extensive core drilling has established the presence of large reserves, but there is no immediate prospect of development. The Ontario occurrences have been described in a recent report.[27] The following table, showing the history of Ontario production, was taken from this report.

According to this report, Ontario has been a producer of actinolite, a variety of asbestos produced elsewhere in negligible quantities. From 1901 to 1934 a total production of 2,187 tons was reported from a deposit in Kaladar Township, Lennox and Addington County.

British Columbia

Cassiar Asbestos Corp., Ltd., subsidiary of Con-West Exploration Corp. of Toronto, Canada, is developing a new asbestos deposit in northern British Columbia. The fiber-bearing rock occurs at an elevation of 6,000 feet on a spur of McDame Mountain and is deeply covered with talus containing 7 to 8 percent of chrysotile fiber already opened by centuries of freezing and thawing. The appearance of the talus slope is shown in figure 8. The area is about 60 miles south of the Yukon Territory-British Columbia boundary and about 70 miles from the Alaska Highway. The company estimates that nearly 6,000,000 tons of asbestos-bearing rock containing 7 percent fiber of spinning grade is already in sight.

A mill having a capacity of 250 tons of rock a day was completed in 1952 and was in production by midsummer 1953. It is designed primarily to process fiber from surface exposures. A larger mill to handle rock from underground workings was under construction in 1953 and 1954. Samples of the asbestos tested in the United States were found to be of good quality for textile use. It appears that the iron content of the processed fiber will be low enough to pass specifications for nonferrous fiber.

Two properties in southern British Columbia have been acquired by Western Asbestos & Development, Ltd., a company formed in 1952. The Okanagan Falls property is on the east side of Lake Vaseaux, 6 miles from the Okanagan Highway. The deposit was discovered in 1910, and 10 opencuts were made by bulldozer in 1947. Further opencut exploration and prospect drilling were under way in 1953. The asbestos consists chiefly of anthophyllite lenses associated with serpentine. Short-fiber chrysotile is reported in places. The deposit appears to be large.

The second deposit, the Revelstoke property, is on Sproat Mountain 2 miles from the Revelstoke Highway and 2½ miles from the Canadian Pacific Railway. The asbestos is the chrysotile variety, occurring in cross-fiber veins up to five-eighth inch long and also as slip fiber up to 5 inches long. A program of geologic mapping, trenching, and prospect drilling is planned.[28]

Newfoundland

Several deposits of chrysotile occur in the Lewis Brook area near the west coast of Newfoundland. Samples of the asbestos examined by the Bureau of Mines some years ago appeared to be of good quality. Difficulty of access and poor transportation are probably the chief handicaps to development. However, it was reported in 1953 that Newfoundland Asbestos, Ltd., was preparing for com-

[26] Hendry, N. W., Chrysotile Asbestos in Munro and Beatty Townships, Ontario: Canadian Min. and Met. Bull., vol. 54, 1951, pp. 28-35.

[27] Hewitt, D. F., and Satterly, J., Asbestos in Ontario: Ontario Dept. of Mines, Industrial Minerals Circ. 1 (rev. ed.), April 1953, 23 pp. and maps.

[28] Stephens, Fred H., Asbestos in Southern B. C.: Western Miner and Oil Review, vol. 26, No. 7, July 1953, pp. 44-46.

TABLE 6.—*Chrysotile-asbestos production in Ontario, Canada*

Year	Tons	Value	Mine	Operator
1917	10	$2, 150	Slade-Forbes	Slade-Forbes Asbestos Co.
1923	6	2, 600	Bowman	Bowman Asbestos Mines.
1924	172	91, 900	do	Porcupine Asbestos Mining Syndicate.
1925	2	901	do	Do.
1926	14	3, 925	do	Do.
1937	1	250	Rahn Lake	Rahn Lake Mines Corp., Ltd.
1939	18	720	do	Do.
1950	10, 518	1, 493, 099	Munro	Canadian Johns-Manville, Ltd.
1951	26, 549	3, 766, 769	do	Do.
	38	6, 300	Slade-Forbes	Taegana Mines, Ltd.
1952	23, 033	3, 847, 853	Munro	Canadian Johns-Manville, Ltd.

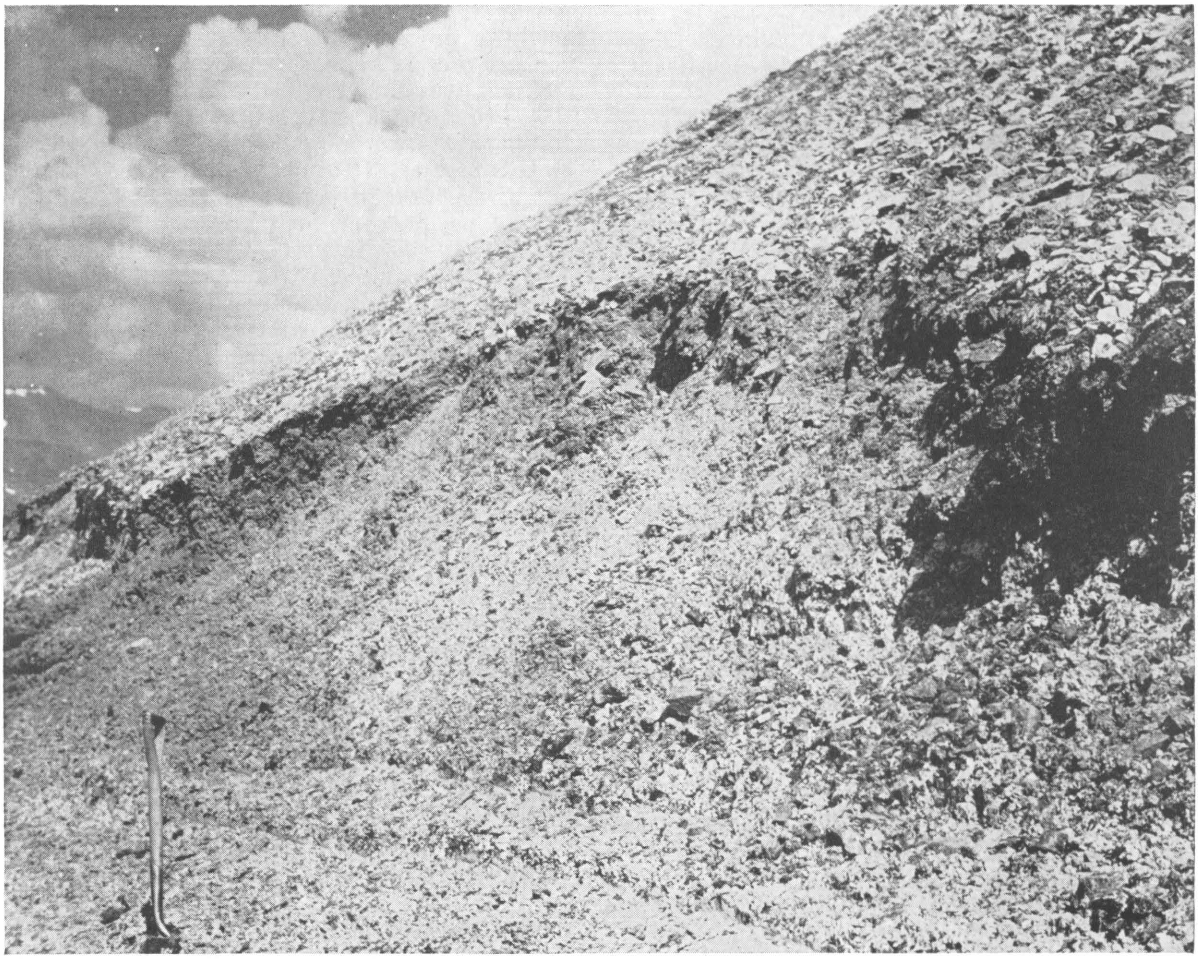

FIGURE 8. Road Cut Through Asbestos Talus of Serpentine Rock, Cassiar Asbestos Corp., British Columbia, Canada.

(Photograph by J. J. Denovan, Montreal, Canada.)

mercial operation. Equipment for a mill of 200-ton daily capacity was being taken by tractor to the mine site on Port au Port Bay. An exploratory adit has been driven 500 feet into the deposit.[29]

SOUTHERN RHODESIA

Southern Rhodesia ranks next to Canada as a world source of chrysotile asbestos. The Russian deposits are doubtless larger, but the Russian output is applied principally to domestic uses; only minor, fluctuating, and uncertain quantities enter international trade.

The growth of the asbestos industry in Southern Rhodesia has been almost phenomenal. From an initial output of only 55 tons in 1908 production increased to over 42,000 tons by 1929 and nearly 88,000 tons in 1953. Annual production since the beginning of activity is shown in table 7.

The fiber is of the chrysotile variety and occurs in serpentine. It is similar in character and occurrence to that found in Canada, except that the iron content is lower and more easily removed.

The most important area is the Shabani, 120 miles east of Bulawayo. The widely known Shabani mine is not a single opening but a group of four mines comprising Birthday, Nil Desperandum, 177, and 170. These mines are operated by Rhodesian & General Asbestos Corp., Ltd., a subsidiary of Turner & Newall, Ltd., of Manchester, England. The Shabani group is in the central part of a serpentine mass about 10½ miles long and 1 to 3 miles wide. The fiber-bearing serpentine zone is 2½ to 3 miles long and 20 to 200 feet thick. The footwall is a talc schist. The fiber-bearing rock is an ultrabasic dunite-serpentine in-

[29] Northern Miner, Moving in Equipment at Newfoundland Asbestos: Vol. 38, No. 47, Feb. 12, 1953, p. 28.

Table 7.—*Annual production of asbestos in Rhodesia, 1908–53* [1]

Year	Short tons	Value	Year	Short tons	Value
1908	55	£552	1931	24, 042	£386, 494
1909	272	2, 722	1932	15, 766	197, 092
1910	332	3, 320	1933	30, 182	555, 993
1911	460	6, 397	1934	32, 214	402, 745
1912	------	------	1935	42, 598	646, 658
1913	290	5, 224	1936	56, 346	836, 469
1914	487	8, 612	1937	57, 014	840, 025
1915	2, 010	32, 190	1938	58, 811	1, 020, 921
1916	6, 157	99, 059	1939	58, 313	1, 088, 782
1917	9, 562	189, 890	1940	[2] 57, 891	1, 419, 566
1918	8, 574	158, 684	1941	44, 134	910, 041
1919	9, 798	425, 240	1942	55, 803	1, 488, 052
1920	18, 823	459, 572	1943	58, 146	1, 673, 025
1921	19, 528	795, 698	1944	58, 293	1, 674, 467
1922	14, 249	577, 699	1945	56, 293	1, 788, 386
1923	20, 364	626, 898	1946	55, 872	1, 676, 503
1924	26, 141	603, 423	1947	54, 094	1, 738, 484
1925	34, 349	765, 926	1948	68, 897	2, 604, 623
1926	33, 344	726, 835	1949	79, 638	3, 986, 703
1927	33, 176	794, 215	1950	71, 527	4, 615, 490
1928	39, 960	970, 327	1951	77, 663	5, 452, 108
1929	42, 634	1, 186, 627	1952	84, 834	6, 651, 975
1930	37, 765	1, 070, 847	1953	87, 739	6, 542, 731

[1] Data from Geological Survey and Bureau of Mines Mineral Resources of the United States and Bureau of Mines Minerals Yearbook.
[2] Exports.

truded by gneissic granite. Cross- and slip-fiber chrysotile occurrences of commercial size are found only in masses of serpentinized dunite. The fiber is white, silky, and very flexible. The formation dips 25° to 45° in the hill country and 5° to 10° in the flat area. It extends down the dip for an unknown distance, probably far below practical working depth. Fiber veins attain a maximum of 6 inches in thickness, but the fibers are rarely over 3 inches long. Data on the geology of the area have been assembled by Badollet.[30]

The Shabani area is a prolific producer furnishing 4,000 tons a month or more of commercial fiber. The most valuable fibers are the C & G Nos. 1 and 2, produced chiefly in the Birthday mine. The Croft mine at Filibusi has attained some importance.

For many years the district was handicapped seriously by difficult transportation; 400 wagons and 7,000 oxen were used for conveying supplies and products many miles over poor roads. In 1928 this hindrance was overcome when a 63-mile railway from Shabani to Somabula was completed.

In 1951 steps were taken to finance a new company, Rhodesia Monteleo Asbestos, Ltd., a subsidiary of African & European Investment Co., Ltd., of Johannesburg. The property involved is a 740-acre tract in the Vukwe Hills about 15 miles southeast of Shabani. The deposit consists of a steeply inclined zone of asbestos-bearing serpentine, 80 to 275 feet wide, lying between masses of granite. The fiber zone is said to have been traced for 5,000 feet along the strike. The asbestos is of the slip-fiber type. According to a published prospectus,[31] surface exploration and prospect drilling have established a reserve of about 12,000,000 tons of fiber-bearing rock above the 400-foot level, yielding 1½ to 2½ percent asbestos. A high percentage of long fiber is indicated. A mill with a capacity of 15,000 tons of rock a month has been built. It was in operation for a short time but was closed down late in 1953. It was reported that asbestos prices were too low to yield a profit.

The Asbestos Mining & Supply Corp., Ltd., controls the Kloef mine adjacent to the Rhomanite mine of Rhodesian Monteleo, Ltd. It is developed with shafts and adits and is said to have large reserves. According to report, a pilot plant was in operation in 1953.

The Johns-Manville Corp. of New York City, in cooperation with British Metals Corp. and other interests, has undertaken to develop two properties, the Temeraire and the Shamala, in the Mashaba district of Southern Rhodesia. One mill will handle the product of both deposits. A new subsidiary company, Rhodesian Asbestos, Ltd., has been organized; and two additional properties, the Shashi and the Darwendale, have been acquired. Preparation was made during 1953 for production on a substantial scale.

There are several small asbestos-producing mines in the Belingwe district south of Shabani,

[30] Badollet, Kay, Geology of Asbestos Deposit in Southern Rhodesia: Asbestos, vol. 32, No. 2, August 1950, pp. 4–8.

[31] Rand Daily Mail, Johannesburg, Sept. 24, 1951.

among which are the Vanguard, Associated Asbestos Mines, Ltd., and the Southern Rhodesian Chrysotile Corp., Ltd. The latter operation furnishes some fiber equivalent to Canadian 3R. During 1951 the mine was producing at a rate of about 75 tons of fiber a month, but late in the year a serious cave-in interrupted production greatly.[32]

The Mashaba district, 42 miles east of Shabani on the road to Fort Victoria, is a producer of a well-known commercial grade of asbestos, VRA. The principal mines are the Gath's and the King, 4 miles apart. They are owned by Rhodesian & General Asbestos Corp., Ltd. Historically they are the oldest producers. Mining was first undertaken about 1907. Production rose from 2,010 tons in 1915 to 9,799 tons in 1919, and 18,823 in 1920. A small production is obtained at times from the Ethel mine in the Lomagundi district more than 200 miles north of Victoria.

Samples of asbestos equivalent to Canadian 3R or better have been obtained from the 14th and 16th levels of the Antelope gold mine in the Bulawayo district. No information is now available on the extent of the occurrences.[33]

About 30 other mines or prospects have been listed, but production from them has been small. Most of them are in an area that includes Mashaba, Shabani, Belingwe, and Filabusi. The shortage of Rhodesian fiber entering the United States in 1951 stimulated more active development. The Economic Cooperation Administration (ECA), later succeeded by the Mutual Security Agency (MSA), gave assistance in some instances.

In 1929 all important mines were consolidated under a single company, Turner & Newall, Ltd., of Manchester, England. This company has controlled almost the entire output of asbestos in Southern Rhodesia since that time.

Rhodesian asbestos is especially important for two reasons. First, the proportion of long fibers of strategic grade is relatively high. It has been estimated that 25 to 30 percent of the fiber produced may be classed as spinning grade, whereas only 4 to 6 percent of Canadian fiber is of this grade. The preponderance of long fiber in the Shabani area is, however, overemphasized on a percentage basis by the fact that there is an enormous market for Canadian short grades, whereas the shorter fibers are recovered in smaller quantity in Rhodesia because they cannot be shipped profitably to markets the chief of which are remote from the mines. The second reason for the outstanding importance of the Rhodesian asbestos is its content of easily removable iron. Thus, after milling, the fiber is well adapted for electrical insulation uses.

There is only a small local market for Rhodesian fiber. The product of the mines is exported, chiefly to Europe and America, by way of the port of Beira, Portuguese East Africa.

The early history of the industry has been described.[34]

UNION OF SOUTH AFRICA[35]

More kinds of asbestos are produced in the Union of South Africa than in any other country in the world. Blue asbestos (crocidolite) is produced in large quantities in the Cape of Good Hope; chrysotile and tremolite have been mined in small quantities in Natal; while four varieties—chrysotile, crocidolite, amosite, and anthophyllite—are mined in the Transvaal. Table 8 shows production by kinds. The output of amosite recorded in this table is exclusively from the Transvaal; the blue variety comes principally from the Cape Province, with smaller quantities from the Transvaal, while the chrysotile originates chiefly in the Transvaal. Table 9 shows production, by Provinces, from 1910 to 1953.

The following descriptions of deposits may be supplemented by consulting certain more detailed South African reports.[36]

Cape of Good Hope

The fiber resources of Cape Province are blue asbestos, which was first discovered between 1803 and 1806. The name "crocidolite" ("woolly stone") was proposed by J. F. L. Hausmann in 1831. The most extensive deposits of crocidolite known in the world occur in Griqualand West, northern Cape of Good Hope, in a belt of banded ironstones of sedimentary origin extending from a point 20 miles south of the town of Prieska northward beyond the village of Kuruman to the borders of the Bechuanaland Protectorate. The maximum width is about 30 miles. The lavender-blue crocidolite occurs in interbedded cross-fiber veins that are widely distributed throughout the entire length of the belt. The asbestos is confined to the lower iron-rich third of the Griquatown formation. As the asbestos is derived from folded sediments with variable dip and strike, knowledge of the geology is essential to intelligent prospecting and development.

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[32] Data from B. C. Burgess, Defense Minerals Production Administration (DMPA), Johannesburg, South Africa.

[33] See footnote 32.

[34] South African Mining and Engineering Journal, The Rise of Rhodesia's Asbestos Industry: Vol. 52, part 1, No. 2531, Aug. 2, 1941, pp. 693–695.

[35] Some of the information herein was kindly furnished by the Geological Survey of the Union of South Africa.

[36] Hall, A. L., Asbestos in the Union of South Africa: Union of South Africa Geol. Survey Mem. 12, 2d ed., 1930; Union of South Africa, Department of Mines, The Mineral Resources of the Union of South Africa: 1940, pp. 320–334.

TABLE 8.—*Asbestos production in Union of South Africa, by kinds, 1926–53,*[1] *in short tons*

Year	Amosite	Crocidolite	Chrysotile	Total	Year	Amosite	Crocidolite	Chrysotile	Total
1926	2, 940	4, 024	7, 133	14, 097	1940	17, 767	8, 901	646	27, 314
1927	5, 093	4, 873	12, 174	22, 140	1941	19, 211	7, 352	1, 658	28, 221
1928	6, 748	5, 144	12, 162	24, 054	1942	24, 924	7, 641	1, 917	34, 482
1929	9, 260	6, 030	17, 747	33, 037	1943	23, 189	10, 344	2, 034	35, 567
1930	3, 281	5, 481	10, 519	19, 281	1944	22, 848	9, 666	2, 014	34, 528
1931	2, 087	3, 651	9, 938	15, 676	1945	16, 737	9, 671	1, 765	28, 173
1932	1, 391	2, 964	7, 715	12, 070	1946	9, 838	8, 691	1, 666	20, 195
1933	3, 090	3, 225	9, 572	15, 887	1947	18, 780	9, 079	2, 253	30, 112
1934	3, 757	2, 811	11, 025	17, 593	1948	30, 372	10, 909	4, 441	45, 722
1935	4, 684	2, 541	15, 483	22, 708	1949	41, 974	21, 180	7, 609	70, 763
1936	4, 823	4, 264	16, 149	25, 236	1950	42, 393	30, 598	14, 334	87, 325
1937	6, 531	5, 247	16, 855	28, 633	1951	54, 053	33, 659	19, 509	107, 221
1938	8, 793	8, 810	5, 573	23, 176	1952	63, 280	44, 735	24, 970	132, 985
1939	11, 299	10, 127	612	22, 038	1953	38, 258	37, 707	18, 840	94, 805

[1] Data from Bureau of Mines Mineral Resources of the United States and Minerals Yearbook. A small output of anthophyllite is omitted.

TABLE 9.—*Asbestos production in Union of South Africa, by Provinces, 1910–53, in short tons*[1]

Year	Cape Province	Transvaal	Total	Year	Cape Province	Transvaal	Total
1910 [2]	680	10	[3] 693	1932	2, 964	9, 106	12, 070
1911	1, 254	-----	[3] 1, 267	1933	3, 225	12, 662	15, 887
1912	1, 217	-----	[3] 1, 220	1934	2, 810	14, 783	17, 593
1913	938	-----	[3] 962	1935	2, 541	20, 167	22, 708
1914	1, 160	30	1, 190	1936	4, 048	21, 188	[3] 25, 236
1915	2, 083	56	2, 139	1937	4, 712	23, 921	[3] 28, 633
1916	4, 228	407	[3] 4, 656	1938	6, 484	16, 505	[3] 23, 176
1917	2, 999	3, 193	6, 220	1939	5, 144	15, 827	[3] 22, 038
1918	-----	-----	3, 674	1940	6, 381	21, 011	27, 392
1919	3, 204	631	[3] 3, 933	1941	6, 576	21, 704	28, 280
1920	3, 526	3, 541	[3] 7, 112	1942	7, 281	27, 278	34, 559
1921	3, 467	1, 593	[3] 5, 122	1943	7, 888	27, 768	35, 656
1922	2, 991	1, 392	[3] 4, 389	1944	7, 835	26, 747	34, 582
1923	4, 317	4, 076	8, 393	1945	8, 200	20, 016	28, 216
1924	3, 001	4, 240	7, 241	1946	7, 589	12, 636	20, 225
1925	2, 540	7, 628	10, 168	1947	8, 183	21, 959	30, 142
1926	3, 993	10, 104	14, 097	1948	8, 301	37, 434	45, 735
1927	4, 827	17, 313	22, 140	1949	11, 999	58, 918	70, 917
1928	5, 078	18, 976	24, 054	1950	15, 211	72, 203	87, 414
1929	6, 030	26, 984	[3] 33, 037	1951	18, 078	89, 290	107, 368
1930	5, 481	13, 800	19, 281	1952	24, 441	109, 398	133, 839
1931	3, 651	12, 025	15, 676	1953	20, 883	73, 934	94, 817

[1] Figures for 1910–17 from Asbestos in the Union of South Africa: Union of South Africa Geol. Survey Mem. 12, 1918, p. 134; figures for 1918–53 from Union of South Africa, Dept. of Mines (includes small quantities of anthophyllite for some years).
[2] Last 7 months.
[3] Includes small production in Natal.

The fibers range in length from less than ½ inch to 2 inches or more but rarely exceed 4 inches. The proportion of spinning fiber is higher than that usually found in chrysotile deposits. Cape blue works up easily into a mass of fibers that are flexible and resilient and have a silky feel. Its tensile strength is generally greater than that of chrysotile, and it is also more resistant to acids and sea-water. It is used principally in filter cloth, boiler mattresses, packings, gaskets, and asbestos-cement pipe.

A highly silicified, pale brown, semiprecious variety, known as "tiger-eye" or "cat's-eye," occurs in the Hay district. The lighter color varieties are obtainable in slabs 9 to 12 inches long and the darker kinds in pieces only ½ to ¾ inch across. In 1935, 9,000 pounds of "tiger-eye" was marketed.

In general, the region is arid, with limited water supplies. Transportation is also difficult; some workings are as much as 130 miles from the nearest railway.

The Cape Asbestos Co. undertook active mining north of Prieska in 1893 and in 1929 was operating 13 mines. During 1951 quite a number of nomad prospectors and diggers operated in the asbestos belt, but the principal producers were the Cape Blue Mines of South Africa Pty., Ltd., a subsidiary of Cape

Asbestos Co., Ltd., and the Griqualand Exploration & Finance Co., Ltd. Turner & Newall, Ltd., has acquired considerable interest in the asbestos belt. Griqualand Exploration & Finance Co., Ltd., produces blue fiber from two mines, each having a mill, in the Kuruman district. Kuruman Cape Blue Asbestos Pty., Ltd., also operates a mine and mill. The output for many years up to 1947 was 7,000 to 10,000 tons annually, but since then it has increased remarkably and exceeded 24,000 tons in 1952. The new Riley Bridge over the Orange River at Koegas, completed in 1952, will greatly facilitate transportation and stimulate increasing production of blue asbestos.

Transvaal

Chrysotile.—*Carolina district.*—Asbestos was first produced in the Transvaal about 1905 from a deposit of chrysotile 20 to 25 miles east of Carolina. In origin and occurrence it is similar to that found in Arizona. Cross-fiber veins occupy a 5-foot zone of altered dolomite overlying a diabase sill. The veins parallel the bedding, which dips 8° to 15° northwest. Mines have been operated at various times, but production has never been large.

A second deposit of chrysotile in the Carolina district occurs on the farm Kalkloof, 3 miles south of the Komati River and 47 miles by road from Carolina. This occurrence is of the usual type—cross-fiber veins in serpentine derived from ultrabasic igneous rock. The fiber occurs in many closely spaced, parallel, thin seams inclined at a steep angle. The asbestos is of good quality, but a large proportion of it is short mill fiber. Evidently reserves are extensive. A mill was in operation in 1929, but production has been small.

Barberton district.—In 1918 Hall [37] directed attention to a chrysotile deposit near Barberton in eastern Transvaal, but it was not developed seriously until after 1921. The deposit occurs in a belt of serpentine bounded by quartzites lying about 3 miles from Kaapsche Hoop and 14 to 17 miles by road from Godwin River station. The asbestos-bearing portion of the serpentine has been traced for a length of 3 and a width of 2 miles. Further exploration may extend its boundaries considerably. Underground mines have been developed extensively near both the eastern and western ends of a 2-mile zone.

The New Amianthus Mines, Ltd. (subsidiary of Turner & Newall, Ltd.), operated near the western end. This deposit proved to be unusually rich. In 1930 the average recovery was 15 to 17 percent of the rock mined, and monthly output averaged about 1,000 tons of fiber. Unfortunately, the reserves proved to be too small to sustain production for more than a few years, and by the late 1930's the mine was said to be nearly worked out. However, it was reopened in the early 1950's by Audax Asbestos Holdings.

The Munnik-Myburgh mine occupies the eastern end of the serpentine area. Mining was begun about 1920, and in 1930 monthly production averaged about 200 short tons of chrysotile fiber. This mine also became inactive; it is claimed that suspension of operations was due to flooding and collapse as a result of heavy rainfall. In 1950 the property was leased by African & European Investment Co., Ltd., of Johannesburg, and active measures were taken to reopen the mine. The corporate name of the operator is Munnik-Myburgh Chrysotile Asbestos, Ltd. Reserves are said to be extensive. The company claims to have four parallel reefs, known as Munnik line, Griffin line, Smithy line, and Jones line. Recent development work has been principally in the Munnik line. The other belts are yet to be explored. Treatment in a pilot mill of rock from the reopened mine is said to show a fiber recovery of 10 percent of rock milled. A new mill with a monthly capacity of 8,000 tons of rock has been completed. Late in 1950 the underground workings had been developed enough to furnish 4,000 to 5,000 tons of asbestos-bearing rock a month. The fiber will be shipped from Neilspruitt Station, 16 miles from the mine, with a direct rail line to the port of Lourenço Marques.

The Staltzburg Asbestos (Chrysotile) Holdings, Ltd. (successor to Staltzburg Asbestos Co., Ltd.), and the Doyershock Asbestos Mine, Ltd., are close together about 19 miles southwest of Barberton. The former company produced at a rate of 3,000 to 5,000 tons a year since 1950. The Doyershock property, situated on a 2,500-acre tract, is said to contain large chrysotile-asbestos reserves. A mill, which was being remodeled in 1951, has produced a moderate tonnage, chiefly 4Z, according to Canadian classification. Mining has been conducted in three underground levels and in an open pit. Extraction is said to be about 2 percent of the rock mined.

Barberton Chrysotile Asbestos, Ltd., began operation in 1947 about 30 miles northeast of Barberton. The company has a mill that can produce about 200 tons of processed fiber a month.

African Chrysotile Asbestos, Ltd., a subsidiary of Msauli Asbestos Mining & Exploration Co., Ltd., has become an important producer. From 300 to 500 tons of processed fiber a month is prepared at the property, which is about 17 miles south of Barberton. Renova-

[37] Hall, A. L., Asbestos in the Union of South Africa: Union of South Africa Geol. Survey Mem. 12, 1918, p. 59.

tion of the mill and addition of improved equipment were reported in progress in 1952.[38] Several other companies operate in the Barberton area.

Amosite.—The only commercial deposits of amosite known in the world occur in the Transvaal. As indicated in the introductory part of this report, amosite does not appear to be a separate mineral species, but it has enough distinctive qualities to justify its continued consideration as a commercial type.

The amosite belt extends from just south of the confluence of the Olifants and Steelpoort Rivers northwestward along the basin of the former river to a point near its junction with the M'Thlapitsi River, and thence westward to Chuniespoort.

The asbestos occurs in cross-fiber veins associated with diabase sills in a series of shales, slates, and quartzites that dip about 18°. The depth to which the asbestos veins persist down dip has not been determined. The strike of the rock parallels the Olifants River; accordingly, the tributaries of the river cut across the strike and create favorable conditions for driving strike adits along the fiber veins.

The most prolific source of amosite is a group of mines near Penge 65 miles north of Lydenburg. These mines are controlled by Egnep, Ltd., a subsidiary of Cape Asbestos Co., Ltd. Amosite is the only asbestos present in this area, usually referred to as the Lydenburg field. The relatively undisturbed nature of the banded ironstones in this region has permitted systematic mining and preparation of a fairly uniform product.

That part of the belt north of the Olifants River is known as the Pietersburg field, where many smaller mines are worked. In this field both amosite and crocidolite are present as cross-fiber veins in banded ironstones, which are intensely and intricately folded. Amosite occurs alone in certain horizons, but crocidolite is usually accompanied by amosite, either in contiguous parallel seams or mixed within a single seam.

Crocidolite is also mined in the same geological formation in the Warmbaths and Rustenburg districts near the iron-ore mine at Thabazimbi.

The asbestos at Penge occurs in three bands. The Upper band is 42 inches thick; 14 percent is asbestos. Below it is 72 inches of waste rock, beneath which is the Main band, 60 inches thick, about 25 percent of which is asbestos. A band of waste rock 108 inches thick lies below it, and beneath is the Lower band, 30 inches thick, 11 percent of which is amosite fiber. The bands are mined separately, and the fiber from each has distinctive properties.

There are four mines along the outcrop. The Amosa and Penge mines are adjacent to each other at the town of Penge. The main milling facilities are at these mines. The Kremellanboog mine is about 8 miles to the southeast along the strike, and the Malips mine is 25 miles northwest of Penge. Each mine has its own milling and housing facilities. Many smaller mines are also worked.

Much of the fiber is 6 inches or more in length, is of strategic importance, and is in strong demand. Output has increased greatly, exceeding 42,000 tons in 1950.

Renewed interest has appeared in the asbestos known as "montasite." This is not a new term; the variety was described by Hall [39] more than 20 years ago as follows:

> The term "montasite" has recently been registered as a trade name to denote a fiber of very superior quality found in the Montana mine of the Pietersburg field. Its mode of occurrence in the banded ironstones, physical characters, and chemical composition show that montasite is identical with amosite, of which it represents merely a very finely fibrous variety; thoroughly fiberized montasite has a very beautiful almost white appearance, and is liable, on cursory examination, to be mistaken for chrysotile.

The term has recently been applied to the product of several mines in the Union of South Africa. Some samples named montasite sent to the Bureau of Mines were identified as amosite. The term "montanosite" has also been used.

Crocidolite.—Occurs in the western part of the amosite belt, a region designated as the Pietersburg district. It is associated closely with amosite, and both varieties are obtained from some of the workings. The blue asbestos is obtained chiefly from open pits near and east of the Malips River. The maximum length of fiber is about 3 inches. The deposits are confined to the lower part of the Pretoria series, where the fiber occurs in banded ironstones. "Transvaal blue" differs mainly from "Cape blue" in that it usually contains minute magnetite crystals which cut the fibers. Furthermore, it fiberizes less readily than the Cape material. In general, therefore, Cape blue is preferred; but improved milling methods are gradually overcoming the difficulties, and a substantial market has been established. The remarkable increase in production to 17,356 tons in 1952 justifies a statistical record of the industry during recent years. Table 10 shows production from 1936 to 1952. Production of Cape blue is shown in table 9 in the column

[38] Information from B. C. Burgess, DMPA, Johannesburg, Union of South Africa.

[39] Hall, A. L., Asbestos in the Union of South Africa: Union of South Africa, Dept. of Mines and Industries, Geol. Survey, Mem. 12, 1930, p. 27.

headed "Cape Province" because this is the only type of asbestos produced in that area.

TABLE 10.—*Crocidolite production in Transvaal, 1936–52* [1]

Year	Short tons	Year	Short tons
1936	216	1945	1, 471
1937	535	1946	1, 102
1938	2, 326	1947	896
1939	3, 983	1948	2, 608
1940	2, 520	1949	9, 181
1941	776	1950	15, 387
1942	360	1951	18, 078
1943	2, 456	1952	17, 356
1944	1, 831		

[1] Bureau of Mines Minerals Yearbook.

Anthophyllite.—Occurs in the Zoutpansberg district, 50 miles west of Waterpoort Siding. The fibrous structure has evidently been developed under the influence of weathering, therefore the persistence of usable fiber at depth is doubtful. Production has never been large; since 1939 it has ranged from 12 to 89 tons a year.

Natal

The most important asbestos deposit in Natal is in the Tugela River Valley east of Kranz Kop, Zululand. Chrysotile asbestos occurs here in vertical cross-fiber veins near contacts of aplite dikes with green serpentine. Production has been insignificant. Tremolite occurs near Pomeroy, Zululand.

SWAZILAND

Development work was begun in 1937 on an important deposit of chrysotile asbestos in an area in Swaziland close to the Transvaal border. The asbestos occurs in cross-fiber veins in a mass of green serpentine lying between a banded chert and a dark, barren serpentine conforming in dip and strike with the sediments. The fiber-bearing rock, which dips 40° to 60° south, has an average width of about 110 feet. The Havelock mine, operated by New Amianthus Mines, Ltd., a subsidiary of Turner & Newall, Ltd., began production in June 1939. The mine is connected with the railroad at Barberton by means of an overhead cableway 12.6 miles long. As indicated in table 11, showing production since operation was begun, the Havelock mine has become one of the world's major producers.

It was reported in 1952 that a new operator, the Msauli Asbestos Co., was mining a property adjacent to the Havelock mine. The company estimates that it has reserves of 2,000,000 tons of rock carrying 5 percent asbestos fiber. The milled asbestos is sold as Grade 4.

TABLE 11.—*Asbestos production in Swaziland, 1939–53* [1]

Year	Short tons	Year	Short tons
1939	7, 973	1947	27, 955
1940	20, 804	1948	32, 431
1941	21, 127	1949	33, 967
1942	25, 595	1950	32, 667
1943	18, 937	1951	34, 964
1944	32, 659	1952	34, 769
1945	23, 416	1953	30, 103
1946	32, 138		

[1] Bureau of Mines Minerals Yearbook.

SMALL PRODUCERS IN RHODESIA AND THE UNION OF SOUTH AFRICA

The major output of asbestos in South Africa is in the hands of strong, well-organized firms that operate efficient mines and mills. There are, in addition, numerous small producers that sell their output chiefly through brokers in Johannesburg. Their mining operations, particularly in the amosite and blue asbestos fields, are usually crude, consisting of surface workings confined to depths of not more than 12 or 14 feet to avoid caving. Timbering, which would be required at greater depths, would automatically bring the operations under the restrictions of the South African mining laws. Accordingly, the asbestos obtained consists chiefly of near-surface material generally inferior to that obtained at depth. Milling processes are generally less efficient than those at the larger mines. The small producers in Southern Rhodesia and the Union of South Africa were having difficulty in marketing their asbestos in 1953. Supply had caught up with demand to such an extent that buyers became selective, and the tendency to buy on tighter specifications reacted most keenly upon the smaller producers that lack facilities for efficient milling.

SOVIET RUSSIA

Before World War I, Russia ranked next to Canada as an asbestos-producing country. During the revolutionary period the industry was almost at a standstill, but later it revived on an extensive scale. Table 12 shows production from 1913 to 1938. No definite production figures since 1938 are available. The great increase after 1929 did not affect world markets greatly, because increasingly large quantities were being used within the country. According to report,[40] the percentage of Russian

[40] Economic Review of the Soviet Union, Oct. 15, 1932, p. 365.

asbestos exported dropped from 51.1 in 1922–23 to only 20.5 in 1931. This condition reflected rapid expansion in the manufacture of asbestos products in Soviet Russia. It is probable that the long, higher priced fibers were exported in larger quantities than the short fibers. In 1954 Russian asbestos was being exported to several European countries under trade agreements.

TABLE 12.—*Asbestos production in Soviet Russia, 1913–39* [1]

Year	Metric tons	Year	Metric tons
1913	17, 494	1927	[3] 21, 156
1914	15, 691	1928	[3] 26, 492
1915	9, 779	1929	[3] 29, 520
1916	8, 192	1930	54, 083
1917	(2)	1931	64, 674
1918	(2)	1932	59, 800
1919	(2)	1933	71, 700
1920	1, 478	1934	92, 500
1921	2, 604	1935	95, 500
1922	3, 215	1936	125, 117
1923	[3] 4, 780	1937	125, 000
1924	[3] 8, 456	1938	86, 000
1925	[3] 12, 330	1939	(4)
1926	[3] 18, 334		

1 Economic Review of the Soviet Union and other sources.
2 Data not available.
3 Year ended Sept. 30.
4 No figures available for 1939 or subsequent years.

The asbestos region providing the major part of Russian production comprises what is known as the Bajenova district in the Urals. Principal production is at Asbest, about 90 kilometers northeast of Sverdlovsk (Ekaterinburg). Minor production in this district is obtained from the Alapaevsk area in the north and the Neviansk area in the northwest. The largest mine in the latter is the Kramouralsk.

At Asbest in the Bajenova district, where the asbestos industry is now centered, 20 or more open pits are worked. They have been under control of the State since 1918 and were operated by the Uralasbest Trust for some years following 1921. Asbestos was first discovered here about 1710, and systematic development under direction of Baron Girard was begun in 1885. The asbestos-bearing serpentinized intrusion is about 21 kilometers long and 200 to 1,200 meters wide. It consists of peridotites, which are bounded by schist or slate on the west and by granite on the east. The asbestos is confined to ellipsoidal masses of serpentine, some of which attain a length of 3,500 feet and a width of 1,000. The highest percentage of asbestos is found in the central parts of these masses. The cross-fiber veins generally run north and south, with a vertical dip. Slip fiber appears in places. Russian asbestos usually is regarded as being higher in iron than the Canadian fiber, but Rukeyser [41] has pointed out that Canadian asbestos is high in ferric iron, whereas in the Russian fiber ferrous iron predominates. This probably accounts for the greater discoloration of the Ural asbestos upon weathering. Russian asbestos deposits have a comparatively shallow overburden and are therefore weathered quite extensively, which may explain the somewhat harsher and less silky condition of the fiber compared with the Canadian. Asbestos occurring below the 50-foot level more nearly resembles that obtained in Quebec. Although the percentage of spinning fiber in the Russian deposits is a little higher than that in the Canadian, the percentage of total commercial fiber is about the same.

There are three major groups of mines in this district. The most northerly, known as the "Proletariat," produces shorts almost exclusively. The two major producing groups are the October (central) and the Ilyinski (southern).

Outside the Bajenova district, the only notable production has been from Minusinsk, on the Yenisei River in eastern Siberia near the Mongolian border. Here the deposits, said to be of the same general character as those of Arizona, have been worked in a small way, a production of 1,490 tons being reported in 1905. Asbestos also occurs in serpentine in various parts of the Altai Mountains southwest of Minusinsk.

A chrysotile asbestos deposit on the Laba River in the Maikop district of the Caucasus, about 98 kilometers from a railway, has been described.[42] The mineral occurs in veins in serpentine which have been intruded by granite. In general, the fibers range in length from 2 to 7 mm., with a maximum of 25 mm. (10 inches). The asbestos is said to be of good quality, but the reserves are not extensive. The deposit was worked in a small way in the 1930's.

A small output was reported from the Katun River district from 1907 to 1909.

Chrysotile has been reported in other parts of Russia, as follows: In a peridotite-serpentine belt in the Province of Transbaikalia, southern Siberia; on the upper course of the Yenisei River in the far north; near the source of the Kuban River east of the Crimea; and in Turkestan.

41 Rukeyser, Walter A., Chrysotile Asbestos in the Bajenova District, U. S. S. R.: Eng. and Min. Jour., August 1933, p. 338.
42 Tatarinov, P., [The Laba (Beden) Deposit of Chrysotile Asbestos in the North Caucasus]: Neues Jahrb. Mineral. Geol., Referate II, 1936, pp. 249–250.

LESS IMPORTANT COUNTRIES

NORTH AMERICA

Mexico

Chrysotile asbestos occurs in a belt of serpentine about 6 miles long and with a maximum width of one-fourth mile, situated about 11 miles west of Victoria, a short distance north of Monterrey in the State of Neuvo Leon. Samples received by the Bureau of Mines in 1942 contained veins consisting of fibers of spinning length and apparently of good quality. The asbestos is concentrated chiefly in the footwall side of the serpentine belt, where it occurs in bands of rock ranging in width from a few inches to 7 or 8 feet, half of which consists of asbestos in places. The cross-fiber veins generally do not exceed 5/16 inch in width, and most of them are 1/16 to 1/8 inch wide. Slip fiber up to 5 inches long appears in a faulted footwall zone. Small stringers of asbestos occur throughout the entire width of the serpentine belt. The quality of the asbestos is high enough to merit investigation. Some development work was reported in 1943, but no subsequent information has appeared.

A sample of mountain cork—a variety of spongy, matted amphibole asbestos—from an undeveloped deposit near San Luis Potosi was sent to the Bureau of Mines in 1931. Asbestos has been reported from the State of Puebla.

SOUTH AMERICA

Argentina

Deposits of asbestos are reported at Alta Gracia, Cordoba; Sierra de la Cortadera, Mendoza; Fiambala, Catamarca; and in the Provinces of San Luis and San Juan. The fiber is said to be too short for spinning or weaving. Annual production from 1939 to 1945 ranged from 51 to 349 tons. Figures for output since 1945 are not available.

Bolivia

Bolivia has the distinction of possessing the only known commercial deposits of crocidolite (blue asbestos) in the Western Hemisphere. They have been mined in a small way for many years. The deposits are about 200 kilometers northeast of Cochabamba in the Province of Chapere, Department of Cochabamba. The asbestos veins range from 1/2 to 30 cm. (12 inches) in width. They dip about 45°, the same as the associated shale. The veins are fairly close together in places; 6 veins have been found in a cut 1 meter wide. The deposits have been described by Gumucio.[43] The following chemical analyses (table 13) of the fiber appear in this report.

TABLE 13.—*Analyses of Bolivian blue asbestos, percent*

	Crocidolite No. 1, 1st class	Crocidolite No. 2, 2d class
SiO_2	54.08	54.50
TiO_2	.04	Trace
Al_2O_3	2.90	3.12
Fe_2O_3	14.50	15.10
FeO	6.85	7.15
MnO	.08	.06
MgO	11.72	11.59
CaO	2.10	1.02
Na_2O	5.55	4.50
K_2O	.40	.22
H_2O	1.80	2.83
Total	100.02	100.09

The fiber-vein area is evidently very extensive. The asbestos fibers are weaker than the African or Australian blue, but the material is in demand for certain important uses, particularly as a filter medium for gas masks. Development work during 1950 uncovered fiber of much greater strength and flexibility than any found heretofore. Conditions for production are unfavorable. Transportation is over a road 210 kilometers long, 60 of which is liable to traffic interruption during the rainy season. Development work is not extensive, and very little mechanical equipment is available. A 6-month rainy season (November to April) hampers operations. Production during recent years has ranged from 13 to 465 metric tons annually.

Brazil

According to information assembled by the Foreign Minerals Region of the Bureau of Mines an important asbestos deposit in Brazil is at Djalma Dutra (formerly Pocões) in the State of Bahía. It is mined by S. A. Minerasão de Amianto, and the milled product is shipped to São Paulo for manufacture of asbestos products, such as pipe covering and roofing shingles. Daily mill capacity in 1944 was said to be 1 1/2 tons of fiber. The asbestos is a slip-fiber chrysotile occurring in ropelike masses up to several inches in length. The fibers are somewhat weaker than Canadian asbestos, and although they are long, they are not well adapted for textile use. Indicated reserves are esti-

[43] Gumucio, Julio F., Memorandum sobre los yacimientos de asbesto del Chapare: Mineria Boliviana, vol. 6, No. 44, May-June 1949, pp. 8-11.

mated at 4,600,000 tons of rock containing 2.5 percent fiber designated as Class 3.

A deposit at Piabas, municipality of Queimadas, about 240 kilometers northwest of Salvador, State of Bahía, was reported in 1939. Analysis indicates that the fiber is chrysotile.[44]

The Foreign Minerals Region of the Bureau of Mines has also obtained information relating to the Correigo de Viriato asbestos mine north of Itabira do Campo and about 20 miles by road south of Nova Lima, State of Minas Gerais. It is owned by the St. John del Rey Mining Co., which also operates gold mines at and near Nova Lima. Chrysotile of spinning quality (fibers ¼ to ⅝ inch long) occurs in cross-fiber veins in serpentine. Locally the rock contains 2.5 to 3 percent fiber. Reserves are reported as large but unmeasured. A processing plant is equipped with screens and air separators to produce six grades of asbestos, which normally are shipped to São Paulo. Spinning fibers are obtainable; but, as no local market exists for long fibers, they are used for non-spinning purposes. Samples of the fiber examined by the Bureau of Mines were strong and flexible and apparently of excellent quality for textile use. The plant has been inactive since late in 1949. Negotiations were underway in 1951 and 1952 for a United States firm to take over operation of the property, chiefly for recovering the high-grade spinning fibers for export to the United States.

It was reported in 1952 that there is another asbestos occurrence on the opposite side of the mountain not many miles from the Viriato mine. This is an undeveloped deposit, but it is claimed that the proportion of spinning fiber is higher than in the mine now worked.

A report appeared in 1942 to the effect that an asbestos-cement-products plant was to be built in the State of Minas Gerais, near an asbestos deposit about to be developed. Data on the location and extent of the deposit have not appeared. A sample of the asbestos was identified by the Federal Geological Survey as anthophyllite. The fibers of the sample submitted were unusually strong and flexible for this type of asbestos. No record of progress on this project has appeared.

Asbestos of unstated quality has been produced near Governador Valadares, Minas Gerais. An amphibole asbestos deposit has been reported near Rio Branco, State of Pernambuco. In 1947 it was reported that a deposit of high-quality asbestos had been located near Juázeiro, a town at the northern boundary of the State of Bahía. Deposits are known also in Goiás, Rio Grande do Sul, São Paulo, State of Rio de Janeiro, Paraiba, Rio Grande do Norte, and Ceara. They are undeveloped and of doubtful value.

Production in Brazil during recent years is indicated in table 14.

TABLE 14.—*Asbestos production in Brazil, 1938–53*

Year	Metric tons	Year	Metric tons
1938	120	1946	1, 214
1939	45	1947	2, 631
1940	500	1948	1, 499
1941	[1] 13	1949	1, 415
1942	185	1950	844
1943	966	1951	1, 321
1944	459	1952	[2] 720
1945	2, 723	1953	[2] 720

[1] Exports.
[2] Produced in Bahía only (incomplete figure).

Chile

Several asbestos deposits have been reported in southern Chile. According to an article,[45] deposits have been developed to a limited extent at Hualane, Curico Province, and Gorbea, Cautin Province. Analyses given in the article indicate that these consist of amphibole fibers. Another deposit is 9 miles north of the port of Corrall, Valdivia Province, near the extreme south of Chile. Here the asbestos occurs in irregular veins in serpentine. A fiber length of 3 inches is mentioned. The reserves are said to be large. Both the rock association and the chemical composition given in the article indicate that the fiber is chrysotile. Very little development work had been done when this report was written in 1944.

Chile has produced asbestos in a small way for several years. From 1945 to 1950 production ranged from 150 to 440 metric tons a year. There is only one plant in operation, and it produces amphibole fiber, but the location for the mine and mill has not been determined.

Colombia

It was reported in 1949 that asbestos deposits at Yarumal and Antioquia, State of Antioquia, were being explored. One of these deposits may be the same as that described by Singewald.[46] He states that a deposit at Morro Norizal, State of Antioquia, was examined in 1944. Nine outcrops that were examined exposed an area of about 49 square meters of rock having a fiber content of 0.81 percent, about two-fifths of which consisted of fibers over 2 cm. long.

[44] Bureau of Mines, Mineral Trade Notes: Vol. 9, No. 5, November 1939, p. 11.

[45] Engineering and Mining Journal, vol. 145, No. 10, October 1944, p. 110.

[46] Singewald, Quintin D., Mineral Resources of Colombia (Other Than Petroleum): Geol. Survey Bull. 964-B, 1949, pp. 87-88.

Other scattered deposits appeared nearby. The asbestos is a chrysotile occurring in cross-fiber veins in serpentine, but the deposit is described as probably small and lean. During 1951 samples of asbestos that appeared to be of good quality were obtained from a deposit at Neira, near Manizales, State of Caldes. An official of Emergency Procurement Service examined this deposit. Samples submitted to the Bureau of Mines for examination were found to consist in part of chrysotile and in part of nemalite, which is fibrous brucite (MgOH). The latter fibers would appear to have little commercial value. Some of the chrysotile fibers are long, but most of them are low in textile strength. All of the asbestos is of the slip-fiber type. No estimate of reserves is available.

According to report,[47] active measures were being taken in 1951 to develop a chrysotile-asbestos deposit in the vicinity of Yarumal or Valdevia, which may be one of the deposits already mentioned. The Institute de Fomento Industrial, in cooperation with Eternit Colombia, and the Johns-Manville Corp., conducted studies and explorations of these deposits, but no steps have been taken to develop them.

Peru

Samples of chrysotile of good strength and flexibility were received by the Bureau of Mines in 1942 from a deposit reported to be in the Department of Junin on the eastern slope of the Andes. No further information has appeared.

Venezuela

Chrysotile deposits of the Quebec type occur in the State of Cojedas, 5 to 7 miles from Tinaquillo and about 35 miles from Valencia. There are two major deposits, El Tigre and La Montanita, about 3½ miles apart. A zone of peridotite, bordered by schist, extends along the flank of the mountain range on which these deposits occur. Asbestos-bearing serpentine bodies are present at various places within the peridotite, but extensive work has been done only on the two deposits mentioned. The asbestos occurs in cross-fiber veins ranging from microscopic to occasional 1½-inch widths. A fair proportion of spinnable fiber is available.

Fiber reserves at La Montanita appear to be larger than at El Tigre. At the former deposit, fiber-bearing rock of commercially workable quality appears in several pits in an area about 1,500 feet long and 300 to 400 feet wide. The uppermost pit is over 400 feet higher than the road-level pit.

[47] Institute de Fomento Industrial Informe del Gerante, June 30, 1951, pp. 53–54.

Compania Anonima Minas de Tinaquillo (CAMAT), with offices in Caracas, prospected the El Tigre deposit by core drilling and began construction of a mill in 1941. Owing to wartime restrictions on building materials and machinery, it was not completed until 1945. Production was begun in 1946, but before 1952 it did not exceed a few hundred tons a year.

In 1952 Amianto Venezuela Compania Anonima (AMVECO) of Caracas was organized, and in 1953 it established ownership to both properties and many adjoining concessions. Production was begun in September 1953 under the new ownership and has attained a much higher rate of output than in previous years. Millrock mined at La Montanita is hauled by truck to the El Tigre mill.

Fiber of shingle-stock grade is sold to an asbestos-cement products plant at Caracas, and an export trade is being developed for the longer fibers.

EUROPE

Albania

Asbestos of uncertain quality is said to occur in the Korcha district. Development work was reported in 1940.

Austria

Short-fibered amphibole, known as "micro-asbestos," was mined many years ago near the Hungarian frontier. It was used in asphalt and concrete road-surface mixtures. Discovery of a deposit of asbestos was reported from Rottenmann, Styria, in 1949.[48]

Bulgaria

Amphibole asbestos of the anthophyllite type occurs over a large area in the eastern Rhodope Mountains of southern Bulgaria. According to official records, production has been insignificant.

Cyprus

The chief asbestos deposits of Cyprus occur at Amiandos, on Mount Troodos in the west-central area. A peridotite plug, consisting largely of olivine, is altered to serpentine on the periphery. Short-fiber chrysotile asbestos occurs in the serpentine in irregular veins that have a maximum thickness of about one-half inch. Faulting and shearing evidently have exerted a definite influence on development of the fibrous structure. The asbestos content of the rock runs only 1 to 2 percent. The deposit is evidently extensive.

[48] Mining World, vol. 11, No. 8, July 1949, p. 52.

The fiber is of the chrysotile variety and generally too short for spinning, but small shipments of spinning fiber were reported in 1934. Milled fiber is graded into three classes—Standard, Shorts, and Fines. The Standard grade, designated "shingle stock," is said to comprise about 90 percent of production.

About 1925 an aerial ropeway 18 miles long was constructed for conveying the asbestos from Amiandos to the seaport at Limasol. The construction cost was about £2,320 a mile. The cost of transporting asbestos by means of the ropeway, including interest on investment and complete amortization of the equipment in 10 years, was given as 6s. 9d. a ton, whereas the motorwagon or animal transport formerly employed on the 37-mile winding road cost 20s. to 25s. a ton.

The industry attained considerable importance from 1926 to 1929, but production declined greatly during the depression years.

Production has been in the hands of a single company. The Cyprus Asbestos Co., Ltd., operated for several years before 1927, but in that year the Cyprus Trading Corp., Ltd., was organized and absorbed the former company. In 1932 the newer firm was reorganized as Cyprus & General Co., a British organization, and in 1936 the assets of the latter company were acquired by the Tunnel Asbestos Cement Co., Ltd., a subsidiary of the Tunnel Portland Cement Co. of West Thurrock, England. The producing company was later known as Cyprus Asbestos Mines, Ltd. The product is used chiefly for the manufacture of asbestos-cement products in England. The deposits have been described in some detail by Whitworth.[4] Mining operations were described briefly in 1948.[50]

Production in 1949 was higher than during any year of the preceding decade and was still higher in 1951 and 1952. Increased activity was attributed to additional mechanization, improved quarry conditions, a plentiful labor supply, and favorable weather. More than 2,400 laborers were employed during the working season of 1949, when 8 mills were in operation.[51] The fiber recovered is about 1 percent of the total rock quarried and about 3 or 3½ percent of the rock milled.

As local consumption is small, a large percentage of the production is exported. Exports began in 1906. Table 15 shows exports for a series of years.

[49] Whitworth, M., Cyprus and Its Asbestos Industry: Mining Mag., vol. 39, September 1928, pp. 143-150.
[50] Mining Journal (London), vol. 240, No. 5883, May 22, 1948, p. 380.
[51] Asbestos, Cyprus Asbestos Mines, Ltd.: Vol. 31, No. 12, June 1950, p. 10.

TABLE 15.—*Asbestos exported from Cyprus, 1923–53* [1]

Year	Metric tons	Year	Metric tons
1923	2, 186	1939	10, 377
1924	4, 442	1940	9, 673
1925	3, 255	1941	4, 874
1926	6, 627	1942	3, 128
1927	11, 079	1943	1, 189
1928	11, 765	1944	1, 983
1929	14, 017	1945	3, 125
1930	5, 487	1946	5, 993
1931	3, 628	1947	[2] 6, 369
1932	1, 626	1948	[2] 8, 106
1933	4, 640	1949	[2] 12, 556
1934	7, 712	1950	[2] 14, 989
1935	7, 634	1951	[2] 17, 180
1936	9, 659	1952	16, 556
1937	11, 892	1953	14, 484
1938	5, 668		

[1] Data from Geological Survey and Bureau of Mines Mineral Resources of the United States and Minerals Yearbook.
[2] Production.

Czechoslovakia

According to the Bureau of Foreign and Domestic Commerce,[52] "Asbest" Gewinning und Verwertung von Asbest Gesellschaft m. b. H. at Dobsina, Slovakia, reported an output of 1,200 metric tons in 1933, 2,100 in 1934, and 2,600 in 1935. In 1940 the operating company was "Asbest" Bergbau u. Industrie A.-G. The product is said to be a poor-quality short fiber, suitable only for mixing with insulation compounds and for the manufacture of asbestos-cement roof shingles.[53]

Finland

According to Mineral Trade Notes,[54] Finland has 2 asbestos mines, 1 at Paakkila in the commune of Tuusniemi and 1 at Maljasalmi in the commune of Kuusjarvi. The former mine supplies about four-fifths of the output. The entire production consists of anthophyllite. According to an analysis reported by Borgstrom,[55] Finnish asbestos is of the following chemical composition, in percent: SiO_2, 56.57; Al_2O_3, 1.02; FeO, 5.72; MgO, 30.78; CaO, 0.57; H_2O+, 4.89; H_2O-, 0.14. This corresponds closely with the analysis of Georgia anthophyllite.

Both mines are operated by Suomen Mineraali Oy., a company established in 1917. At

[52] U. S. Bureau of Foreign and Domestic Commerce, Foreign Metals and Minerals: Circ. 3, April 1936, p. 9.
[53] Bureau of Mines, Mineral Trade Notes: Vol. 10, No. 1, January 1940, p. 10.
[54] Bureau of Mines, Mineral Trade Notes: Vol. 37, No. 6, December 1953, pp. 35–36.
[55] Borgstrom, L. H., [Finnish and Foreign Asbestos]: Tek. Foren. Finland Forh., vol. 55, 1935, pp. 105–107.

Paakkila operations are both opencut and underground. The smaller mine is an open pit. Suomen Mineraali Oy. operates a refining mill at Tapanila, 12 kilometers from Helsinki, and also a factory for manufacture of asbestos products. Finnish asbestos has high acid- and fire-resistant qualities. The principal domestic use is for making so-called asbestos-wood slates used as inner sidings for house walls. Short fibers are also used in flooring, rubber and bitumen compositions, and other fireproof products. Imported chrysotile, chiefly from the Urals, is also used. Some of the shorter grades are exported. They are said to be used chiefly in Sorel-cement flooring. Production in Finland during recent years is shown in table 16.

TABLE 16.—*Asbestos production in Finland, 1937–53* [1]

Year	Metric tons	Year	Metric tons
1937	7, 260	1946	5, 781
1938	6, 422	1947	6, 351
1939	6, 220	1948	10, 818
1940	5, 337	1949	10, 486
1941	3, 842	1950	10, 949
1942	4, 679	1951	11, 850
1943	7, 466	1952	6, 100
1944	7, 733	1953	10, 929
1945	4, 197		

[1] Includes asbestos flour.

France

Although a small output of asbestos has been recorded for 1934 to 1938, no information is available on the source of the fiber for those years. The only deposit for which data have been obtained is near Chateau-Queyras, Department of Hautes Alpes. It was discovered in 1939, but active measures for its development were not taken until the property was acquired by Guy H. Montmartin and associates, 535 Fifth Ave., New York, N. Y., in 1947. In 1948 serious floods destroyed a dam and power station adjacent to the mine, and in consequence development was delayed. A new mill was under construction in 1949. According to Rukeyser [56] there is, in this area, a mass of dense, tough, dark-green serpentine, probably derived from peridotite. At the mine elevation, about 8,000 feet above sea level, is a mass of light-green serpentine about 130 feet thick, which appears to have resulted from hydrothermal alteration of dolomite. The asbestos is found only in this zone. Although claims have been made that the fiber closely approaches chrysotile in physical characteristics, samples received by the Bureau of Mines were definitely identified as tremolite. The fibers, however, have unusual strength. The long fibers are said to be suitable for spinning, but there is no evidence that they have been accepted in quantity by textile manufacturers. No production figures are available to indicate the scope of operations since the mill was built.

The Canari mine in Corsica was under development in 1948. The deposit, which is evidently of considerable extent, consists of slip-fiber chrysotile. Milling at a rate of 15 to 20 tons of fiber a day was expected in 1949. It is reported that the mine produced 1,050 tons of asbestos during the first quarter of 1950. A brief description of the operation has been published.[57] Available production figures for France are indicated in table 17.

TABLE 17.—*Asbestos production in France, 1934–53*

Year	Metric tons	Year	Metric tons
1934	400	1944	31
1935	450	1945	400
1936	405	1946	575
1937	250	1947	934
1938	450	1948	1, 309
1939		1949	1, 090
1940		1950	6, 080
1941		1951	6, 940
1942		1952	6, 300
1943	78	1953	9, 300

Germany

Discovery of a greenish white chrysotile in Bayerischer Wald, East Bavaria, was reported in 1935, but no record of production has appeared. This is said to be the only occurrence known in Germany to have commercial possibilities.

Ireland

An asbestos deposit at Avoca, County Wicklow, was reported in 1931. No data are available on variety, quality, or extent.

Italy

Italy is called "the cradle of the asbestos industry," because the mining of asbestos and the manufacture of its products were begun on an industrial scale in that country. Italy also is unique in that much of the fiber produced in

[56] Rukeyser, Walter A., Asbestos at Chateau-Queyras, France: Asbestos, vol. 29, No. 10, April 1948, pp. 8–20.

[57] Asbestos, The Canari Mine—Corsica: Vol. 30, No. 3, September 1948, pp. 20–22.

early years was tremolite, a variety of amphibole asbestos little used elsewhere. Before discovery of the Canadian deposits, Italy was the chief source of supply of asbestos for both Europe and America. After the Quebec deposits were developed, the demand for Italian asbestos declined.

One important deposit is in the Susa Valley region of western Torino near the French border. Here tremolite asbestos, which is particularly well adapted to the manufacture of chemical filters, is mined in the mountains 8,000 to 9,000 feet above sea level. A second deposit is along the Aosta Valley near Ivrea in northeastern Torino, about 46 miles from Turin. Tremolite asbestos has been mined in the mountains in this locality since 1865, but there has been little activity since 1905. The fibers are long and highly resistant to acids and heat; but, owing to the difficulty of separating them, they are not well adapted to weaving. A third source of supply of tremolite asbestos is near Sondrio, northern Lombardy. This asbestos also is a long-fibered variety similar to that of the Torino deposits.

The Balangero mine, situated in Torino about 20 kilometers north of Turin, has been the chief producer during recent years. The asbestos of this district is chrysotile, disseminated in a large serpentine mass. A geological report on the area, prepared in 1942, has been published.[58] Short fiber only is produced. Mining is by open pit, with gloryholes. Shallow blast holes are drilled on low benches, and high explosives are used to obtain complete fragmentation. Fiber is separated from rock in 2 mills, 1 of which is of similar design to those used in Quebec, Canada. Fiber recovery represents about 1½ percent of the rock milled. Considerable detail on mining and milling has been published.[59] Notes from various sources on Italian asbestos deposits were assembled some years ago.[60] Annual production over a period of more than 50 years is indicated in table 18. About 95 percent of recent production has been from the Balangero region.

TABLE 18.—*Asbestos production in Italy, 1898-1953*

Year	Metric tons	Year	Metric tons
1898	131	1926	2, 900
1899	81	1927	3, 840
1900	126	1928	4, 950
1901	243	1929	2, 847
1902	243	1930	851
1903	202	1931	632
1904	182	1932	1, 284
1905	220	1933	3, 267
1906	209	1934	2, 252
1907	359	1935	4, 320
1908	359	1936	6, 113
1909	190	1937	6, 393
1910	175	1938	6, 860
1911	170	1939	6, 765
1912	169	1940	8, 271
1913	175	1941	10, 766
1914	171	1942	11, 695
1915	163	1943	8, 459
1916	82	1944	7, 238
1917	85	1945	5, 222
1918	60	1946	8, 814
1919	98	1947	10, 719
1920	165	1948	13, 044
1921	420	1949	15, 877
1922	540	1950	21, 433
1923	1, 538	1951	22, 612
1924	2, 160	1952	23, 938
1925	2, 105	1953	20, 397

Portugal

Anthophyllite asbestos is mined in two localities in Portugal. Samples examined by the Bureau of Mines were found to be of good quality. The most important deposit is near Evora, Province of Alemtejo, southern Portugal. Sociedade Portuguesa de Amiantos, Lda, Porto, Portugal, has operated a mine in this area for several years and began development of a new deposit near Braganca in the northern area in 1948. Following is an analysis of the fiber from the Evora mine furnished by the producing company:

	Percent
SiO_2	56. 08
Al_2O_3	. 82
Fe_2O_3	6. 26
CaO	13. 62
MgO	21. 51
Ignition loss	1. 67
Total	99. 96

Production is small but has been increasing somewhat as more industrial uses for the product have been found. Table 19 shows the output during recent years, according to official figures.

TABLE 19.—*Asbestos production in Portugal, 1943–52*

Year	Metric tons	Year	Metric tons
1943	96	1948	414
1944	33	1949	101
1945	20	1950	257
1946	12	1951	312
1947	91	1952	168

Spain

Two occurrences of chrysotile asbestos in Spain were reported in 1920—one in the

58 Asbestos, Asbestos Deposit at San Vittore (Balangero) Italy: Vol. 29, No. 12, June 1948, pp. 16–24.

59 Bureau of Mines, Mineral Trade Notes: Vol. 22, No. 4, April 1946, pp. 22–26.

60 Asbestos, Geology of Italian Deposits: Vol. 29, No. 7, January 1948, pp. 16–24.

Pyrenees and the other in the Cantabrian Mountains. No further information concerning them has appeared. Production has been small and irregular. The official record of output in metric tons during recent years follows: 1941, 2 tons; 1942, 84; 1943, 50; 1948, 35; 1949, 40; 1950, 41; 1951, 41; and 1952, 30.

A small intermittent operation has been reported at Mellid, Province of La Coruña, in northwestern Spain, but the largest operation is in Malaga Province near the southern coast. As reported by Cabot Sedgwick, American consul at Malaga,[61] chrysotile asbestos occurs in nearly vertical cross-fiber veins in serpentine associated with peridotite. The asbestos is recovered from a large number of small pits scattered over two mountains. It is mined chiefly by independent workers, who sell their output to the operating company, Asbestos Espanoles, S. A. The company hauls the mine product to the milling plant at Mijas. Most of the fiber is under one-fourth inch in length. It is milled by crushing, screening, and air separation and is used locally as a constituent of roofing and cement pipe. Daily production of about 2 tons or less was begun in 1951. Monthly production of 30 tons of asbestos, reported in the press in 1952 from a deposit at Ronda, is probably the output of this operation, as Ronda is in Malaga Province.

Switzerland

Asbestos occurs in the Cantons of Grisons, Tessin, Valais, and Graubunden, but output is small; a maximum of about 400 tons was obtained under the war stimulus of 1918 and 1919. The most important deposits are at Poschiavo, Canton of Grisons, where a small amount of chrysotile of spinning quality is available. Both chrysotile and tremolite are said to occur in Graubunden. Production for each of the 5 years, 1942–46, amounted to 6, 11, 7, 35, and 40 metric tons, respectively. No other official figures are available.

Yugoslavia

Several chrysotile asbestos deposits occur in Yugoslavia. The following information is abstracted from a series of articles by Millar.[62]

At Karlaca, about 225 kilometers south-southeast of Belgrade in Serbia, a short distance from Raska, a deposit of considerable extent contains semibrittle chrysotile in fibers chiefly under one-fourth inch in length. The better zones are said to carry 2 to 3 percent fiber. The rock is mined from an open pit with a face about 1,500 feet long. An exploratory adit was run for about 900 feet at right angles to the bench face and was still in fiber-bearing rock, hence the deposit is large but is quite low grade. A small mill produces an ungraded fiber, most of which would fall in Group 6 of the Canadian classification.

An adjoining property at Belci has been developed to some extent. It is a short-fiber prospect, although the fiber is a little longer and stronger than at Korlaca. Adit samples contain only 1.75 to 2.5 percent fiber.

The Rujiste property about 50 miles south-southeast of Korlaca is on a mountain. The fiber is confined to a zone about 1 yard wide along a major fault plane, hence the supply is limited, but the fiber is of higher quality than that occurring elsewhere in the country. Crudes No. 1 and No. 2 are recovered. The asbestos is said to be of good quality, being somewhat harsh, and almost as strong as Canadian fiber. Production in 1952 averaged 1 or 2 tons a month of hand-cobbed crudes.

The Bogoslovac asbestos mine is about 83 kilometers southeast of Skopje in Macedonia. The fiber-bearing zone is large, but the asbestos content is low, and the fiber is brittle and consistently short. A new mill having a capacity of 170 tons of rock a day was built in 1952.

A unique asbestos deposit occurs at Stragari, about 50 kilometers south of Belgrade. The asbestos occurs in tough, leathery sheets in a shear zone at a contact of serpentine with limestone. No commercial method has yet been developed for freeing the fiber for normal use. The deposit is extensive, and a mill to handle 340 tons of rock a day is planned. It is believed that, by a dry-milling process, the material can be broken into small sheets and shredded enough to permit blending with normal chrysotile for use in asbestos-cement products.

A deposit of weak, short-fiber chrysotile having ribbon structure occurs at Petrovo Selo in Bosnia-Herzegovina. Several areas have been developed with adits and opencuts, and a mill was under construction in 1952.

A small prospect having little promise occurs at Goc, about 220 kilometers southeast of Belgrade.

The following production, in metric tons, has been reported for recent years: 1947, 309; 1948, 752; 1949, 1,138; 1950, 958; 1951, 1,523; and 1952, 2,506.[63]

Further detail on the industry was published in 1953.[64]

[61] Bureau of Mines, Asbestos in Spain: Mineral Trade Notes, vol. 37, No. 1, July 1953.

[62] Millar, W. B., Asbestos in Yugoslavia: Asbestos, vol. 34, No. 2, August, pp. 2–10; No. 3, September, pp. 2–10; No. 4, October, pp. 2–6, 1952.

[63] Monthly Review of Yugoslav Economic Statistics, May 1953.

[64] Bureau of Mines, Mineral Trade Notes: Vol. 37, No. 3, September 1953, pp. 42–47.

ASIA

China

Asbestos said to be of the chrysotile variety occurs in a number of Provinces in China, including Chihli, Jehol, Chahar, Suiyuan, Shensi, Szechuan, Hupeh, and Kwangtung. The most important deposits are in the Laiyuan district, Chihli (Hopeh) Province. (The spelling "Hopei" in the footnote reference is not now recognized.) Here the asbestos occurs in numerous generally parallel cross-fiber veins in limestone. The maximum fiber length is about 1½ inches. The asbestos has evidently been formed by mineralizing solutions derived from igneous intrusions, therefore it is similar in origin to the Arizona deposits. Hou [65] has described the deposits. The longer grades are of spinning quality. The deposit has been worked since 1914. Production in 1927 was 180 metric tons. The fiber, conveyed on horseback to Yiksian (106 kilometers) and from there to Tientsin by train, supplies manufacturing plants in the latter city. Four such plants were reported in 1927. Their products are mostly for domestic consumption, though some are shipped to Japan.

Asbestos mines about 5 miles from Chinchu, Manchuria, have been worked in a small way for over 20 years. The output was shipped to factories at Osaka and Tokyo, Japan.

A small production was recorded for China for several years before 1939, but from 1939 to 1943, under Japanese stimulation, production increased sharply. Most of the output was probably shipped to Japan. Table 20 shows production for a series of years.

TABLE 20.—*Asbestos production in China, 1927–44*

Year	Metric tons	Year	Metric tons
1927	241	1936	[1] 69
1928	----------	1937	----------
1929	277	1938	700
1930	315	1939	18,015
1931	264	1940	20,015
1932	250	1941	20,515
1933	236	1942	20,615
1934	290	1943	[2] 20,000
1935	[1] 70	1944	(3)

1 Manchuria only.
2 Estimated.
3 No figures available since 1943.

India

The Hassan district of Mysore State has been the most productive area in India. Production consists chiefly of amphibole fibers. A small output of tremolite originated in Bihar and Orissa during 1921 to 1932. In 1940 the Bureau of Mines received a sample of asbestos from a deposit near Cuddapah in the Madras Presidency about 125 miles northwest of Madras. The sample consisted of light-amber chrysotile resembling the Arizona fiber. It was exceptionally soft and silky, displayed superior strength and flexibility, and had a maximum fiber length of 3½ inches. It occurs at a contact of magnesian limestone with an intrusive basic sill. Small quantities of the fiber have reached the United States market.

It was reported in 1946 [66] that the most promising deposits of chrysotile in India occur near Pulivendla, a considerable distance south of Cuddapah (approximately 11° 30′ N.: 78° E.). In this area the asbestos occurs at a contact of traprock with limestone. The asbestos veins are confined chiefly to a zone of serpentinized limestone at the contact. Veins up to 7 inches wide have been found, but they average ¼ to 1 inch thick. The occurrence is evidently of the Arizona type.

In 1951 and 1952 production as large as that of the Cuddapah district was recorded for the Singhbhum district of Bihar. The fiber is chrysotile, which is said to be somewhat brittle. It occurs in serpentine intruded by dikes.

Asbestos occurs in many other parts of India; but no estimates of reserves are available, and none of the deposits seems capable of a large production of high-grade fiber. The development of a substantial asbestos-producing industry in India apparently will depend largely upon the establishment of domestic asbestos-products plants that will utilize the weaker and shorter fibers. India has been a producer of asbestos for many years, but the output has never been large. Table 21 shows production since 1917.

Japan

Before 1939 a small production of asbestos was obtained from various scattered deposits, but after that date intensive exploration and development were undertaken, and a subsidized asbestos industry of moderate size was established. The most important mines are in the Hokkaido district, where about 94 percent of the chrysotile output originates. The other 6 percent is mined in southwestern Honshu district. In the Hokkaido district the chrysotile occurs in irregular veins in serpentine. In some areas the fiber is of good quality; in others it is brittle, a condition which is attributed to the presence of talc between the

65 Hou, T. F., Notes on the Asbestos Deposit of Laiyuan District, Hopei Province (in English): Nat. Geol. Survey China Geol. Bull. 25, March 1935, pp. 39–43.

66 Bureau of Mines, Mineral Trade Notes: Vol. 22, No. 2, February 1946, p. 26.

TABLE 21.—*Asbestos production in India, 1917–52*

Year	Metric tons	Year	Metric tons
1917	150	1935	64
1918	363	1936	57
1919	394	1937	102
1920	1, 847	1938	90
1921	321	1939	266
1922	246	1940	251
1923	251	1941	372
1924	127	1942	514
1925	16	1943	909
1926	59	1944	592
1927	69	1945	833
1928	159	1946	312
1929	324	1947	163
1930	34	1948	83
1931	6	1949	148
1932	91	1950	211
1933	----------	1951	526
1934	25	1952	694

fibers. All of the asbestos is low grade. A mere fraction of it is Group 3 or better (Canadian classification), but most of it is below 5. It is used chiefly in asbestos-cement products. Six open-pit mines have been worked in the area. The fiber-bearing rock is processed in mills patterned after those in Canada in which the fibers are separated by screening and air suction. Most of the production in the Honshu district has been from the Seimi mine in Shimane prefecture.

Another asbestos-producing area is in the Kyushu district in the extreme south of the Japanese group of islands. All asbestos of this region is of the amphibole type. There are two groups of mines—the Meiji group producing slip and cross fibers and the Kondo group producing mass fibers. The slip fiber is said to consist of tremolite and actinolite. The Kondo group covers an irregular area about 400 feet long. Here the asbestos occurs in radial aggregates of white to gray mass-fiber anthophyllite. The fibers are intermixed with talc and hornblende. Both dry and wet milling has been employed at Kondo. In the dry mill the fibers were picked up by air suction. In the wet-process mill the rock is broken with jaw crushers or stamps and the fiber floated off with water. Production of amphibole fiber ranged from 1,500 to more than 4,000 metric tons a year from 1940 to 1945, but thereafter the output declined greatly. The uses of the amphibole varieties are too limited to permit sustained production under normal conditions.

Under intense stimulation production of all kinds of asbestos exceeded 12,000 tons in 1944, but thereafter it declined greatly. Table 22 shows production during recent years. A detailed description of the Japanese asbestos industry has been published.[67]

TABLE 22.—*Asbestos production in Japan, 1936–53* [1]

Year	Amphibole	Chrysotile	Total
1936	400	0	400
1937	400	30	430
1938	400	30	430
1939	400	30	430
1940	3, 900	30	3, 930
1941	3, 830	90	3, 920
1942	2, 005	1, 486	3, 491
1943	1, 564	3, 738	5, 302
1944	4, 679	8, 221	12, 900
1945	3, 050	4, 994	8, 044
1946	44	3, 953	3, 997
1947	551	3, 698	4, 249
1948	219	4, 590	4, 809
1949	248	5, 208	5, 456
1950	(2)	(2)	5, 664
1951	788	5, 351	6, 139
1952	(2)	(2)	3, 060
1953	(2)	(2)	4, 078

[1] Data for 1936-46 from Natural Resources Section, SCAP, Asbestos Resources of Japan: Rept. 115, 1948, p. 9; data for 1947-53 from Mineral Resources of Japan.
[2] Data not available.

Korea

A small output of asbestos was reported in Korea in the 1930's. In 1943 production reached 5,310 metric tons and in 1944, 4,532 but dropped to 1,303 in 1945. No output has been reported since. No information has been obtained on the location or extent of the deposits or the type of fiber produced. Over 90 percent of the 1944 output came from South Korea.

Republic of the Philippines

Samples of amphibole asbestos have been obtained from the Republic of the Philippines, but apparently the deposits have not been developed, as there is no record of production.

Turkey

Asbestos has been produced near Kutaia (Kutahya) about 70 miles southeast of Burra in western Turkey. The Bureau of Mines obtained promising samples of cross-fiber chrysotile in 1934 from a deposit near Sarikamis, Province of Kars, Turkish Armenia, not far from the U. S. S. R. border. Deposits are reported also at Karakose and Kogizman in the valley of Agri, in the Eskischir region, western Turkey. The writer received a sample of good-quality tremolite asbestos originating in Turkey in 1947, but the location and extent

[67] Natural Resources Section, SCAP, Asbestos Resources of Japan: Rept. 115, 1948, 32 pp.

of the deposit are unrecorded. Little is known of the character or extent of any of the Turkish deposits. Production for a series of years is given in table 23.

TABLE 23.—*Asbestos production in Turkey, 1931–51*

Year	Metric tons	Year	Metric tons
1931	4	1942	295
1932	58	1943	133
1933	120	1944	231
1934	4	1945	138
1935	104	1946	55
1936	119	1947	36
1937	157	1948	203
1938	668	1949	250
1939	88	1950	245
1940	99	1951	80
1941	146		

AFRICA

Asbestos has been reported in various other points in Africa, in addition to the major deposits already described, namely those of Southern Rhodesia, the Union of South Africa, and Swaziland.

Bechuanaland

Late in 1951 the Marlime Chrysotile Asbestos Corp., Ltd., a subsidiary of Marble, Lime & Associated Industries of Johannesburg, acquired what is known as the Moshaneng asbestos mine, about 40 miles northwest of Lobatsi. The property is on a railroad 60 miles north of Mafeking. The asbestos occurs in cross-fiber veins in dolomite underlain by a sill of diabase. A relatively high percentage of spinning fiber is said to be present; its quality is generally good, although some harsh fiber appears in places. A mill capable of handling 5,000 tons of fiber-bearing rock a month was being built in 1952. Several shafts have been sunk paralleling the dipping beds. The shafts and a single drill hole have blocked out a mass, which is estimated to contain 16,000 tons of asbestos. This property may become an important source of chrysotile.[68]

Egypt

An asbestos deposit has been reported in the Eastern Desert of Upper Egypt, about 500 miles south of Suez and approximately 33 miles by road from Mersa Alam on the Red Sea. The asbestos was described in 1950 as a short-fiber anthophyllite. In view of the very limited market for this type of asbestos there is little prospect of successful development, although a production of 1,247 metric tons was reported for 1951.

[68] Data from B. C. Burgess, DMPA, Johannesburg, South Africa.

Madagascar

In 1951 samples of an unusual type of asbestos were obtained in Madagascar. The fiber is peach color, of spinning length, and very strong, flexible, and silky. It was submitted to three laboratories for identification—the Bureau of Mines Eastern Experiment Station, College Park, Md.; Rutgers University, New Brunswick, N. J.; and the Johns-Manville Research Center, Manville, N. J. Each of these laboratories identified it independently as anthophyllite. This is the first instance on record of anthophyllite possessing the strength and flexibility of a spinning fiber. No information is available at this time as to the location or extent of the deposit.

A white, iron-free, amphibole asbestos has been produced in small quantities from a deposit 290 kilometers north of Tananarive near the village of Antsiafabositra. About 17 tons was shipped to France in 1951.

Morocco

In the early 1940's there was considerable interest in the Bou Azzer asbestos mine, in desert country about 100 kilometers (62 miles) north of the Sahara Desert. A good dirt road leads from the mine to Americane (66 miles) on the Marrakech-Ouartzate Highway about 101 miles southerly from Marrakech, a terminus of the Morocco State Railroad. The asbestos is chrysotile occurring at a contact of a mass of greenstone with granodiorite. The fiber occurs in lenses, many of which are small. The association of the asbestos with cobalt ore is unique. The company that mines the cobalt has developed the asbestos property. A sample of the fiber about 2 inches long was sent to the Bureau of Mines and found to be of good spinning quality, but only a very small fraction of the fiber is of spinning length. Short fiber was recovered from the rock by a crude milling process. It is claimed that up to October 1944 about 500 tons of short fibers had been hauled by truck to Casablanca, where it was used in the manufacture of building materials. No activity has been reported since that date.

Several other asbestos deposits have been worked in the vicinity of Bou Azzer. The Bou Affroh deposit about 7 miles west of Bou Azzer consists of cross-fiber veins in serpentine. In the Aghbar deposit about 9 miles east of Bou Azzer several adits have been driven in a mass of serpentine. Fiber-bearing serpentine has been noted on a mountain about 23 miles east of Bou Azzer.

An asbestos deposit of considerable importance occurs near N'Cob at a high elevation on the Siroua Mountains about 20 miles from the Tazenakht-Agadir Highway. It is about 185 miles by road from Marrakech. The deposit was first prospected in 1942. Société Minibre du Siroua, organized in 1946, has carried on underground mining and operated a small mill. The asbestos occurs in dolomites; but, unlike the Arizona deposits, the dolomites are interbedded with quartzites. The fiber is said to be a high-quality chrysotile with an unusually large percentage of long fibers. It is claimed that as much as 50 percent of the fiber would qualify as 3T (Canadian classification) or better. A "possible" reserve of 20,000 tons of fiber has been estimated. Another deposit at Tif Dra near N'Cob is small and contains short fiber only.

Production in Morocco was 604 metric tons in 1951 and 576 in 1952.

Kenya

A deposit of anthophyllite was discovered in 1949 in the Teita Hills about 120 miles from the port of Mombasa. A mill has been built, and progress has been made in developing uses in such products as chemical filters, compound packings, and thermal and acoustical insulation.[69]

An anthophyllite asbestos deposit has been developed about 40 miles west of Kitate in western Kenya. The fiber, prepared in a simple mill, is used in making asbestos-cement sheets and roofing tiles and asbestos-lime hollow blocks for building construction. Further details have been given by Sinclair.[70]

Other African Occurrences

A small output of asbestos was reported from the Macheria deposit, Algeria, in 1942. No information is available on the variety or quality of the fiber. Fibers of unspecified type occur in Nyasaland. Anthophyllite occurs at Morogore in what was formerly German East Africa, and chrysotile was reported near Macequece, Portuguese East Africa, in 1929. In 1953 samples were received by the Bureau of Mines of anthophyllite having exceptionally strong fibers from a deposit 38 miles from Vila Pery, Mozambique, which is on the main railway line from Beira.

AUSTRALASIA

Asbestos deposits are numerous in Australasia. The principal deposits are described briefly herein. A more detailed description of Australasian deposits has been prepared by Noakes.[71]

Western Australia

For many years a small production of chrysotile was obtained in Western Australia, but since 1937 blue asbestos has attained greater importance. Chrysotile has been obtained in the Sherlock property, in the Roebourne district, about 24 miles from the port of Balla Balla. Here the asbestos occurs in veins that are restricted to a relatively narrow zone. Two main veins, separated by a dolerite dike, have peen proved for a length of 1,000 feet. The percentage of fiber 2 inches long and over is said to be much higher than in the principal producing regions of the world and is of good quality. Up to 1934 about 1,000 tons of fiber had been mined by contract laborers and shipped to Europe, but no systematic mining had been followed. Shaft sinking and the erection of a pumping plant were begun in 1934.

Other producing areas are Lionel in the Nullagine district and Soansville and Cooglegong in the Marble Bar district. These deposits are all in the Pilbarra goldfield area. At Soansville chrysotile occurs in veins up to 30 inches wide, with a maximum fiber length of 6 inches. The veins have been proved over a length of 1,200 feet.

Asbestos was discovered in the Marble Bar area in 1909. A large deposit has been reported 15 miles west of Cooglegong. Chrysotile veins range from threads up to 6 inches wide.

Table 24, compiled by Elford,[72] shows production in Western Australia from 1921 to 1932. Figures on production in Australia for later years are shown in table 25, which follows.

Important deposits of crocidolite (blue asbestos) have been discovered in the Hamersley Ranges in the northwestern part of the State. The fibers are found in beds of the Nullagine series, which form a belt 180 miles long and 20 to 30 miles wide, trending east-southeast from Millstream Station, about 45 miles south of Roebourne, to the Ophthalmia Ranges. The deposits closely resemble those of the Griqua Town series in South Africa, the principal world source of blue asbestos. The Hamersley Range deposits are said to have a higher percentage of long fibers. One important area is in Yampire Gorge, where several seams of crocidolite ¼ to 2½ inches wide appear. The

[69] Asbestos, The Makinyambu Asbestos Deposits, Kenya, British East Africa: Vol. 34, No. 1, July 1952, pp. 2–8.

[70] Sinclair, W. E., Asbestos in East Africa: Asbestos, vol. 32, No. 7, January 1951, pp. 16–22.

[71] Noakes, L. C., Mineral Resources of Australia, Commonwealth of Australia, Department of Supply and Shipping: Summary Report 17 Asbestos, Aug. 28, 1945, 26 pp. plus tables and maps.

[72] Elford, Harold S., Australian Nonmetallic Minerals, II. Asbestos: Chem. Eng. and Min. Review, vol. 25, Sept. 5, 1933, p. 396.

TABLE 24.—*Asbestos production in Western Australia, 1921–32*

Year	Quantity, tons	Value, £	Locality where mined
1921	202	12, 221	Lionel.
	32	1, 360	Cooglegong.
1922	179	7, 350	Lionel.
	2. 5	250	Cooglegong.
1923	111	3, 865	Lionel.
	3	150	Cooglegong.
1924	73	2, 206	Lionel.
1925	50	1, 619	Do.
1926	91	2, 436	Do.
	14	292	Roebourne.
1927	10. 8	304	Lionel.
1928	11. 7	782	Soansville and Lionel.
1929	191	8, 568	Sherlock.
	63	6, 113	Soansville.
1930	65	4, 228	Pilbarra.
	17	500	West Pilbarra.
1931	108	1, 446	Roebourne.
1932	110	1, 762	Do.

region is 30 miles by road southeast of Mulga Downs, which is about 180 miles southeast of Roebourne. A small mill was built in this area in 1939 by Asbestos, Molybdenum & Tungsten Co., Ltd., and was acquired in 1943 by Australian Blue Asbestos, Ltd. A second company, West Australia Blue Asbestos Co., Ltd., later operated in this area.

Another producing area is the Wittenoom Gorge, 17 miles by road southwest of Mulga Station. Australian Blue Asbestos, Ltd., completed a new mill in this area in 1946.[73]

A more complete description of the Australian blue-asbestos deposits has been published.[74] Unofficial reports indicated an increase in output to more than 3,000 tons annually in 1952 and 1953.

Two asbestos seams, 2 and 6 inches thick, are mined by a room-and-pillar method. The asbestos occurs in a hard, ferruginous quartzite. First, about 48 inches of the quartzite is removed from above the asbestos, and then the bottom 24-inch section containing the 2 seams of cross-fiber crocidolite is mined. Other deposits in the same general area where the fiber seams may be thick enough and close enough together to merit commercial operation are Dale's Gorge and Marramamba Homestead.

The principal production of Western Australia shown in table 25 is blue fiber. Small tonnages that reach the American market are of good quality. The output of Australian Blue Asbestos, Ltd., is marketed through the Building Materials Division of the Colonial Sugar Refining Co., of which it is a subsidiary. Because of the remoteness of the region, transportation is costly.

Anthophyllite asbestos deposits are reported near Bindi Bindi, 138 miles north-northeast of Perth; at Goomalling, 76 miles northeast of Perth; and at several other points. A small output has been reported from the first of these deposits.

South Australia

Crocidolite occurs over a wide area in a belt of pre-Cambrian metamorphic rocks extending north from Encounter Bay for about 400 miles. Deposits have been prospected in many localities between Truro, 47 miles northeast of Adelaide, and Blinman, 220 miles farther north. A deposit 10 miles north of Hawker, about 248 miles north of Adelaide, was worked in a small way many years ago. The fiber, which apparently is derived from magnesian limestone, has a maximum length of about 2 inches, but most of it is short and matted. Two shafts 40 feet apart were sunk to a depth of 26 feet and connected with a drift. Unfortunately, the fiber-bearing rock was faulted at the 26-foot level, and nothing is known of its continuation. Another deposit 18 miles south of Blinman in this same general locality produced a small tonnage in 1941.

Crocidolite has also been mined 9 miles north of Robertstown, 83 miles north-northeast of Adelaide. The fiber occurs in a narrow belt in altered magnesian limestone. Amalgamated Asbestos Industries, N. L., built a small mill in 1940, but the high cost of mining and preparation discouraged sustained production. This area is said to have produced 628 tons of blue fiber up to the end of 1944.

Chrysotile asbestos has been found in pre-Cambrian metamorphic rocks near Cowell, 6 miles northwest of Franklin Harbour, on the eastern side of Eyre Peninsula. All the deposits are within 15 miles of Cowell. They occur in white magnesian marble, which has been serpentinized. Because of erratic occurrence and low percentage of fiber, mining is said to be unprofitable.

Anthophyllite has been produced in small quantities at Kenton Valley about 20 miles east-northeast of Adelaide. Amphibole asbestos, probably actinolite, occurs at Lyndock, 28 miles north-northeast of Adelaide. Small quantities were produced in 1936, 1937, and 1940.

Production in South Australia, which consists chiefly of blue fiber, is indicated in table 25 (p. 55).

[73] Asbestos, Asbestos Mill at Wittenoom, Australia: Vol. 28, No. 3, September 1946, pp. 10–12.
[74] Miles, Keith R., and Foxall, J. S., Part I, The Blue Asbestos Bearing Banded Iron Formations of the Hamersley Ranges, Western Australia, and Part II, The Blue Asbestos Deposits of the Hamersley Range and Their Economic Importance: Western Australia Geol. Survey Bull. 100, 1942, 61 pp.

Queensland

Asbestos has been noted in many localities in Queensland, mainly within the serpentine belt northeast and north of Rockhampton, extending from Balnagowan near the Fitzroy River to Marlborough. The deposits at Princhester and Marlborough appear to be the most important, although little is yet known of their quality or extent. A small amount of fiber has been mined. On Marlborough Creek near its junction with the Fitzroy River well-defined veins having a maximum fiber length of 1½ inches are reported. Queensland asbestos is said to be coarse textured and of low strength. It is well adapted for asbestos-magnesite flooring, for boiler covering, and as an ingredient of paints. Anthophyllite has been found at Canoona, 40 miles north of Rockhampton, and other points.

New South Wales

Asbestos is associated with serpentine in three main belts of ultrabasic rocks—the Gordonsbrook belt on the Clarence River, northeastern New South Wales; the Great Serpentine belt, which runs through Barraba, about 200 miles north-northwest of Newcastle; and the Gundagai-Wallendbeen belt, 200 miles south-southwest of Sydney.

Wunderlich, Ltd., developed a deposit in the Gordonsbrook belt in 1940. The mine is near Baryulgil, 52 miles by road northwest of Grafton. A mill was built in 1943, and several hundred tons of chrysotile was produced by the end of 1944. In 1944 the owners organized a new company, Asbestos Mines Pty., Ltd. The fiber occurs in veins up to 1 inch wide and is mined by opencut. This area is the principal producing one in New South Wales.

Another area that is said to have produced 2,478 tons of chrysotile before activity ceased in 1923 is at Wood's Reef, 12 miles east of Barraba in the Great Serpentine belt. The asbestos occurs in steeply inclined cross-fiber veins in serpentine derived from peridotite. Mill rock constituted slightly less than half of the rock mined, and recovery from the mill rock averaged 5 percent. High costs and unsuitability of the fiber for asbestos-cement products discouraged further activity. The evolution of chrysotile fiber from serpentine in this area has been discussed by Proud and Osborne,[75] who made a detailed study of the deposits.

Small quantities of chrysotile were obtained in 1931 from a deposit 10 miles east of Broken Hill in a serpentine area outside of the three belts mentioned heretofore. Amphibole asbestos, probably tremolite, occurs near Orange and Lewis Ponds in the Orange district, and actinolite was produced in small quantities many years ago near Gundagai.

Tasmania

An asbestos deposit at Anderson's Creek in the Beaconsfield district about 25 miles northwest of Launceston was discovered over 45 years ago, and a production of 200 tons was recorded in 1899. Chrysotile occurs in a belt of serpentinized peridotite and pyroxenite about 5 miles long and 1 mile wide, into which small granitic dikes have been intruded. Asbestos is concentrated chiefly where alteration of the peridotite is most complete and in areas close to the dikes. Most of the fiber is ¼ to ½ inch in length. The first asbestos mill in Australia was erected here in 1917. Only about 8 percent of the rock mined was milled, and the selected mill rock yielded about 10 percent fiber. Fiber extraction proved to be too costly, and the mill was removed to Barraba, New South Wales, about 1919.

Small quantities of amphibole similar to the actinolite produced at Gundagai, New South Wales, have also been mined in the Beaconsfield area.

A second asbestos-producing area is about 5 miles east of Zeehan, western Tasmania. Chrysotile occurs in cross-fiber veins ½ to 1½ inches wide in an extensive body of serpentine and peridotite. There are prospects of large reserves, but their extent has not yet been determined. Mining is conducted in both opencuts and adits. A mill was built in 1942. The operating company is Tasmanian Asbestos Pty., Ltd., a subsidiary of the Colonial Sugar Refining Co. A deposit 2 miles south of the mine has been under investigation.

A third asbestos area is on Asbestos Point on the southwestern shore of Macquarie Harbour.

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[75] Proud, John S., and Osborne, George D., Stress-Environment in the Genesis of Chrysotile, With Special Reference to the Occurrence at Woodsreef, Near Barraba, New South Wales: Econ. Geol., vol. 47, No. 1, January–February 1952, pp. 13–23.

Prospecting and shaft sinking reported in 1943 indicated that chrysotile-fiber veins, ⅛ to 1½ inches in width, were spaced at intervals in serpentine. The fiber is said to be of good quality. The proportion of fiber to rock appeared to be high enough for economic mining, but reserves may be limited. A chrysotile occurrence has been noted at the mouth of the Spers River about 20 miles south of Asbestos Point. Table 25 shows Australian production, by Provinces, during recent years.

New Zealand

Chrysotile asbestos in veins as wide as 3 inches occurs in a serpentine area at least 3 miles long near Mount Arthur in the upper Takaka district. Both cross fiber and slip fiber are available. The cross-fiber veins occur principally in shells 6 to 30 inches thick surrounding cores of massive serpentine with few or no veins. The fiber yield of the shells is estimated at 10 to 25 percent. It is reported that a mill and power plant were completed and 53 tons of fiber produced in 1941. The deposit is said to be extensive. A production of 42 tons in 1950, 826 tons in 1951, and 693 tons in 1952 has been reported.

TABLE 25.—*Asbestos production in Australia, 1930–53, in metric tons*

Year	New South Wales	South Australia	Western Australia	Tasmania	Total
1930	--------	--------	144	--------	144
1931	8	6	116	--------	130
1932	--------	20	112	--------	132
1933	--------	13	270	--------	283
1934	--------	--------	157	--------	157
1935	--------	36	143	--------	179
1936	--------	81	162	--------	243
1937	--------	123	43	2	168
1938	--------	49	123	4	176
1939	--------	46	279	--------	325
1940	9	119	370	--------	498
1941	138	152	62	4	356
1942	142	64	121	7	334
1943	422	11	247	19	699
1944	2, 598	6	313	105	3, 022
1945	2, 674	7	1, 109	281	4, 071
1946	241	8	380	--------	629
1947	290	40	1, 069	--------	1, 399
1948	330	41	977	--------	1, 348
1949	336	17	1, 318	--------	1, 671
1950	380	13	1, 250	--------	1, 643
1951	439	6	2, 154	--------	2, 599
1952	(1)	(1)	(1)	--------	4, 124
1953	(1)	(1)	(1)	--------	5, 049

[1] Data not available.

PRODUCTION AND CONSUMPTION

HISTORY OF PRODUCTION IN THE UNITED STATES

Scattered deposits in California and other Western States furnished a limited tonnage of asbestos many years ago. Georgia, North Carolina, California, and several other States have supplied small quantities of anthophyllite and tremolite at various times. Chrysotile is produced principally in Vermont. The deposits are extensive but furnish short fibers predominantly. Vermont has produced intermittently since 1908, and the output has increased greatly during recent years. Arizona has supplied a small tonnage of chrysotile annually with some interruptions since 1913. Some of the Arizona output is of excellent spinning quality.

Table 26, compiled from data reported by producers to the Federal Geological Survey until 1924 and thereafter to the Federal Bureau of Mines, shows the history of production in the United States since 1880.

A preponderance of the asbestos produced in the United States is of the chrysotile variety. Small quantities of amphibole (anthophyllite and tremolite) have been produced annually for many years, but for some years there were so few producers that the figures were concealed to avoid revealing the output of individuals. Table 27 shows available figures for the production of amphibole asbestos since 1920. These figures are included in the United States output presented in table 26.

WORLD PRODUCTION

Table 28, compiled by the Foreign Minerals Division, Federal Bureau of Mines, shows the production of asbestos, by countries, during recent years. These figures include both long and short fibers of all varieties of asbestos. The output in Rhodesia and the Union of South Africa consists principally of spinning fiber and the better grades of mill fiber, because the local demand is small and the value of the

TABLE 26.—*Asbestos sold or used by producers in the United States, 1880–1953*

Year	Short tons	Value	Year	Short tons	Value
1880	150	$4, 312	1917	1, 958	$291, 014
1881	200	7, 000	1918	998	118, 687
1882	1, 200	36, 000	1919	1, 161	248, 265
1883	1, 000	30, 000	1920	1, 648	678, 231
1884	1, 000	30, 000	1921	831	336, 968
1885	300	9, 000	1922	67	10, 120
1886	200	6, 000	1923	227	9, 626
1887	150	4, 500	1924	300	42, 526
1888	100	3, 000	1925	1, 258	51, 700
1889	30	1, 800	1926	1, 358	134, 731
1890	71	4, 560	1927	2, 981	336, 882
1891	66	3, 960	1928	2, 239	351, 178
1892	104	6, 416	1929	3, 155	351, 004
1893	50	2, 500	1930	4, 242	289, 284
1894	325	4, 463	1931	3, 228	118, 967
1895	795	13, 525	1932	3, 559	105, 292
1896	504	6, 100	1933	4, 745	130, 677
1897	580	6, 450	1934	5, 087	158, 347
1898	605	10, 300	1935	8, 920	292, 927
1899	681	11, 740	1936	11, 064	314, 161
1900	1, 054	16, 310	1937	12, 079	344, 644
1901	747	13, 498	1938	10, 440	247, 264
1902	1, 005	16, 200	1939	15, 459	512, 788
1903	887	16, 760	1940	20, 060	674, 508
1904	1, 480	25, 740	1941	24, 391	725, 753
1905	3, 109	42, 975	1942	15, 481	498, 857
1906	1, 695	28, 565	1943	6, 014	334, 815
1907	653	11, 899	1944	6, 667	380, 334
1908	936	19, 624	1945	12, 226	446, 045
1909	3, 085	62, 603	1946	14, 075	504, 764
1910	3, 693	68, 357	1947	24, 035	918, 558
1911	7, 604	119, 935	1948	37, 092	1, 806, 261
1912	4, 403	87, 959	1949	43, 387	2, 614, 416
1913	1, 100	11, 000	1950	42, 434	2, 925, 050
1914	1, 247	18, 965	1951	51, 645	3, 912, 500
1915	1, 731	76, 952	1952	53, 864	4, 713, 032
1916	1, 638	180, 994	1953	54, 456	4, 853, 965

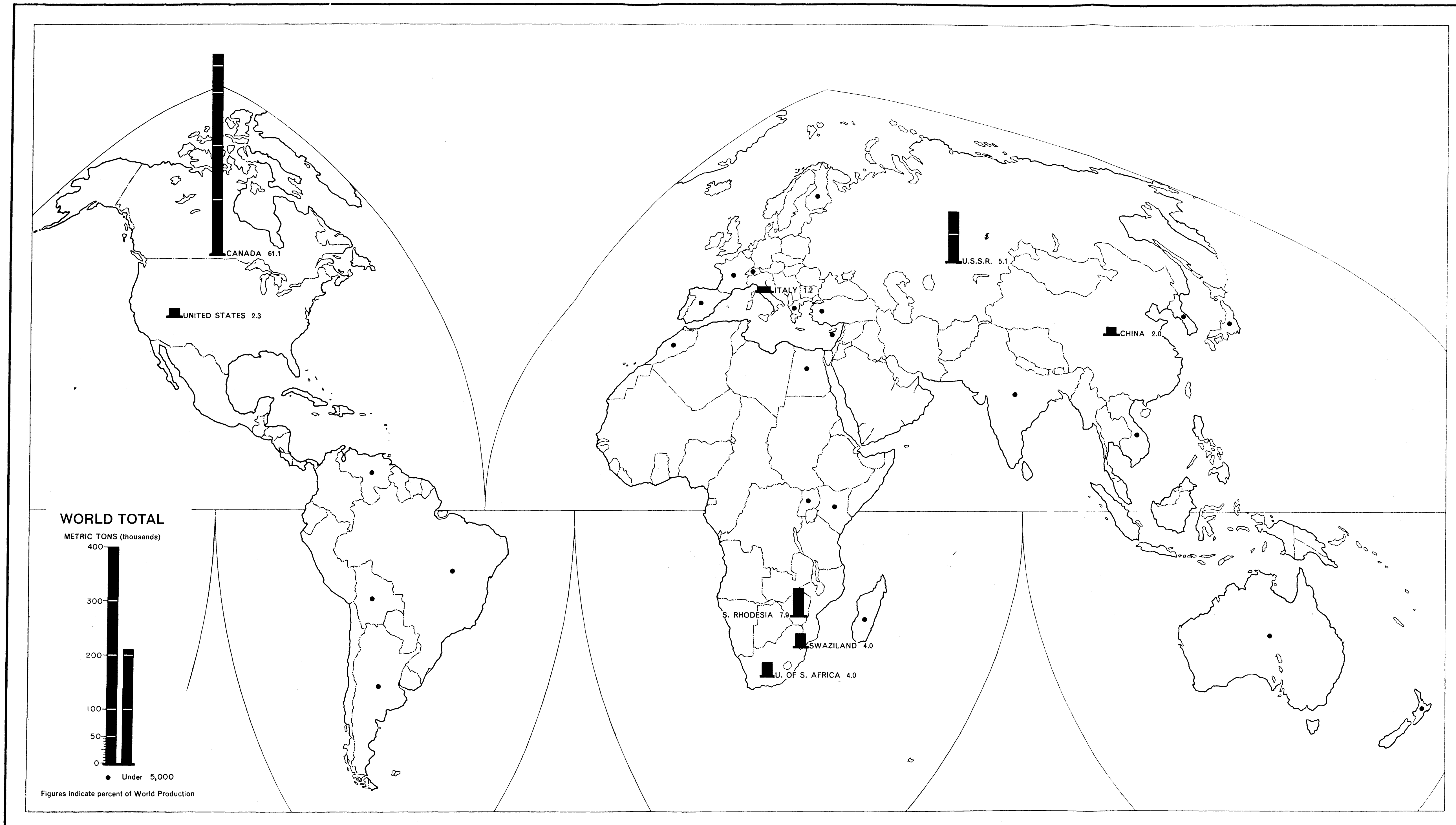

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FIGURE 9.—World Production of Asbestos and Production by Countries, Averaged for 3 Selected Years—1938, 1941, and 1945.

(Courtesy Prentice-Hall, Inc.)

TABLE 27.—*Amphibole asbestos sold or used by producers in the United States, 1921–53*

Year	Short tons	Value	Year	Short tons	Value
1921	393	$23, 700	1938	(1)	(1)
1922	42	6, 800	1939	416	$9, 691
1923	158	5, 193	1940	1, 388	9, 988
1924	127	8, 585	1941	1, 952	18, 164
1925	1, 165	10, 950	1942	2, 108	18, 612
1926	(1)	(1)	1943	2, 114	32, 526
1927	(1)	(1)	1944	392	7, 222
1928	(1)	(1)	1945	240	3, 989
1929	1, 172	33, 420	1946	430	5, 504
1930	589	15, 992	1947	449	6, 218
1931	371	7, 259	1948	(1)	(1)
1932	(1)	(1)	1949	(1)	(1)
1933	(1)	(1)	1950	(1)	(1)
1934	(1)	(1)	1951	(1)	(1)
1935	(1)	(1)	1952	(1)	(1)
1936	345	11, 860	1953	(1)	(1)
1937	532	11, 897			

[1] Bureau of Mines not at liberty to publish.

very short fibers too low to justify shipment to foreign markets. Russia, on the other hand, has developed important asbestos-products industries that utilize large quantities of short fiber from the Urals. Canada has small local demand for short fiber, but the industrial centers of the eastern United States provide a ready market; for this reason the shorter grades constitute a large proportion of the asbestos production.

The figures for total output in table 28 are more or less rough estimates because Russian output is large but unavailable. In 1951 Canada produced about 63 percent of the world total and the United States about 3½ percent. More complete data on the output for each individual country are given earlier in this report in the sections devoted to discussion of asbestos deposits throughout the world. A table of world production appears each year in the Asbestos chapter of the Minerals Yearbook, published by the Bureau of Mines.

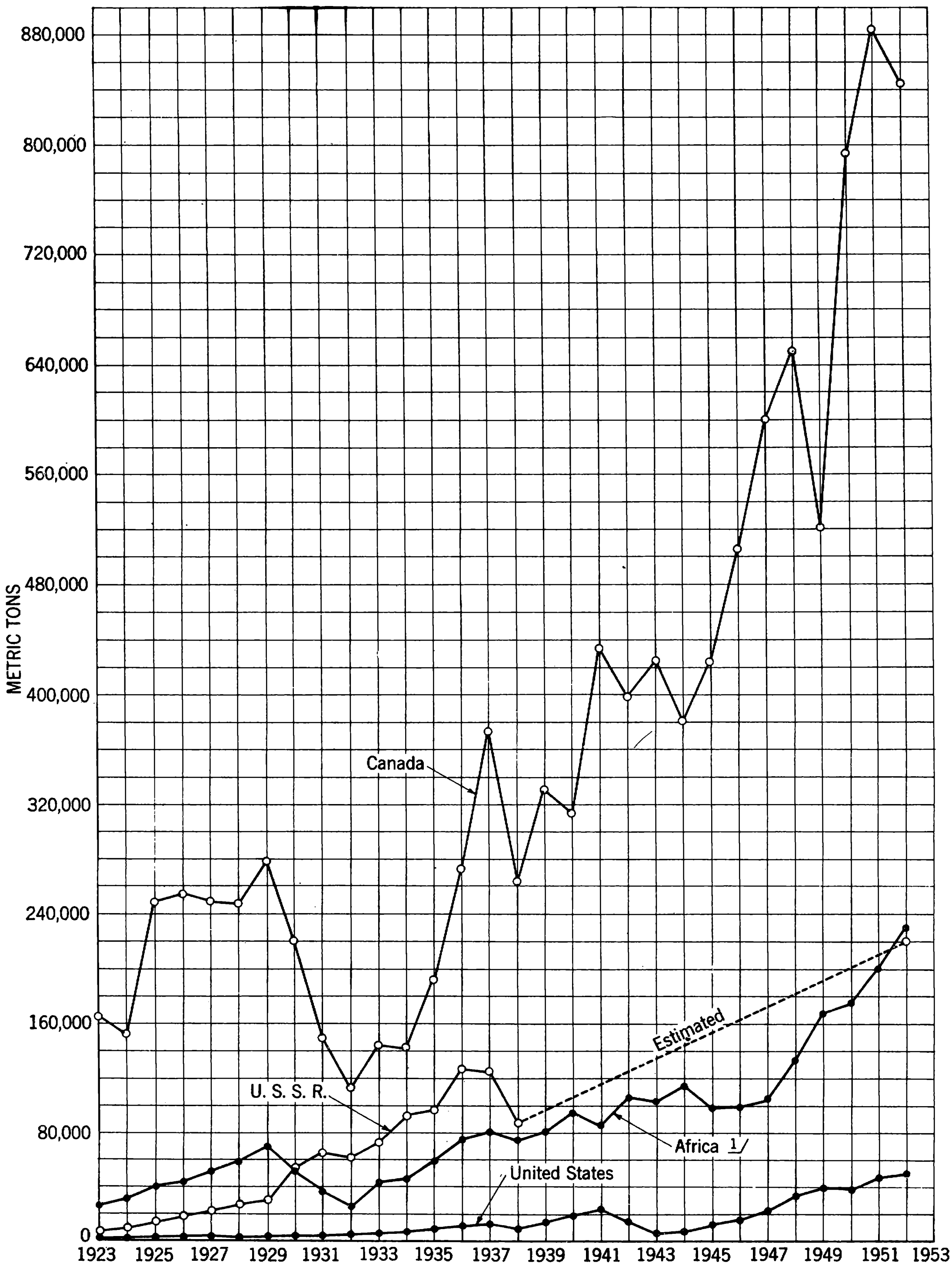
World production of asbestos and production, by countries, are shown graphically in the columnar chart, figure 9. The figures used in this chart are the averages of production for 3 selected years—1936, 1941, and 1945. The chart was compiled by the Department of

TABLE 28.—*World production of asbestos, by countries,[1] 1947–53, in metric tons*

[Compiled by Helen L. Hunt, Foreign Minerals Division, Bureau of Mines]

Country	1947	1948	1949	1950	1951	1952	1953
Australia	1, 399	1, 348	1, 671	1, 643	2, 599	4, 124	5, 049
Bolivia (exports)	141	147	182	166	316	465	735
Brazil	2, 631	1, 499	1, 415	844	1, 321	720	720
Canada (sales)[3]	600, 391	650, 239	521, 543	794, 095	882, 866	843, 078	826, 303
Chile	440	150	291	172	(2)	(2)	(2)
Cyprus	6, 795	8, 106	12, 556	14, 989	17, 180	16, 556	14, 484
Egypt	1, 015	1, 625	117	260	1, 247	60	(2)
Finland[4]	6, 351	10, 818	10, 486	10, 949	11, 850	6, 100	10, 929
France	934	1, 309	1, 090	6, 080	6, 940	6, 300	9, 300
French Morocco	825	399	402	511	604	576	544
Greece	40	9	9	30	34	25	-------
India	163	83	148	211	526	694	(2)
Italy	10, 719	13, 044	15, 877	21, 433	22, 612	23, 938	20, 397
Japan	4, 249	4, 809	5, 456	5, 664	6, 139	3, 060	4, 078
Kenya	582	510	716	229	379	354	151
Madagascar	(5)	(5)	2	1	17	3	(2)
New Zealand	-------	-------	-------	42	826	693	(2)
Portugal	91	414	101	257	312	168	(2)
Southern Rhodesia	49, 073	62, 502	72, 246	64, 888	70, 454	76, 960	79, 595
Spain	-------	35	40	41	41	30	(2)
Swaziland	25, 360	29, 421	30, 814	29, 635	31, 719	31, 542	27, 309
Taiwan (Formosa)	-------	652	410	216	35	24	-------
Turkey	36	203	250	245	80	-------	-------
Union of South Africa	27, 344	41, 490	64, 334	79, 300	97, 402	121, 416	86, 016
United States (sold or used by producers)	21, 804	33, 649	39, 360	38, 495	46, 851	48, 864	49, 401
Venezuela	240	192	192	190	260	394	40
Yugoslavia	309	752	1, 111	958	1, 523	2, 506	3, 748
Total (estimate)	900, 000	1, 025, 000	975, 000	1, 300, 000	1, 425, 000	1, 425, 000	1, 375, 000

[1] In addition to countries listed, asbestos is produced in Argentina, China, Czechoslovakia, Korea, and U. S. S. R. Estimates by the Bureau of Mines are included in total.
[2] Data not available; estimate by the Bureau of Mines included in total.
[3] Exclusive of sand, gravel, and stone (waste rock only), production of which is reported as follows: 1947, 8,718 tons; 1948, 40,066 tons; 1949, 32,015 tons; 1950, 43,551 tons; 1951, 30,628 tons, 1952, 35,982 tons; 1953, 19,158 tons.
[4] Includes asbestos flour.
[5] Less than 0.5 ton.



1/ Union of South Africa, Southern Rhodesia, and Swaziland

FIGURE 10.—Production of Asbestos in the Three Leading Foreign Centers and in the United States, 1923–52, in Metric Tons.

TABLE 29.—*Consumption of asbestos in selected countries, 1948, in metric tons*

Continent and country	Production [1]	Imports [2]	Exports [2]	Apparent consumption [3]
Africa:				
Algeria		455		455
Belgian Congo		508		508
Egypt	1, 625	457		2, 082
Southern Rhodesia	62, 505		61, 474	1, 031
Swaziland	29, 421		} [4] 58, 043	12, 868
Union of South Africa	41, 490			
Asia:				
India	28	3, 702		3, 730
Japan	4, 809			4, 809
Turkey	203			203
Australasia:				
Australia	1, 348	15, 095	282	16, 161
New Zealand		1, 813	21	1, 792
Europe:				
Austria		1, 588	29	1, 559
Belgium-Luxembourg		17, 386	37	17, 349
Cyprus	8, 106		8, 108	−2
Denmark		6, 181		6, 181
Finland	10, 818	525	2, 512	8, 831
France	104	20, 696	268	20, 532
Germany		[5] 3, 000		3, 000
Iceland		10		10
Italy	13, 044	2, 098	3, 355	11, 787
Netherlands		4, 184	8	4, 176
Norway		1, 333		1, 333
Portugal	414	1, 534	175	1, 773
Spain	35	218	9	244
Sweden		3, 620		3, 620
Switzerland		2, 095	50	2, 045
United Kingdom		93, 957	1, 802	92, 155
North America:				
Canada	650, 239		626, 261	23, 878
Mexico		[5] 3, 500		3, 500
United States	33, 649	585, 304	5, 924	613, 029
South and Central America:				
Bolivia	147		142	5
Brazil	1, 304	4, 972	51	6, 225
Chile	150			150
Colombia		900		900
Costa Rica		14		14
Venezuela	192	500		692
Total	859, 631			866, 625

[1] Compiled by Foreign Minerals Division, Bureau of Mines.
[2] Data from Mineral Resources Division (British), Colonial Geological Surveys, Statistical Summary of the Mineral Industry, Production, Imports and Exports: 1950 (long tons in report converted to metric tons).
[3] Production plus imports minus exports.
[4] Union of South Africa, Annual Statement of Trade and Shipping.
[5] Estimate based on imports of previous years.

NOTE.—Excludes Russia, its satellite countries, and Yugoslavia.

Geography, University of Maryland, from data supplied by the Bureau of Mines, United States Department of the Interior, and appeared in the Atlas of the World's Resources, Mineral Resources of the World (vol. II), published by Prentice-Hall.

Figure 10 shows the output in the three leading foreign asbestos centers and in the United States for a 30-year period. The location of the Russian curve since 1938 is problematical. The minor position of the United States among leading world producers is apparent. On the basis of value of output, Africa holds a relatively stronger position than is indicated on the chart, because Canada produces a preponderance of the lower priced short fibers.

FREE WORLD CONSUMPTION

It is more difficult to determine the consumption of asbestos than its production. Production plus imports minus exports of raw asbestos for any year may not give a true picture of consumption, because stocks may be held over for use in a following year, or material consumed may consist of stocks imported in a previous year; however, apparent consumption (production plus imports minus exports) is an approximate measure of true consumption. Table 29 shows the approximate consumption for 1948. Because of the unavailability of figures from beyond the Iron Curtain, table 29 is confined to countries of the Free World.

The excess of consumption over production, as indicated in the totals of table 29, is due in some measure to substantial imports of asbestos from the U. S. S. R. into the United States and other countries, which swell consumption by that amount, while the unknown U. S. S. R. output is not included under production.

In 1948 the United States consumed about 71 percent of the total Free World consumption, the United Kingdom about 11 percent, Canada 3 percent, Australia and New Zealand, Belgium-Luxembourg, and France about 2 percent each, and Italy and Switzerland about 1 percent each. These figures are on a tonnage basis. On the basis of value, the United States percentage would be somewhat lower.

WORLD RESERVES

Current production throughout the world is an important element in the asbestos-supply situation, but consideration of the availability of asbestos fibers cannot be confined merely to the present. Even though immediate supplies may be adequate, the question inevitably arises, What are the prospects for obtaining equal or larger quantities of suitable fiber in the years to come? The answer depends largely upon the extent of reserves of commercial fiber in the various asbestos-producing areas of the world. A knowledge of reserves is so important in planning future operations that the larger companies have spent large sums on geologic surveys and prospect drilling in order that adequate reserves may be definitely established as a solid basis for investment in mining and milling facilities. Much of the information thus assembled is confidential, but enough is available to afford a fair measure of overall world reserves.

UNITED STATES

The Federal Geological Survey and the Bureau of Mines estimated in 1944 that United States reserves of all grades of chrysotile amounted to about 750,000 short tons. Since that time considerable prospect drilling has been conducted in the deposit operated by Vermont Asbestos Mines near Eden, Vt., to a depth of about 800 feet; as a result, a 20-year supply at the current or even an enlarged production rate seems to be assured. This would imply a reserve of at least 800,000 to 1,000,000 tons of fiber in that area. A large percentage of the asbestos mined in the Vermont region is of the shorter grades, but further exploration in that State may uncover deposits of longer fibers.

Long fibers of chrysotile of good spinning quality are available in Arizona, but the known reserves are small.

Estimates of reserves are generally confined to the vicinity of producing areas, but there is always the possibility of discovering new deposits that may supplement those already known. Promising samples of chrysotile of spinning grade have been found in several places in Shasta, Trinity, and Siskiyou Counties, Calif., in an extensive serpentine area that merits exploration. Prospect drilling by a private company was conducted on a deposit north of Redding, Calif., in 1950, but the reserves were evidently found to be too limited to justify large-scale operations. Exploratory work, financed chiefly by the United States Government, under supervision of Defense Minerals Exploration Administration, was begun in Trinity County in 1951. Reserves of considerable size may be found in this extensive serpentine belt.

Known reserves of spinning fibers in the United States are very small. Aside from those in Vermont, there are no known large deposits of short-fiber chrysotile. Many deposits of amphibole asbestos are known, particularly in Georgia, North Carolina, and California, and they are probably adequate to supply the limited demands for this type of fiber for many years. There are no known reserves in the United States of either amosite or crocidolite.

CANADA

Estimates of Canadian reserves are incomplete. A great deal of prospect drilling has been done, but only in some instances are the results available. Asbestos Corp., Ltd., the second largest producer in Quebec, has published quite complete data in its annual reports. The company estimates its ore reserves, as of 1953, as follows:

	Short tons
King mine	5, 975, 000
Beaver mine	10, 000, 000
British Canadian mine	43, 375, 000
Vimy Ridge mine	3, 000, 000
Normandie mine	35, 000, 000
Other properties	7, 300, 000
Total	104, 650, 000

Assuming a 6-percent fiber recovery, this would indicate a fiber reserve exceeding 6 million tons. Drill exploration at the King mine shows asbestos-bearing serpentine to a depth of 1,700 feet. Johnson's Co. has increased its reserves greatly by diamond drilling. Bell Asbestos Mines has purchased a new property in range 4, Thetford Township, on which it has developed a high-grade 2,000- by 800-foot ore body, which is at least 300 feet deep.

The Johns-Manville Corp. has conducted extensive prospect drilling for many years. From information supplied by drill cores, the company has constructed large models of its undeveloped areas showing quantity and grade of fibers, both laterally and vertically, as a guide to future development. The comprehensive data thus assembled have enabled the company to estimate that it has, within its present holdings, enough available fiber to last at least 100 years at the present rate of mining. These extensive deposits at Asbestos are predominantly short-fiber occurrences.

The overall picture of reserves in the Quebec area is indefinite. The heavy investment in facilities and their substantial current enlargement indicate that the principal producers have assured themselves of reserves adequate for continuous operation at the current rate, or on an enlarged scale, for at least 25 or 30 years. As current production is at a rate exceeding 900,000 tons of asbestos a year, a reserve in the Quebec area of at least 30 million tons seems to be assured, simply on the basis of expectation implied by capital investment and current rate of production. In view of the supplies available for a much longer period than 30 years, established by exploration conducted by the largest producer, together with probable reserves in unexplored areas, the figure of 30 million tons could probably be doubled or even trebled.

Of greatest interest are the reserves of crudes and spinning fibers. In 1948 and 1949 these groups comprised about 4 percent of the total production. Accordingly, if total reserves are tentatively estimated at a minimum of 60 million tons, the reserves of crudes and spinning fibers would appear to be about 2,400,000 tons. Such a figure is based on the assumption that the proportion of longer fibers will be approximately the same in the future as in 1948 and 1949. Production by grades was not published from 1933 to 1947, hence no definite figures are available for that period. For 1928 to 1932, during which such figures were published, the proportion of crudes and spinning fibers to total production averaged about 6 percent. Accordingly, the figure of 4 percent for 1948 and 1949 indicates a decline, which may be more apparent than real. Consideration must be given to the great recent increase in recovery and sale of the very short fibers. This accession to the total will automatically lower the percentage of crudes and spinning fibers, although the actual quantities of these fibers produced may be as high as in earlier years. There is no statistical evidence that would imply a reduction in output of spinning grades in the near future.

From the foregoing, it may be concluded that Quebec reserves are adequate for a half century of production, even at an increasing rate.

The new development in Munro Township, Ontario, provides a supplementary supply. The reserves are probably extensive but are not of the magnitude of those in Quebec. This development has not produced grades and qualities of fiber suitable for textiles. Reserves in British Columbia may be tentatively estimated at 6 million tons running about 7 percent fiber.

SOVIET RUSSIA

In the early 1930's, when information concerning Russian minerals was more readily available than at present, a statement was published that extensive and systematic core drilling had established a reserve, for the entire Bajenova district, of more than 3 million metric tons of fiber within 50 feet of the surface. This estimate was based on a 2-percent recovery, and as recovery is probably about 4½ percent, the estimate of reserves given above might easily be doubled. As the deposits extend far below the 50-foot level, a further substantial enlargement of the figure would be justified. In 1939 the reserves of asbestos in the Soviet Union were estimated at 18 million metric tons.[1]

SOUTHERN RHODESIA

According to an estimate made in 1928, the reserves of asbestos in the Southern Rhodesian deposits totaled about 7 million tons. During the ensuing 22 years about 1 million tons has been mined, which would reduce the reserves to about 6 million tons; however, the rate of depletion probably has been reduced to some extent by enlargement of established reserves through prospect drilling. The 170 and Birthday fiber-bearing rock masses, which are approximately 2,000 feet long and 100 feet wide and dip 25°, have been proved by drilling to a vertical depth of 1,000 feet. One diamond-drill hole in the Birthday section intercepted rock of good grade at a depth of 2,300 feet. The Nil Desperandum deposit has been proved to a depth of 850 feet.

The proportion of fiber of spinning grades produced in the Shabani area is exceptionally high. An estimate as high as 25 or 30 percent has been made, but in 1949 it was said that 20 percent of the output would satisfy stockpile specifications, which call for the spinning grades that are designated as C & G Nos. 1 and 2. As the largest known Rhodesian reserves are in the Shabani area, a reserve of spinning fibers that exceeds 1 million tons may be assumed.

UNION OF SOUTH AFRICA

TRANSVAAL

Moderate reserves of chrysotile occur in the Carolina district, but the New Amianthus mine near Barberton, a prolific producer in past years, ceased operation about 1940 because of reported depletion of reserves; however, it has recently been reopened. The nearby Munnik-Myburgh mine, idle for some years, has been reopened, and it is claimed that reserves of considerable extent are still available. Chrysotile reserves of considerable extent are known also in certain other properties in the Barberton area.

[1] Industriya (Moscow), May 10, 1939.

CAPE OF GOOD HOPE

The crocidolite deposits of the Cape extend over an area 240 miles long, with a maximum width of 30 miles. The area is so large and the fiber veins are distributed so generally throughout it that the reserves are undoubtedly very great, but no definite figures are available.

OTHER DEPOSITS

SWAZILAND

The reserves at the Havelock mine are said to comprise 14 million tons of rock carrying 4 percent of asbestos. This would indicate the presence of over half a million tons of fiber. The reserves may, in fact, be greater than these estimates would indicate, because recent exploration has revealed the presence of an extension of the serpentine belt from the Havelock mine south-southwest to the Transvaal border, a distance of 17 miles. A newly developed property adjoining the Havelock mine is said to have a reserve of 2 million tons of rock carrying 5 percent asbestos.

CHINA

China may have large reserves of asbestos. It was estimated in 1935 that Hopeh Province had a reserve of 400,000 tons.

SUMMARY

The world as a whole appears to have adequate asbestos reserves for at least 25 or 30 years at current or moderately enlarged rates of output. United States reserves of the shorter fibers are small compared with domestic needs. Of the longer grades the reserves are very small. The chief suppliers of United States markets—Canada and Africa—appear to have adequate reserves for long-range planning. The Soviet Union probably has reserves large enough to supply its domestic economy for many years. To provide for a possible downward scaling of reserves for greatly enlarged consumption, the discovery and development of new deposits, especially in the United States, are highly desirable.

POLITICAL AND COMMERCIAL CONTROL

Asbestos deposits of commercial importance are not abundant and are widely scattered over the earth. The demand for this mineral has, at times, exceeded the supply; therefore, both political and commercial control of deposits is of primary interest, not only to individual consumers but to national governments, because asbestos is regarded as a mineral of strategic importance.

POLITICAL CONTROL

The Russian deposits are under absolute control of the Soviet Union. All other producing areas of primary importance—those of Canada, Southern Rhodesia, Union of South Africa, and Swaziland—are within the political orbit of the British Commonwealth. Moderately important deposits in Cyprus, Australia, New Zealand, and India also are under British political control. Deposits of moderate importance outside the British Commonwealth are in the United States, Venezuela, Italy, Finland, China, and Japan. Relatively small deposits are controlled politically by Argentina, Bolivia, Brazil, Portugal, France, Turkey, French Morocco, and several other countries.

COMMERCIAL CONTROL

The only large asbestos producer in the United States—Vermont Asbestos Mines—is a subsidiary of the Ruberoid Co. of New York City. Nearly all of the smaller United States companies are financed by domestic capital.

Commercial control of the Canadian asbestos industry is diverse. Several mines are owned by United States manufacturers of asbestos products. The largest operation in Quebec, Canada—in fact, the largest operation in the world, that of Canadian Johns-Manville Corp., Ltd.—is a subsidiary of the Johns-Manville Corp. of New York City. This company also operates a new property—the Munro Mine—near Matheson, Ontario, which began production in 1950. The mine and mill of the Quebec Asbestos Corp., Ltd., are owned by the Philip Carey Manufacturing Co. of Cincinnati, Ohio. The Nicolet Asbestos Mines operation is owned by Nicolet Industries, Inc., of New York City, and Flintkote Mines, Ltd., is owned by the Flintkote Co., also of New York. The Bell Asbestos Mines, a large producer, is controlled by Turner & Newall, Ltd., of Manchester, England. Asbestos Corp., Ltd., the second largest producer in the Quebec area, is financed by British and Canadian capital. The Johnson's Co., one of the pioneer operators, is wholly owned by Canadian capital.

Two British companies, Turner & Newall, Ltd., and the Cape Asbestos Co., control the major output of asbestos in Southern Rhodesia, the Union of South Africa, and Swaziland. As Africa is an important source of asbestos (particularly of special grades and varieties, such as amosite, crocidolite, and low-iron chrysotile, found in limited quantities elsewhere in the world), this restricted ownership is a limiting element. These companies have extensive asbestos-products-manufacturing plants whose raw-material needs claim first priority. European and Australian customers also are favored at times over United States consumers. Accordingly, a shadow of uncertainty always rests upon the United States users of these highly important foreign fibers. Recent trends have been in the direction of larger demands and smaller supplies of low-iron chrysotile. However, the continuing shortage of supply has stimulated research on substitute materials that may eventuate in a decreasing demand for the foreign fibers.

The one company operating in Cyprus is controlled chiefly by British, Swedish, and French capital. The Australian mines are controlled by British and Australian interests. The blue asbestos mines of Bolivia are owned by Bolivian interests. A French company formerly held a 48-percent interest in the Venezuelan asbestos industry at Tinaquillo, but in 1953 the property was taken over by a new company controlled by Venezuelan capital. The Soviet Union controls, both politically and commercially, the activities of the asbestos industry of the Urals.

INTERNATIONAL TRADE

WORLDWIDE MOVEMENT OF ASBESTOS

With one notable exception, the countries that are large producers of asbestos are relatively small consumers, and the more important consuming countries have relatively limited supplies of asbestos within their borders. The exception is the Soviet Union, which is both a large producer and a large consumer. What are normally the important asbestos-consuming countries outside the Soviet Union—the United States, England, France, Italy, Germany, Belgium, Japan, and Australia—produce no asbestos or only relatively small quantities. Canada, the Union of South Africa, and Southern Rhodesia are becoming increasingly important asbestos consumers, but they use far less than they produce. Because of this situation, a large proportion of all asbestos mined enters international trade, and all the principal nations are profoundly interested in foreign sources of supply and their availability.

Figure 11 presents a general picture of the export and import situation for selected countries in 1950, which may be regarded as a representative year. As the United States depends so extensively on foreign asbestos, sources of supply are of the utmost importance to national economy.

FOREIGN TRADE OF THE UNITED STATES

The United States is the largest consumer of asbestos in the world. Table 30 shows domestic production, imports, exports, and apparent consumption for a 10-year period. Imports comprise 92 to 96 percent of the annual requirements. These imported supplies constitute the major part of the raw materials employed by more than 100 asbestos-products plants that manufactured goods valued at over $332 million in 1952.

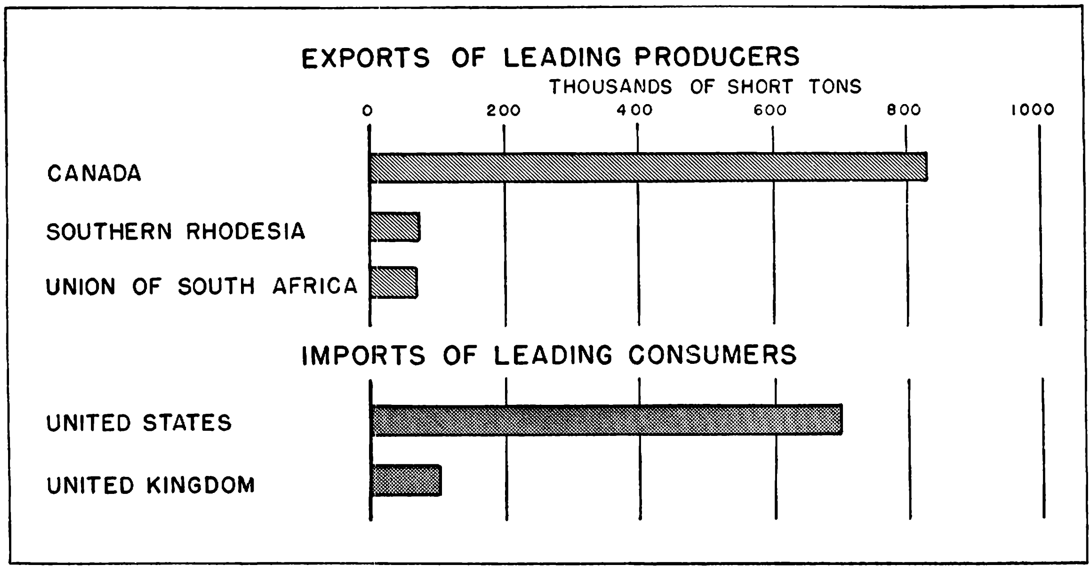


FIGURE 11.—Asbestos Exports and Imports, by Leading Countries, in 1950.

TABLE 30.—*Asbestos production and consumption in the United States, 1944–53, in short tons*

Year	Production (sold or used)	Imports	Exports	Apparent consumption	Year	Production (sold or used)	Imports	Exports	Apparent consumption
1944	6, 667	383, 049	475	389, 241	1949	43, 387	509, 366	20, 045	532, 708
1945	12, 226	374, 199	8, 550	377, 875	1950	42, 434	705, 458	20, 890	727, 002
1946	14, 075	456, 688	11, 011	458, 727	1951	51, 645	761, 873	16, 526	796, 992
1947	24, 035	594, 839	2, 680	616, 194	1952	53, 864	709, 469	10, 724	752, 609
1948	37, 092	647, 881	9, 227	675, 746	1953	54, 456	702, 838	3, 076	754, 218

TABLE 31.—*United States imports of asbestos, by country of origin, 1944–53, in short tons*

[Data compiled by M. B. Price and E. D. Page, of the Bureau of Mines, from records of the U. S. Department of Commerce]

Country [1]	1944	1945	1946	1947	1948
Africa:					
Southern Rhodesia	7, 966	2, 545	5, 463	8, 992	10, 513
Union of South Africa	19, 196	13, 247	6, 050	20, 034	19, 551
Swaziland					692
Australia		2	24		3
Bolivia	15				68
Canada	353, 247	355, 768	442, 073	559, 279	602, 216
Italy			8	8	10
U. S. S. R.	2, 610	2, 625	2, 750	6, 524	15, 514
United Kingdom [2]	1		1	1	
Total [3]	383, 049	374, 354	456, 688	594, 839	647, 881

Country [1]	1949	1950	1951	1952	1953
Africa:					
Southern Rhodesia	13, 722	9, 892	7, 725	10, 543	9, 990
Union of South Africa	22, 730	14, 805	23, 583	26, 902	37, 023
Swaziland	497	1, 522	712	607	619
Australia	249	273	311	274	1, 750
Bolivia	69	39	324	413	828
Canada	470, 788	678, 358	726, 770	668, 900	652, 117
Italy	100	19	23	11	4
U. S. S. R.	1, 221	426	2, 237	1, 761	325
United Kingdom [2]	5	5		5	120
Total [3]	509, 366	705, 253	761, 873	709, 469	702, 838

[1] Small imports have been received sporadically from Brazil, Cuba, Chile, China, Cyprus, Finland, France, India, Mozambique, Morocco, Netherland Indies, Portugal, Turkey, and Venezuela.
[2] Asbestos from United Kingdom probably originated either in Rhodesia or Union of South Africa.
[3] Includes, for most of the years, small quantities imported from 1 or more of the countries mentioned in footnote 1.

Table 31 shows United States imports of asbestos for the period 1944–53, by countries of origin. On a tonnage basis, over 90 percent ordinarily is imported from Canada, but a large part of it consists of the shorter grades. Of greatest significance, particularly at times of national emergency, are the imports of crudes and spinning fibers, of which the United States produces very small quantities. Imports of such grades from Canada during recent years are indicated in table 32.

As referred to elsewhere in this report, there is a demand for substantial quantities of asbestos with a lower iron content than that produced in Canada. The low-iron types are needed, in particular, for electric-cable insulation. The principal types are the so-called C. & G. Nos. 1 and 2 grades obtained from Southern Rhodesia. Table 33 shows imports of these grades during recent years.

The relatively small quantities obtained during the early 1950's created a critical situation. Demands became less urgent by 1953, and the situation was relieved further by shipments of satisfactory low-iron fiber from the Cassiar Asbestos Co. mine in British Columbia, Canada.

Crocidolite (blue asbestos) is used in large quantities in the United States, particularly in the manufacture of asbestos-cement pipe. Small quantities are used for gas and air filters. A

TABLE 32.—*Imports of spinning grades of asbestos into the United States from Canada, 1949–53, in short tons*

[Based on Dominion Bureau of Statistics data]

Grades	1949	1950	1951	1952	1953
Crude No. 1	215	390	122	144	168
Crude No. 2	192	260	217	332	207
Other crudes	437	180	382	80	467
Spinning and textile	12, 987	24, 417	22, 463	24, 112	19, 417
Total	13, 831	25, 247	23, 184	24, 668	20, 259

TABLE 33.—*Imports of chrysotile asbestos into the United States from Southern Rhodesia, by grades, 1949–53, in short tons*

[U. S. Department of Commerce, Bureau of the Census]

Grades	1949	1950	1951	1952	1953
C. & G. No. 1	1, 270	2, 124	678	461	1, 039
C. & G. No. 2	2, 905	1, 844	1, 239	1, 363	814
Spinning and textile		556	25	177	730
Other	9, 547	4, 950	5, 783	8, 296	7, 304
Total	13, 722	[1] 9, 474	7, 725	10, 297	9, 887

[1] Includes imports from Mozambique.

type of blue fiber mined in Bolivia is preferred for this specialized use. No blue fiber is produced in North America.

Amosite has specialized uses that create a strong demand for it. This variety is mined exclusively in the Union of South Africa. Imports of these varieties are presented in table 34.

TABLE 34.—*Crocidolite and amosite imported into the United States, by country of origin, 1949–53, in short tons*

Year	Crocidolite				Amosite—Union of South Africa
	Union of South Africa	Australia	Bolivia	Total	
1949	4,941	249	69	5,259	14,892
1950	5,046	273	104	5,423	8,105
1951	6,130	348	327	6,805	15,131
1952	6,885	274	413	7,572	18,218
1953	7,781	1,748	767	10,296	15,261

Although the United States produces only a fraction of its requirements of asbestos, it nevertheless exports substantial quantities, as indicated in table 30. Small quantities of Vermont and Arizona asbestos are exported at times, but exports from the United States consist principally of foreign fibers, chiefly Canadian, blended in various ways to suit the needs of Latin American or European countries.

South America has over 20 asbestos-products plants. Some of them are supplied in part from small local asbestos mines, and fiber shipments are sometimes received from Africa, but the plants must depend primarily on direct shipments from Quebec or on imports of prepared fibers from United States suppliers.

FOREIGN TRADE OF CANADA

Although Canada is attaining considerable importance as an asbestos-products-manufacturing country, domestic requirements amount to only 3 to 5 percent of domestic production. Foreign sales of asbestos are therefore important elements in the Canadian national economy. The value of asbestos exports exceeded $86 million in 1952. All exports of asbestos from Canada consist of chrysotile, except, possibly, small quantities of other varieties that are imported and later shipped to other countries.

Canada is the principal source of supply of asbestos for the United States and a substantial source for many other countries. Table 35, showing exports for a 10-year period of crudes and milled fibers (Groups 1 to 5), indicates the destination of shipments. Of the total exports of these grades during the period 1948 to 1952, the United States received 63, continental European countries 13, United Kingdom 10, Latin American countries 7, and all other countries 7 percent. Since 1949 relatively larger proportions of the crudes and milled fibers are being shipped to countries other than the United States. Of the shorter grades exported (Groups 6 and 7), which are not included in table 35, the United States receives 80 to 90 percent.

FOREIGN TRADE OF SOUTHERN RHODESIA

Southern Rhodesia has a small asbestos-products-manufacturing industry, which is expanding. One new plant was built at Salisbury during recent years. Accordingly, a large percentage of the asbestos produced is exported. Of total shipments from Southern Rhodesia during the period 1948 to 1952, the United Kingdom received 56 and the United States 15 percent. Australasia is next in importance to the United States as a consumer of Rhodesian fiber. Destinations of exports for several years are indicated in table 36.

TABLE 35.—*Asbestos crudes and milled fibers exported from Canada, by destination of shipments, 1943–52, in short tons*

[Data from Trade of Canada]

Year	United States	United Kingdom	Continental Europe	Latin America	Other	Total
1943	160,906	27,541	1,973	12,470	9,932	210,837
1944	145,852	16,027	1,130	9,251	10,948	181,668
1945	135,432	28,799	19,682	18,904	7,811	210,628
1946	150,099	23,063	23,289	10,325	9,096	215,372
1947	161,835	20,418	19,661	14,769	7,963	224,646
1948	168,855	24,435	20,627	14,418	9,614	237,949
1949	126,797	19,058	18,996	8,958	8,463	182,272
1950	181,409	29,912	38,847	20,848	19,627	290,643
1951	199,632	30,807	45,339	23,451	26,025	325,254
1952	192,811	36,726	59,221	23,941	27,811	340,510

TABLE 36.—*Asbestos exported from Southern Rhodesia, by destination of shipments, 1943–52, in short tons*

[Data: 1943–49, Trade of Southern Rhodesia; 1950–52, Economic and Statistical Bulletin of Southern Rhodesia]

Year	United States	United Kingdom	Continental Europe	Latin America	Australasia	Other	Total
1943	32, 503	11, 553	600	1, 950	8, 800	976	56, 382
1944	6, 806	17, 637	980	3, 915	16, 281	1, 136	46, 755
1945	2, 281	17, 499	12, 313	3, 700	13, 808	650	50, 251
1946	4, 476	26, 438	14, 908	2, 865	11, 660	1, 398	61, 745
1947	10, 982	25, 705	6, 971	2, 463	9, 947	257	56, 325
1948	10, 142	35, 766	6, 577	3, 104	10, 895	1, 279	67, 763
1949	13, 574	37, 354	7, 204	1, 310	10, 994	2, 372	72, 808
1950	11, 316	39, 971	(1)	(1)	(1)	22, 492	73, 779
1951	9, 032	39, 521	(1)	(1)	(1)	19, 781	68, 334
1952	10, 180	51, 600	(1)	(1)	(1)	21, 355	83, 135

1 Included under "Other."

FOREIGN TRADE OF UNION OF SOUTH AFRICA

Three varieties of asbestos are exported from the Union of South Africa—chrysotile, crocidolite, and amosite. The Union is the world's principal source of crocidolite (blue asbestos) and the only source of amosite. Although there are several asbestos-products-manufacturing plants in the Union, a large percentage of the asbestos output is exported. Exports, by destination, are shown in table 37. The figures in this table include not only asbestos produced in the Union but also substantial quantities of chrysotile produced in nearby Swaziland and shipped through Barberton.

Of the total quantities exported during 1946 to 1950 the United States received 24, the United Kingdom 38, continental Europe 18, Latin America 4, Australasia 9, and other countries 7 percent. Increasing shipments to continental Europe and Australasia, with relatively smaller quantities to the United States, have characterized recent years.

TABLE 37.—*Asbestos exported from Union of South Africa, by destination of shipments, 1943–51, in short tons* [1]

[Data from Union of South Africa Annual Statement of Trade and Shipping]

Year	United States	United Kingdom	Continental Europe	Latin America	Australasia	Other	Total
1943	23, 250	20, 078	410	292	878	5, 274	50, 182
1944	18, 846	25, 932	5, 190	908	1, 902	5, 500	58, 278
1945	9, 674	23, 119	1, 212	6, 003	184	109	40, 301
1946	9, 933	12, 089	15, 471	213	7, 906	2, 282	47, 894
1947	18, 190	27, 593	6, 070	1, 107	4, 121	7, 685	64, 766
1948	18, 950	27, 611	7, 073	1, 955	4, 030	4, 363	63, 982
1949	20, 637	37, 158	17, 136	4, 417	6, 479	6, 286	92, 113
1950	16, 115	37, 324	21, 821	7, 265	12, 537	6, 516	101, 578
1951	24, 810	40, 020	28, 412	6, 632	13, 283	13, 343	126, 500

1 Includes asbestos produced in Swaziland.

PROSPECTING AND EXPLORATION

GENERAL FEATURES OF EXPLORATION

Asbestos is usually associated with serpentine, a mineral easily recognized by its green or yellowish green color and greasy luster; therefore, the formations in which asbestos occur are traced easily when exposed. The exposure may be widened by stripping or trenching and the quality of the fiber judged by visual inspection. Surface fiber may be discolored by weathering, but such effects usually are confined to a depth of a few feet only. Geologic mapping of the serpentine and associated formations is a desirable prelude to intelligent prospecting. Exploration at depth may be conducted with diamond or shot core drills. Deposits are commonly explored by means of test pits, which may be enlarged into active quarries or mines if favorable results are obtained.

URGENT NEED FOR EXPLORATORY WORK

During recent years, nearly all grades of chrysotile have been in short supply, but shortages have been most acute in the spinning grades. An imperative need for discovering new sources of supply has become apparent; the United States Government recognized this need and took steps to stimulate active search. The Defense Minerals Exploration Administration of the United States Department of the Interior, under the provisions of the Defense Production Act of 1950, made available exploration-assistance funds on a participating basis to encourage a search for strategic and critical minerals. For asbestos exploration the ratio of contribution originally was 90 percent by the Government and 10 percent by the operator. Late in 1953 the ratio was changed to 75 and 25 percent, respectively. Several asbestos companies were granted assistance under the terms of this fund, and exploratory work was begun during the latter part of 1951. The Federal Bureau of Mines and the Federal Geological Survey rendered assistance in this exploration program. Help was also received from some State geological surveys. Several asbestos companies conduct exploratory work continuously as a part of their regular development programs.

METHODS AND PROBLEMS OF EXPLORATION

Methods of exploration are governed, to some extent, by the character of the deposit. Most of the commercial asbestos deposits of the world, like those in Canada, are associated with massive serpentine, serpentinized peridotite, and similar rocks that extend to great depths. A more unusual type, like that of Arizona, consists of fiber zones bedded in altered limestone. The former, which might be called the three-dimensional type, requires exploration, both laterally and vertically. The bedded deposits are predominantly two-dimensional, and the main problem is to determine the areas of the fiber-bearing zones. However, occasional exploration at depth is desirable to determine the presence or absence of additional fiber zones at other levels.

The magnetometer, which has proved useful in prospecting for other minerals, has recently been applied, with some success, to prospecting for asbestos. Serpentine masses, with which chrysotile asbestos is generally found, can be detected with a magnetometer, even though they may be blanketed deeply with overburden. The magnetometer will not detect the presence of asbestos, but it enables the prospector to delineate the areas where serpentine—the host rock of the asbestos—exists, and thus it narrows the field for later core-drill prospecting. The magnetometer is less effective in prospecting the sheetlike deposits occurring in limestone.

If, by the use of the magnetometer or other means, a promising area has been delineated, more intensive prospecting may be pursued. If the deposit is covered with a moderate depth of overburden, pits or trenches may permit wide exploration of surface and near-surface rock. The modern bulldozer is a useful tool for stripping or trenching. Exploration at depth is best accomplished with diamond-bit core drills. Survey lines are commonly run at 100-foot intervals and in 2 series at right angles to each other. Drill holes are spotted at the intersections of the grid thus formed. The spacing may be more or less than 100 feet, depending upon circumstances. The holes may be either vertical or inclined. A direction is chosen that will furnish the most useful information concerning the rocks intersected. A study of the cores will give information on the spacing and thickness of the fiber veins and the length and quality of the fiber.

The evaluation of cores by visual study has attained remarkable refinement during recent years. The width of fiber veins in increments of one-sixteenth inch is determined by measurement. A 5-foot section of core contains 960 sixteenths, and it is within the realm of accuracy to assume an even 1,000. Therefore, by adding the total number of sixteenths of fiber contained in a 5-foot section and dividing this number by 10, an uncorrected percentage of fiber content is obtained. This figure may be corrected according to the angle at which the veins intersect the axis of the core. The fiber may be evaluated by determining the proportions of the various lengths that appear in the veins.

The proportion of fiber to rock may also be determined by proper sampling of the cores and by crushing the rock and screening out the fiber. If the cores are badly broken, as they commonly are in fractured and veined serpentine, a method for sampling the drill sludge has been devised. The findings of the fiber content of the rock by the drill-core or sludge methods should be checked by determining the fiber content of representative bulk samples taken from outcrops, pits, or drifts. Laboratory or pilot-plant mills may be used for such determinations.

If a commercial mill is available, a test run of several hundred tons of average mill rock would indicate the total recovery and recovery by grades that may be expected. However, each deposit has its peculiar features, and milling processes and equipment must be adapted to suit the prevailing conditions. A mill adjusted to treat most efficiently the rock of a certain deposit may not be suited for the best treatment of rock brought in from another source. Therefore, the percentage of recovery obtained on the sample may be lower than could be obtained when, as a result of experience, maximum mill efficiency was attained.

The length, strength, and flexibility of the fibers are of first importance. For fibers one-fourth inch long or longer, a simple test is to hold firmly a wisp or fiber between the thumb and finger, using both hands, and to twist it by rotating the hands. Weak fibers will break readily under such treatment. If the asbestos can be twisted for some time without breakage, it has high strength, and, if the fibers are long enough, they are probably suited for spinning uses. Fibers one-fourth inch long and longer are much more valuable than the shorter grades. However, for weak fibers, like those of anthophyllite, fiber length has little significance because the milling process will break them into short lengths.

Authoritative information on methods of exploring and evaluating asbestos deposits has been presented by staff members of two asbestos-producing companies.[1]

[1] Messel, Michael J., Examination and Valuation of Chrysotile Asbestos Deposits Occurring in Massive Serpentine: Trans. AIMME, vol. 173, 1947, pp. 79–84.
Foster, George K., and Borror, Charles C., Asbestos-Fiber Exploration and Production Forecasts by Core Drilling, Jeffrey Mine, Asbestos, Quebec: Trans. AIMME, vol. 173, 1947, pp. 85–93.

ESSENTIAL REQUIREMENTS FOR NEW DISCOVERIES

Certain conditions must be satisfactorily met before successful commercial operation of a new asbestos deposit can be reasonably assured.

1. **Quality of Fiber.**—Chrysotile fibers of commercial grade must be strong and flexible. These qualities are adequate in most occurrences. Surface weathering tends to weaken the fibers; accordingly, samples should be taken below the weathered zone. Minability depends upon the adaptability of the fibers to use. Thus filtration qualities, harshness, flexibility, and brittleness bear directly upon commercial application.

2. **Length of Fiber.**—Some asbestos deposits are worked profitably, even though virtually all of the fiber is below spinning grade, because there are extensive uses for short fibers. However, the presence of fiber of spinning length is highly desirable, especially in times of national emergency. Even a small proportion of fiber veins three-eighths inch or more thick is a favorable factor. Deposits furnishing both spinning and nonspinning fibers are more likely to prove profitable than those producing short fibers only.

3. **Proportion of Fiber in the Rock.**—In general, the fiber recovered should be not less than 4½ or 5 percent of the rock cobbed or milled. If the percentage drops below 4½ the project probably will be unprofitable. However, a deposit with smaller yield might be workable if the fibers were of exceptionally high value—if, for instance, the deposit furnished a substantial proportion of spinning asbestos. Fiber yield can best be determined by making a commercial mill run using a large representative sample.

4. **Extent of Reserves.**—Asbestos milling is a costly process that requires a heavy investment in equipment. The investment is justified therefore only if the workable deposit is large enough to insure adequate supplies of commercial-quality, fiber-bearing rock for at least 20 years of operation at an established rate, and with average profits. Prospect core drilling to determine the extent of reserves is a necessary forerunner of any asbestos milling project.

5. **Economic Factors.**—Mining and other operating costs, power and water supply, transportation facilities, and availability of labor are important factors in determining minability.

Asbestos deposits throughout the world differ widely in character; and, as the mining method must be adapted to the prevailing conditions, a great variety of methods is followed. Open-pit quarry methods. gloryhole, underground room-and-pillar, shrinkage stoping, block caving, and other methods are represented. A brief description of mining operations in the principal localities follows.

UNITED STATES

ARIZONA

In Arizona there is no massive fiber-bearing rock, as in Canada. The serpentine with which the asbestos veins are associated is in bands from a few inches to a few feet thick, paralleling the Mescal limestone. The mines are entered from cliff faces or the steep sides of canyons. The veins pinch and swell irregularly and are so erratic in size and direction that development cannot be planned as definitely as in the mining of many other minerals. The fiber is mined in drifts and tunnels, and conditions are most favorable where two or more veins of workable size are close enough to be worked on one drift. Modified room-and-pillar methods are followed. Mining is so costly that a high price must be obtained for the fiber if any profit is to be earned.

VERMONT

The chrysotile asbestos deposit of Vermont is on Belvidere Mountain about 15 miles from Hyde Park. About 1944 a new quarry opening was made over the ridge about 1 mile from the quarry that was formerly worked. Overburden is not heavy; and, as the asbestos veins occur in massive serpentine as in Canada, open-pit methods are employed. In 1953 the quarry was operated on 3 benches, each about 600 feet wide and 125 feet high. A series of 7-inch blast holes is sunk with churn drills, and about 50,000 tons of rock is thrown down with each multiple blast. The rock is loaded with 3-yard electric shovels into 15-ton Euclid trucks, which dump into a 48- by 60-inch jaw crusher. The crusher will handle such large masses that very little secondary blasting is necessary. Secondary crushing is accomplished in Symons cones, which reduce the rock to walnut sizes. The product of the cones is carried on a conveyor belt about one-fourth mile to an open stockpile at the mill site. Material from the stockpile is conveyed to a drier and thence to a dry-storage bin, from which the mill feed is drawn. When the present Lowell quarry was first opened, the rock was carried up hill 1 mile by overhead cableway to the old mill at the Eden quarry, but this operation was abandoned when the new mill began producing.

CANADA

Canadian asbestos occurs in irregular veins in massive serpentine deposits that are extensive both laterally and at depth. Accordingly, well-ordered, large-scale mining operations have been developed. For many years asbestos rock was obtained from large open-pit quarries served by massive overhead cableways. About 1927 methods were modified by the introduction of cranes or power shovels for loading, locomotives for hauling cars on the quarry floor, and cable cars for removing rock from the pits up inclined planes or through tunnels. Crudes were hand-cobbed on the quarry floor or removed from picking belts after the rock was crushed. The Jeffrey mine of Canadian Johns-Manville Corp., Ltd., was operated as an immense open pit, with circular spiral benches that permitted power-shovel loading and locomotive haulage. A detailed discussion of the open-pit method has been published.[1]

A still later development was the introduction of shrinkage stoping. Stopes 40 feet wide and about 200 feet long were equipped with steel chutes through which the broken rock was drawn into cars trammed through drifts to the open pit from which the material was hoisted by high-speed cableways.

The most recent mining method is an elaborate block-caving system first introduced at the King mine of Asbestos Corp., Ltd., about 1932. A haulage system was established 500 feet below the surface. The overlying fiber-bearing rock was worked in blocks 160 feet square. Four grizzly drifts 40 feet apart were driven beneath the block 40 feet above the haulage level. The drifts were timbered and provided at 20-foot intervals with heavy steel-rail grizzlies with 16-inch openings. Finger raises were driven upward at each side of the drift, and 20 feet above the drifts the block was undercut completely by driving drifts and blasting out the intervening pillars. The finger raises were funneled to permit access to large pieces of rock that were broken at the grizzlies. The boundaries of the block were weakened by projecting raises and connecting drifts. The entire block sank and was broken by its own weight. Rock was worked through the grizzlies until the block was exhausted. Satisfactory

[1] Chellson, H. C., Operating the World's Largest Asbestos Mine; parts I and II: Eng. and Min. Jour., vol. 142, 1941, No. 9, pp. 43–46; No. 10, pp. 49–52.

results were attained, and mining costs were considerably lower than by the shrinkage-stoping method. The method has been employed also by Johnson's Co., and Canadian Johns-Manville Corp., Ltd., has been developing an extensive block-caving system at the Jeffrey mine for several years. In this mine each block is 200 feet square. The crushing plant is situated at an underground level of 816 feet and loading facilities at a 950-foot level. Several blocks were being worked in 1952. A detailed description of the method followed has been presented.[2]

Other companies are preparing for or have adopted similar processes and considerable detail concerning their methods has been published.[3] Both the open-pit and underground methods followed in Quebec have been covered in a series of articles in the magazine Asbestos.[4]

SOUTHERN RHODESIA

The largest asbestos mines in Southern Rhodesia comprise the Shabani group. They are classed among the most important asbestos mines in the world, having attained a production rate of over 72,000 metric tons of fiber a year in 1949. The most important ore bodies are the 170, Birthday, 177, and Nil Desperandum. The 170 and Birthday ore bodies have a length of over 2,000 feet and a width of about 100 feet, and dip about 25° south. Mining is concentrated on the 400- and 500-foot levels (vertical depth). The Nil Desperandum ore body has a length of 500 to 600 feet and dips about 45°.

Two mining methods—quarrying and shrinkage stoping—have been used in the Shabani mines. The quarrying method, as described some years ago, was unusual in that the rock was broken in open pits but was removed through vertical shafts. Shafts or winzes were sunk in rows 50 to 60 feet apart and connected with crosscuts at a lower level. The rock around them was drilled and blasted, and the longer fibers were cobbed from the broken fragments. For the fiber to be broken as little as possible, light powder charges were fired in shallow holes. The broken rock was thrown into the shafts (which were kept nearly full), drawn into cars on the level below, and taken to the mill for extraction of the short fiber or recovery of the long fiber not removed in cobbing. The cobbed fiber was thrown down a separate shaft. The shafts were also used for disposal of waste and for drainage.

A shrinkage-stoping method was introduced about 1926. The fiber-bearing rock is removed in blocks 80 feet square, leaving pillars 20 to 30 feet wide, which are subsequently reclaimed.

It was reported in 1949 that conditions had developed underground that made it necessary to change from a room-and-pillar to a caving system of mining and that mining had to be pursued with care to avoid excessive caving that might obstruct operations. The precautionary measures designed to preserve the safety and integrity of the mine tended to restrict output. As the areas affected are sources of long fibers, the modification in mining method may account in some measure for the shortage of Rhodesian spinning fibers in 1951 and 1952.

UNION OF SOUTH AFRICA

The largest asbestos mines that have been worked in the Union of South Africa are the New Amianthus and the Munnik-Myburgh in the Barberton district. Both were idle for some years but have been reopened. The Munnik-Myburgh mine was said to have had 3,300 feet of underground workings in 1928, but no data are now available on the extent to which the old workings will be utilized or the nature of the new developments. Several chrysotile mines are in operation in the Barberton district, but descriptions of the mining methods followed are not available at this time.

In the Carolina district of the Transvaal chrysotile occurs in cross-fiber veins occupying a 5-foot zone of altered dolomite dipping 8° to 15°. Mines have been operated since 1905 and were said to have reached a depth of 300 feet in 1936. As production has never been large, the workings probably have not been extended greatly during subsequent years.

Amosite of the Lydenburg district of the Transvaal occurs in banded ironstones that have been highly folded and contorted. The fiber-bearing beds usually stand at angles ranging from 15° to vertical. As they are unsuited for open-pit working, underground mining is generally followed. Where the beds are intersected by transverse valleys, tunnels are driven along the strike, and the fiber-bearing rock is stoped out at various levels. Outcrops are numerous over a wide area, and fiber is obtained from many mines worked at relatively shallow depths.

The largest mines are the Egnep and the Amosa, near Penge. In this region the fiber-bearing zone dips from 15° to 22°. The Egnep mine was worked on seven levels. A vertical shaft 215 feet deep served the seventh level and

[2] Lindell, Karl V., World's Largest Asbestos Producer Uses Block Caving and Concreted Slusher Drifts: Min. Eng., vol. 4, No. 3, March 1952, pp. 265–271.

[3] Ross, J. G., Block Caving at the King Mine of the Asbestos Corp., Ltd., Thetford Mines, Quebec: Canadian Min. and Met. Bull. 264, April 1934, pp. 184–218.
Sherman, Gerald, Review of Progress in the Caving of Asbestos Ore: Min. and Eng., vol. 187, No. 4, April 1950, pp. 467–474.

[4] Smith, C. V., Asbestos-Mining Methods: Asbestos, vol. 26, 1944, No. 3, pp. 3-8; No. 4, pp. 3-10; No. 5, pp. 3-12.

in 1930 was connected with the sixth by a crosscut. The Amosa mine, as described by Hall in 1930, comprised 11 drifts, starting from the outcrop and ranging from 80 to 1,140 feet in length down the dip. Its inclined shaft, 320 feet long, corresponded to a vertical depth of 290 feet.

The following information on mining methods was supplied by the Cape Asbestos Co. in 1945.[5]

From the adits and levels the rock is stoped overhand. Material from the upper band is dropped to the haulage way on the main band. To mine the asbestos, the entire band is knocked down with blasts in drill holes placed in the waste rock between the seams of asbestos. Coarse waste is sorted out and used for stope filling. The asbestos and finer size waste are conveyed to the mill. It was stated in 1952 that a haulage tunnel in one of these mines had been driven to a length of 3,500 feet.[6]

Crocidolite occurs over a wide area in the Prieska and Kuruman districts of the Cape of Good Hope. The veins are so irregular and discontinuous that systematic mining is difficult. Simple surface workings in early days were later supplemented by shallow adit tunnel openings. Much of the work was done by native labor on a contract basis. Where fiber veins persisted at depth and were reasonably close together, underground methods were developed. Within the past 15 years, compressed-air drills have been introduced in most mines. Some mines have vertical and others inclined shafts. Waste material discarded underground is used as packing for roof support. Further sorting is conducted at the surface to eliminate rock too lean for profitable milling. Mill rock may be collected from many scattered workings. A few mines have been worked to depths of 250 feet with drifts over 1,000 feet long. Hall[7] described asbestos mining in the Union in some detail in 1930.

In the Transvaal all mining was by contract in opencut workings along the exposures for many years. Underground mining was introduced later. Compressed-air drills are now used extensively.

The demand for asbestos during the past few years has stimulated interest in the search for new deposits, and large numbers of prospectors and individual miners are operating in the asbestos areas. Where mining is conducted it consists essentially of stripping outcrops and operating at shallow depths limited by their small financial resources. Such a scale of operations is not conducive to production of asbestos of uniform grading or quality.

SWAZILAND

At the Havelock mine about one quarter of the rock is obtained from open-pit quarries and three quarters from underground stopes. After crushing, the fiber-bearing rock is passed through a rotating grizzly with 4-inch openings. The minus-4-inch product passes through a trommel with 2½-inch circular openings. The plus-4-inch and the minus-4-inch plus-2½-inch products are carried on a picking belt, where fiber-bearing and barren rock is separated and the latter carried to waste.

SOVIET RUSSIA

The asbestos deposits of the Bajenova district have a thin overburden. Hand methods of removal were first employed, but power shovels or hydraulic methods have superseded them to quite an extent.

More than 20 shallow, open quarries were worked for many years. Up to 1929 drilling was the only mechanical process used, and all other operations were conducted with hand tools. Owing to inadequate milling facilities, hand picking became an important concentration process, and only one-fourth to one-fifth of the rock quarried was sent to the mill. The average fiber content of the rock mined was only about 6 percent; but, because of the concentration attained by hand picking, rock sent to the mill contained 22 percent.

The first steps toward more complete mechanization were taken in 1929, with installation of 2- to 4-ton-capacity overhead cableways with fixed foot towers and traveling head towers, supplemented by inclined haulageways served by electric hoists. The rock was blasted in benches 5 to 6 meters high and classified into crudes, mill feed, and waste.

In 1929 two shafts were sunk and connected with a haulage level at a depth of 50 meters. They were designed for gloryhole mining, which proved uneconomical. This method was supplemented and largely superseded in 1930 by electric-shovel loading in open pits, with transportation by locomotives to inclined haulageways, up which cars were taken by electric hoists. Rukeyser[8] has described quarrying and mining methods in some detail.

These conditions prevailed in the early 1930's, and no data are available as to what has transpired since that time. It is a fair

[5] Asbestos, Amosite Mines, South Africa: Vol. 27, No. 2, August 1945, p. 8.
[6] Isaacs, H. Sailing, The Story of Amosite: CAC Magazine, The Cape Asbestos Co. (London), vol. 2, No. 1, December 1952, p. 26.
[7] Hall, A. L., Asbestos in the Union of South Africa: Geol. Survey of South Africa Mem. 12, 2d. ed., 1930.

[8] Rukeyser, Walter A., Mining Asbestos in U. S. S. R.: Eng. and Min. Jour., vol. 134, September 1933, pp. 375-381.

assumption that the scope of mining has been enlarged and methods improved.

CYPRUS

Chrysotile asbestos occurs on the slopes of Mount Troodos in irregular veins traversing serpentine formed by alteration of olivine. The expansion accompanying metamorphism of the original olivine resulted in excessive fracturing, which makes excavation easy. Cyprus Asbestos Mines, Ltd., is the sole operator. The workings consist of open-pit terraces reaching a maximum height of 250 feet. Much of the rock is so fractured and decomposed that it can be broken with picks without the aid of explosives. Before 1927, when compressed-air drills were introduced, the harder rock was drilled for blasting by hand methods. The larger masses of barren rock are removed as waste. Fiber-bearing material is sun-dried and then passed over gravity screens. That passing through an 18-mm.-mesh screen and retained on a 5-mm. screen (about one-fifth of the total material quarried) is sent to the mills. Oversize rock retained on the upper screen and sand passing the lower screen are trammed to waste heaps. As the quarries are at an elevation of about 4,500 feet above sea level, they can be worked only from March to December. Further details of quarry methods followed in the late 1920's have been given by Whitworth.[9] Mining activities of a later date have been recorded briefly.[10]

CHINA

Before World War II mining methods in the Laiyuan district, where the most important asbestos deposits of the country are situated, were primitive. The mining tools used were hammers, chisels, picks, and shovels. No machinery or explosives were employed. Small inclined tunnels were sunk along the veins to a maximum depth of about 30 meters. The fiber was cobbed and sorted by hand. During the war production increased greatly under Japanese stimulation, and it may be presumed that more modern methods were introduced.

ANTHOPHYLLITE AND TREMOLITE MINING

Both tremolite and anthophyllite usually occur in pockets or lenses of relatively small size and are generally confined to near-surface zones. Most of the mines, therefore, are shallow open pits. There are workings of this type in Georgia, North Carolina, California, Montana, and some other States. Exceptionally, the fiber is mined in drifts or tunnels.

[9] Whitworth, M., Cyprus and Its Asbestos Industry: Mining Mag. (London), vol. 39, September 1928, pp. 143-150.
[10] Mining Journal (London), vol. 240, No. 5883, May 22, 1948, p. 380.

MILLING METHODS

DEFINITIONS

Asbestos fibers fall into two main groups—crudes and mill fibers. The term "crude" in Canada and Vermont is applied to fiber of spinning grade, measuring three-eighths inch or longer, which is hand cobbed and not passed through a mill. In Arizona the term is used more loosely. There are four grades of Arizona "crudes" that include all fiber lengths. Although some are hand-cobbed, most of them are produced by simple mechanical cobbing and screening. In other countries also the term is used more loosely. In both Soviet Russia and Africa it includes fibers prepared by hand cobbing alone or in conjunction with simple mechanical crushing, disintegrating, and screening processes. Mill fibers are obtained by crushing and beating the fiber-bearing rock until the asbestos is freed and then removing the fiber from the rock by screening and air separation.

GENERAL FEATURES

Chrysotile, the principal asbestos of commerce, is a fibrous form of serpentine and is always associated with massive serpentine. The concentration process is therefore unique in that it involves separation of a fibrous mineral from a massive form of the same mineral. Neither chemical composition nor specific gravity can therefore be used as a basis for separation. The property that makes mechanical separation possible is the fibrous structure, which permits it to be opened or divided into filaments amenable to separation from the gangue by air suction or screening.

The value of chrysotile asbestos depends largely upon the length of the fibers, as the long fibers are worth several times as much as the short ones. A most important principle underlying asbestos milling is separation of fiber from rock with a minimum of fiber breakage. Unnecessarily rough treatment is to be avoided. Modern mills are designed to remove the separated fiber after each crushing process. If the fiber already freed from rock enters the next crushing unit along with sand and rock fragments, it will be broken into shorter grades. Asbestos milling consists essentially of coarse crushing, drying, and recrushing in stages; each step is followed by screening and air separation of fiber from rock.

Fiber processing consists briefly of separation of the aspirated fibers according to length and cleaning of the respective grades for removal of granules and dust. The process is flexible enough to provide finished fibers of varying textures.

Milled fibers of spinning grade require considerable further processing at the asbestos-textile-manufacturing plant. Crude asbestos retains more or less of the natural solid form in which it occurs in the veins, and several successive opening processes are required. These processes are conducted at the textile plant.

The development of improved processes whereby fiberization (fiber opening) may be accomplished with minimum breakage of fibers is a profitable field for research. Some success has been attained by using dispersing agents to supplement or replace mechanical means. Impregnation with air at high pressure, followed by sudden release of the pressure, has been tried.[1] This is essentially the same process as that followed for fiberizing wood. When applied to masses of crude asbestos, the method gave satisfactory fiberization but is said to be uneconomic.[2]

The milling process can break the longer fibers into shorter lengths and weaken the fibers; this is avoided as far as possible. Methods have been devised whereby the tensile strength of asbestos fibers can be tested and the results expressed in terms of pounds per square inch.[3] Although this is a slow and tedious process, it has at least one important application. It has been found possible to submit bundles of crude asbestos to processing equipment such as crushers, rolls, hammer mills, etc., and to test the tensile strength of the fiber before and after processing. By comparing the degree of weakening of the fiber one can determine the type of equipment best suited for opening the fiber with minimum effect on the fiber strength.

Mill design varies greatly because it must be modified to suit the nature of the fiber, the ease or difficulty of fiberization, and the hardness or toughness of the enclosing rock. An approved design may represent many months or even years of testing and experimentation.

CANADA

Canadian milling practice is described first because the Quebec operators were pioneers in milling and established a pattern that is followed with some modifications in many other regions.

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[1] Joyce, William J. (assignor to Raybestos-Manhattan, Inc.), Method of Fiberizing Asbestos: U. S. Patent 2,386,401, Oct. 9, 1945.

[2] Information supplied by Jesse M. Weaver, Raybestos-Manhattan. Inc., 1951.

[3] Badollet, M. S., Research on Asbestos Fibers: Canadian Min. and Met. Bull., vol. 51, 1948, pp. 213-216.

RECOVERY OF CRUDES

Before the mid-1930's most of the Quebec fiber was obtained from open pits. It was customary then to sledge the rock on the quarry floor and to separate the masses of longer fiber by hand. With gradual conversion from open-pit to underground mining, conditions became less favorable for cobbing. In some instances the crudes are collected from picking belts. Much of the fiber formerly handpicked as crudes now passes through the mill and appears as mill fiber.

The handpicked chunks of crude asbestos are taken to cobbing sheds, where they are manually processed by flattening with hammers, thus freeing any adhering rock. The separated rock, dust, and short fibers are dropped into a receptacle under the bench, and the remaining high-grade fibers are classed as Crude No. 1, material three-fourths inch long and over, and Crude No. 2, material three-eighths to three-fourths inch long. To separate further the short fiber and rock dust, Crude No. 1 is screened on a flat shaking screen with ⅜-inch holes and No. 2 on one with 3/16-inch holes. After being screened, the fibers are packed in jute bags of 100 pounds capacity. Crudes constitute a very small proportion of the recovered fiber, but they are the most valuable products.

MILLING PRACTICE

Primary crushing is the first step in milling. Rock from the mine or quarry is dumped into an ore skip and conveyed to the crusher by controlled apron feed. A jaw crusher with a 48- by 60-inch opening set for a 6-inch discharge is a popular primary breaker, but smaller units may be used. To avoid unnecessary milling, obvious barren rock is discarded before, or both before and after, primary crushing.

The crushed rock is passed to trommel screens—large revolving cylinders with openings that permit the finer sizes to pass through but retain the sizes too large to be fed to the driers. The oversize lumps, which may be 4 to 6 inches in diameter, are fed to secondary crushers, usually of the gyratory or cone type. The secondary-crusher product joins the screen product of the trommels and is conveyed to drier bins.

Mill rock, especially during the winter or rainy seasons, contains considerable moisture, which must be removed because efficient mill operation requires dry rock. The rock is dried in vertical or rotary driers; the latter may be 50 or 60 feet in length and 5 to 7 feet in diameter. The rock is cascaded through a current of air heated by oil or coal furnaces. The dried rock is conveyed to large dry-storage bins.

From dry storage the rock is carried through a third crushing stage in crushers of the gyratory or cone type; the product is fed to shaking screens equipped with suction hoods, where the first step in fiber removal occurs. The free fiber is lifted by air suction. The rock, which passes over the end of the screen, and the undersize, which passes through the screen, are carried forward for further treatment. The rock is reduced in a fourth and last crushing stage to about one-fourth-inch size and is again passed over shaking screens to remove fiber and fines.

Up to this point size has been reduced by crushing; for subsequent reduction fiberizers are used. The difference in action of crushers and fiberizers is significant. Reduction by crushers is accomplished by pinching or compressing. The fiberizer, however, is a high-speed hammer mill that breaks the rock by impact. The falling rock is struck by hammers revolving at a speed up to 10,000 feet per minute. Either method releases the fiber from the rock, but the impact method is more intense and ordinarily is not used until the longer, more valuable fibers have been separated.

It follows also that fiber produced during primary milling stages tends to be "crudy," a condition preferred by some users. During subsequent processing the fibers become more and more "opened"; that is, the fiber bundles are separated into finer bundles—the fiber spicules are of smaller diameters.

The product of the fiberizers, like that of the crushers, is fed to shaking screens from which the fiber is collected by air suction, and the rock and screenings are carried forward for further treatment. The three steps—fiberizing, screening, and air suction—are the major elements in asbestos milling. The accompanying flowsheet, figure 12, which is essentially that prepared by Kelleher,[4] may assist in visualizing the progress of rock and fiber through a modern mill. On this flowsheet only two fiberizer stages are shown, but there may be several such stages. The complexity of detail, including many repetitive processes, is too involved for discussion herein. A mill may be 10 stories or more in height and may have hundreds of shaking screens.

Fiber processing and cleaning merit brief mention. Fibers are fed to duplex (two-deck) shaking screens equipped with suction hoods, where they are separated into long, medium, and short fractions. The long fiber remains on the top screen and is picked up by air suc-

[4] Kelleher, J. C., Milling Asbestos: Asbestos, vol. 27, No. 3, September 1945, p. 4.

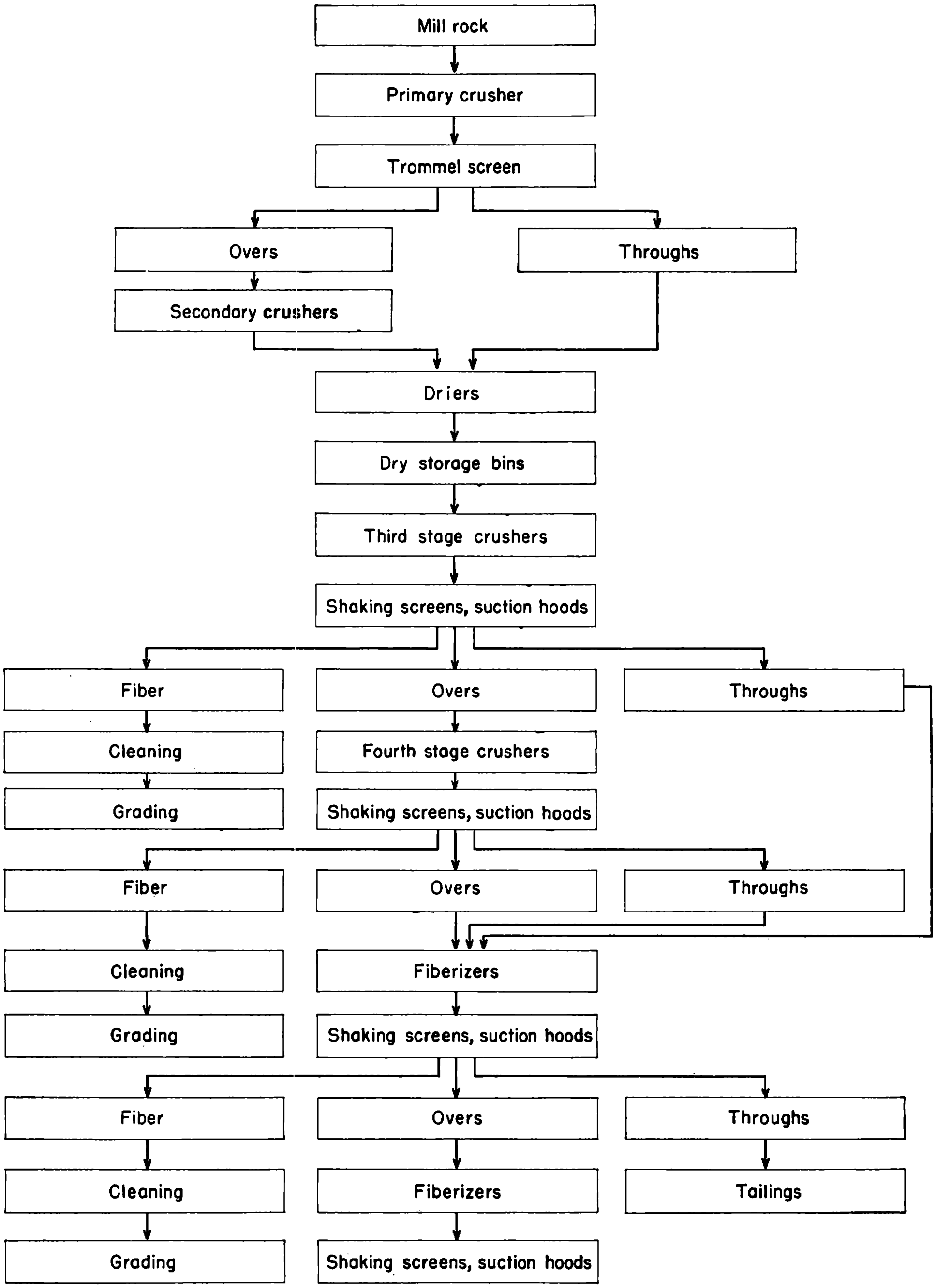

FIGURE 12.—Typical Flowsheet of a Canadian Asbestos Mill.

tion and delivered to a fiber collector. The medium-length fiber, which collects on the lower screen, is fed to a single-deck shaking screen, where it, in turn, is picked up by suction and delivered to a separate collector. The short fibers pass through the lower screen and are conveyed to bins for further grinding and cleaning.

There are five major classifications according to fiber length, namely, Spinning or Group 3, Shingle or Group 4, Paper or Group 5, Stucco and Plaster or Group 6, and Shorts or Group 7. Each group has several subdivisions, and an average mill produces at least 24 separate grades. Barren screenings, which constitute about 90 percent of the rock milled, are conveyed to waste areas.

Fiber cleaning is an important process. It consists essentially of screening and air separation. Screens are used in preference to tables. The screen permits the dust to pass through. Well-opened fibers tend to cling together in masses which do not pass through a screen readily. This is an advantage, as it permits the use of coarse screens which drop out the rock without loss of fiber. Several repetitions of the cleaning process may be needed.

Grading is done in long, rotary screens covered with screen wire of various size mesh. The grader is driven by a five-lobe cam which imparts a bumping action to the screen. The fiber is fed into one end of the slowly rotating grader. The short fibers pass through the fine mesh at the entering end, longer fibers pass through the larger mesh in the second half of the screen, and the longest materials pass out at the end. Experienced operators obtain desired grades by blending materials of two or more screen sizes. Graded fiber may be conveyed to bins or mechanical mixers before bagging. It is placed in jute or paper bags of 100 pounds net weight. Manual bagging has been largely replaced by mechanical bagging units in recent years.

In 1951 Canadian Johns-Manville Corp., Ltd., developed a pressure packer. The paper sacks are enclosed in steel during packing. Each rectangular sack, containing 100 pounds, occupies only about 2 cubic feet. Storage and shipping space is thus conserved.

Disposal of the extremely fine fibers and rock dust is an important phase of milling. The enormous volume of air handled in the collecting systems is heavily laden with fines, which are controlled not only for their intrinsic value but to remove dust hazards from workers and the surrounding community. The fan exhaust is discharged into a large chamber known as a float shed. As the velocity of the air drops, the solid particles settle. The shed is divided into several compartments at varying distances from the air inlet. The heavier materials will settle first, and the finer particles will be carried to more distant points; hence, each compartment collects floats in a different range of particle size. The finest dust is collected by electric precipitation or in filter bags.

Further detail on milling processes is given in several publications.[5]

A new-type air-swept mill designed to process the fiber-bearing rock in a single stage has been introduced at several plants. Its capabilities have not yet been thoroughly explored.

The most pronounced recent trend in the Canadian asbestos industry is the greatly increased use of shorts for such products as asphalt floor tile. Some of these products contain 35 percent or more of asbestos, which is said to impart exceptionally high qualities. All companies now operating mills in Quebec have introduced additional screens and suction facilities to recover part of the shorts formerly regarded as waste.

The dry process is universally employed in asbestos milling. Wet methods were tried experimentally many years ago but were not adopted commercially. Recently, however, Johnson's Co. has erected a new wet-process plant for re-treating mill tailings to recover shorts. The process was developed by Selective Treatment Co., Ltd., under patents now expired. If operation of this mill proves advantageous, it may mark the beginning of a trend toward wet milling in the Quebec area. It is claimed, however, that a wet process tends to remove certain fractions of the fiber mass, the retention of which is desirable.

Tramp iron can be removed easily with magnetic devices, but no mechanical means of removing wood fragments has yet been devised. Because of its flammability, wood fiber is a serious impurity in a product whose fire resistance is an outstanding asset. Accordingly, the utmost care is taken to keep wood fragments out of the mill rock. Steel mine supports and steel ties are substituted for wood. The use of matches in mines, quarries, and mills is prohibited. In some of the arid African asbestos areas contamination of the fiber by wind-blown vegetable matter has become a serious problem.

CAPACITY

Table 38 shows the milling capacity of the Canadian asbestos industry, as recorded in a recent report.[6] Such mill capacity, on a 300-day basis, would represent an annual capacity of 10,260,000 tons. The actual quantity of rock milled in the peak year of production (1951) was 10,219,658 short tons. According to this report, milling capacity in Quebec will be increased considerably in the near future. Johnson's Co. was building a new mill at Black Lake in 1952 with a daily capacity of 4,000 tons of rock.

[5] Kelleher, J. C., Milling Asbestos: Asbestos, vol. 27, 1945, No. 3, pp. 2–10; No. 4, pp. 3–10; No. 5, pp. 6–12.
Denovan, R. A., Operating the World's Largest Asbestos Mine—III: Eng. and Min. Jour., vol. 142, No. 11, November 1941, pp. 51–55.

[6] Hayes, F. T. (Drafting Officer), and Cross, Cecil M. P. (U. S. Consul General), Notes on the Canadian Asbestos Supply Situation (submitted Jan. 16, 1951): Bureau of Mines, Mineral Trade Notes, February 1951.

TABLE 38.—*Canadian milling capacity, 1950*

Company and mill:	*Daily rock capacity, short tons*
Asbestos Corp., Ltd.:	
Beaver and King mills	6, 000
British Canadian mill	4, 000
Vimy Ridge mill	2, 800
Canadian Johns-Manville Corp., Ltd.: Danville mill	12, 500
Johnson's Co.:	
Thetford Mines mill	2, 000
Coleraine mill	1, 200
Bell Asbestos Mines, Ltd. (Turner & Newall): Bell mill	1, 500
Nicolet Asbestos Mines, Ltd. (Nicolet Industries, Inc.): Danville mill	1, 500
Quebec Asbestos Corp., Ltd. (Philip Carey Manufacturing Co.): East Broughton mill)	1, 500
Flintkote Mines (Flintkote Co.): Thetford Mines mill	1, 200
	34, 200

Mill capacity as indicated in this table is being increased considerably. Canadian Johns-Manville Corp., Ltd., is completing an extensive remodeling program at its Jeffrey mill, increasing its capacity to 16,000 tons a day. A new mill, the Normandie, of the Asbestos Corp., Ltd., was scheduled for production on a scale of 5,000 tons a day in 1954. This company is also expanding its facilities at Black Lake. Continental Asbestos Co., Ltd., has a mill of 600 tons a day capacity at Coleraine, but production to the end of 1952 was small. The Dominion Asbestos Co. new mill of 2,200 tons a day capacity near Saint Adrien, Quebec, began production in 1953.

UNITED STATES

ARIZONA

In 1952, 10 mills were in operation in Arizona, 3 in Globe, and the others at various mines. Only the carefully hand-cobbed rock is milled. Such rock may contain as high as 50 percent fiber. It is passed through a jaw crusher and over shaking screens. At some mills they are designated "bumper" screens, because the screen strikes a post at the end of each stroke. Such action is said to improve screening efficiency. Fiber that passes over a ½-inch mesh is designated No. 1, that which passes over ¼-inch mesh and through ½-inch mesh is designated No. 2, while Grades 3 and 4 pass through the ¼-inch-mesh screen. The above milling process is known locally as "cruding." Several mills have equipment for further processing, including hammer-mill reduction, screening, and air separation.

No. 1 is spinning-grade fiber if not too harsh. No. 2 contains some spinning fiber. Grading equipment is less efficient than that used in Canada or Vermont, and the grades sold commonly lack consistency of quality or classification.

VERMONT

A new mill recently built about one-fourth mile from the new quarry of the Vermont Asbestos Mines is said to be one of the most modern and complete asbestos mills in existence. (See fig. 13.) The rock, of walnut sizes, delivered to the mill is broken in a series of vertical hammer mills with separation of fibers by air suction at each stage. Table screens are used. The fiber is classified in regular graders, as in Canada. The major output falls in Groups 5 and 6 of the Canadian classification, although substantial quantities of Groups 4 and 7 are produced. Limited quantities of Group 3 are obtained. Groups 4, 5, and 6 are used in the company asbestos-products plants and supplemented by purchases from outside sources.

In 1953 the company introduced an improved pressure-packing system in its bagging department. Further details on milling practice in Vermont have been published.[7]

UNION OF SOUTH AFRICA

General principles underlying milling practice, particularly in relation to the African asbestos industry, have been discussed in some detail by Sinclair.[8]

Crocidolite and amosite are the principal varieties of asbestos mined in the Union. Hand cobbing, much of it by native women, is employed to recover crocidolite fibers over three-fourths inch long. Mechanical cobbing was introduced during recent years. The shorter grades are recovered by milling processes differing considerably from those used on chrysotile. The blue fiber occurs in an extremely hard rock, and much study has been devoted to methods of milling that will minimize attrition during crushing. The rock is first broken with jaw crushers, followed by gyratory crushers. Crushing to finer sizes is accomplished with high-speed rolls. Fine dust is removed at each stage. Trommel screens are used to remove grit and fine gangue and to retain the asbestos, which is fluffed without being excessively beaten. Eccentric-drive shaking screens are used at times instead of trommels. It has been stated that the fiber cannot be removed satisfactorily by aspiration through a hood placed over screens, as in chrysotile milling, but the more recent descrip-

[7] Messel, Michael J., Recent Trends in Mining and Milling Practice: Trans. AIME, vol. 184, 1949, pp. 52–55.
Trauffer, Walter E., Ruberoid Co.'s New Vermont Asbestos Operation Sets New Standards for Industry: Pit and Quarry, vol. 45, No. 8, February 1953, pp. 70–76.

[8] Sinclair, W. E., Milling Asbestos Ore: Asbestos, vol. 33, No. 9, March 1952, pp. 8–18; No. 10, April, pp. 4–12; No. 11, May, pp. 4–10; No. 12, June, pp. 2–10.

FIGURE 13.—Mill of Vermont Asbestos Mines Near Eden, Vt.

tions of processes mention the use of suction hoods. In the Transvaal amosite occurs with the blue fiber in places, and is milled with it. Further detail on milling is given by Sinclair.[9]

Methods of milling crocidolite vary greatly in different localities. In the southern belt of the Cape Provinces the workings are numerous, and many are relatively small. At the smaller workings all the fiber is hand-cobbed and hand-sorted into grades according to length, but at the larger workings, the hand-cobbed asbestos is graded by machinery. A hand-turned trommel of perforated sheet iron covered with wire netting usually is employed. Cobbed fiber from several workings may be shipped to a central screening plant, where asbestos ½ inch and over is recovered, and the minus-½-inch product is taken to a mill for crushing and grading. At one mill the rolls travel at slightly different speeds to subject the fiber to a tearing action.

In the northern belt, material over three-fourths inch long is hand-cobbed. At first the mill grades were not standardized, but later a large mill was erected at Kuruman, and the grades manufactured there followed established standards that offered decided marketing advantages. In this mill rock carrying the shorter fibers is passed through crushers, heavy rolls, and disintegrators. The fiber thus separated is classified on grading screens.

In 1953 a new mill to process blue fiber, designed by Giorgio Marchioli, was built near Pietersburg. It is claimed that the new design furnishes a high-quality, well-fluffed fiber relatively free from unopened splinters, grit, and dust and that the percentage of recovery is high.

Because of its unusual length, much of the amosite produced is hand-cobbed to remove a large part of the waste remaining after the underground coarse sorting. Picking belts facilitate the hand sorting. The fiber thus freed from adhering rock is passed through a series of rolls and disintegrators and then graded on shaking screens or trommels. The principal amosite-milling facilities are at the Amosa and Penge mines, but the Kremellanboog and Malips mines also have mills. No descriptions of the individual mills have been noted in literature. During 1951 over 50 mills, with daily capacities ranging from a few tons to several hundred tons of rock, were in operation in the asbestos fields.

[9] Sinclair, W. E., Production of Crocidolite or Blue Asbestos in South Africa: Asbestos, vol. 33, No. 1, July 1951, pp. 4–10; No. 2, August, pp. 4–12.

SOUTHERN RHODESIA

At the Shabani mines as much as possible of the asbestos is separated from the rock close to the working face to avoid damage to the fibers. Hand cobbing is therefore an important part of the operation. Fiber-bearing quarry rock is first broken in jaw crushers and rolls and sorted into three groups on a picking belt. Rock containing little or no fiber is left on the belt and conveyed to the waste dump. Rock containing large seams of fiber is carried on a second belt to the cobbing sheds. Rock carrying small fiber seams is conveyed to the mill on a third belt. Cobs from both the cobbing sheds and the quarries and stopes are fiberized and graded in one mill, and the fiber-bearing rock is reduced in another.

After primary crushing in the mill the rock is dried and reduced in a series of small grinding pans operated like pug mills. Fiber is separated from rock with shaking screens and air suction, as in Canada. Undesirable brittle fiber is ground in the pans and passes through the screens with the waste.

One type of disintegrator is the Cloasens impactor, which consists of a series of revolving horizontal plates enclosed in an hourglass-shaped casing. The rock particles carried on the plates are thrown against the walls by centrifugal force, which reduces them to smaller sizes, and they pass downward to successive revolving disks. The fiber is removed by suction as soon as it is released.

Fiber carried by air current from the disintegrators is deposited in a centrifugal settler, and the air passes on through a dust trap to an outlet. The recovered asbestos is freed further from dust and graded in trommels. Cylindrical trommels have the disadvantage of causing the fiber to roll and form balls in its line of travel around the screen. This tendency is overcome by using hexagonal trommels in which the fiber is thrown from one panel to the next. Fiber recovery is said to represent about 3 percent of the rock milled. Further information on Rhodesian milling has appeared in the technical press.[10]

In general, the smaller mines have less efficient milling equipment than the larger operations. In 1953, when demands for fiber fell to some extent and became more selective, quality of fiber assumed increasing importance. To furnish fiber of higher grade a newly designed asbestos-cleaning plant was established at the Lanninhurst mine in the Gwanda district. It is claimed that when asbestos that is virtually unsalable because of its content of dust, grit, and short fibers is treated in this mill, high-grade products can be made. The cleaning plant consists of a rotary impactor followed by airlift, shaking screens, and grading trommels.

SWAZILAND

At the Havelock mine the minus-2½-inch product from the primary crusher is dried and the fiber removed by suction fans. The rock, with hand-sorted materials from the picking belt mentioned under Mining Methods, is crushed and the fiber removed in successive stages by air suction. Initial reduction is by a 16- by 10-inch jaw crusher, but the later stages of reduction are accomplished with least damage to the fibers by the use of edge runners. The longest fibers, known as HVL, correspond with the C. & G. grades from Rhodesia but are of somewhat poorer quality. More detailed information on milling methods has been published.[11]

SOVIET RUSSIA

At the Russian quarries most of the crude fiber is hand-sorted on picking belts after the rock is crushed. At a mill that began operation in 1932 the quarry rock was reduced to about 6-inch size with a gyratory crusher. It discharged to a picking belt, where 20 percent or more of the primary feed was thrown out as waste, because it consisted of rock too lean to justify milling. The asbestos-bearing rock was reduced to 1½- to 2-inch size in 2 gyratory crushers discharging to heavy shaking screens. The oversize passed to picking belts, where more barren rock was eliminated. The good rock from the picking belt was reduced to about 1-inch size in a jaw crusher and joined the undersize from the shaking screens in a wet-storage bin. Moisture was thereafter reduced in three rotary driers and the product conveyed to a dry-storage bin.

The most noteworthy feature of the preliminary milling stage was the concentration on picking belts. Because the serpentine tends to break cleanly along the borders of the fiber veins, effecting a more or less distinct separation of barren and fiber-bearing rock, conditions particularly favor this method of concentration. Of the original mill feed, consisting of 2,400 tons a day, about 1,400 tons was eliminated as waste, leaving only 1,000 tons for the later milling processes. Thus picking belts saved operators a great deal of useless milling.

In the more advanced milling stages the dried rock was passed over heavy shaking screens, from which four products were obtained: (1) Fiber removed by suction fans; (2) oversize rock conveyed to a set of rolls; (3)

[10] Sworder, E. H., Fiberizing and Conditioning: Rhodesian Min. Jour., vol. 18, No. 4, April 1953, pp. 21-26; No. 5, May, pp. 29-35.

[11] Starkey, Roland, Recovery of Raw Asbestos at the Havelock Mine: Asbestos, vol. 28, No. 11, May 1947, pp. 4-8.

middlings that bypass the rolls and are carried to the next screen; and (4) fines conveyed to a disintegrator. By means of a series of such rolls, screens, suction pipes, and disintegrators, virtually all of the fiber was recovered. Fiber from the collecting hoppers was sent to a series of shaking screens for cleaning. The cleaned fiber was collected again by suction fans and classified by length in slowly rotating grading trommels.

A large, new mill designed to handle 2 million tons of rock annually and produce 80,000 tons of fiber in 6 grades was nearing completion in 1934. This mill, with other Russian facilities, would, it was estimated, provide the nation with a total milling capacity of approximately 175,000 tons of fiber a year. Production in 1936 was reported to be 125,117 metric tons; in 1937, 125,000 metric tons; and in 1938, only 86,000 metric tons.

Much of the information herein has been abstracted from an article by an engineer who was employed for some time in the Russian asbestos industry.[12]

SUPPLEMENTARY MILLING IN ASBESTOS TEXTILE FACTORIES

As pointed out in preceding pages the milling process is designed to remove impurities and to separate the fibers from each other (fiberize) effectively, but the milled fibers require considerable subsequent processing before they are in satisfactory condition for use. Crude fibers are not milled before delivery to the user and are opened in the asbestos-products manufacturing plant.

The preliminary opening of crude fibers is generally accomplished in a pan crusher, also known as a chaser mill or edge runner. A steel wheel with a 14- to 18-inch face runs in a circle in a pan to which a batch of crude fiber is added. Scrapers push the fiber inward from the circumference and outward from the center to keep it under the roller. Conical rolls running in a circular trough are sometimes used to reduce the grinding action between the surface of the roller and the bottom of the pan. The running time required to complete a batch varies greatly, depending upon the ease or difficulty of fiberization of the particular asbestos under treatment. It may range from 2 to 12 minutes on milled fiber and 12 to 20 minutes on crudes. The time of completion is determined by the operator who, by long experience, can judge the condition of the fiber by its feel. To conserve fiber length and strength, excessive crushing and grinding are avoided. Separated impurities are removed by screening.

Some milled fibers, which are more or less completely opened, do not require pan-crusher treatment; others require some degree of "pan softening." The extent to which pan treatment is needed depends entirely upon the character of the fiber. Some milled fibers may bypass the pan, while others bearing the same brand and grade may require "pan softening." Milled fibers that require no pan treatment are passed through a vertical opener or some other type of equipment that disintegrates the fibers. A rotating toothed cylinder may be used.

The next stop in treatment beyond the preliminary pan crusher or other fiberizing machine is conducted in a grader. It consists of a sheet-metal enclosure with a horizontal rotating shaft in the center, equipped with steel paddles set at intervals and in spiral positions. These paddles beat the fiber, separating iron minerals, rock particles, or dust, as well as splinters of unopened fiber. The latter are returned to the openers for further treatment. The fluffy fiber is picked up by an air current and carried away for further treatment in ceiling condensers and breaker cards. Fiberization is one of the most critical operations in the textile plant, for it involves as complete separation of the fibers from each other as can be accomplished without sacrificing their length or strength. These processes have been described in some detail.[13]

[12] Rukeyser, W. A., Asbestos Milling in the Urals: Eng and Min. Jour., vol. 134, October 1933, pp. 415-419.

[13] Bloomfield, Gerd M., Speaking About Asbestos Yarn: Asbestos, vol. 31, No. 12, June 1950, pp. 4-10; vol. 32, No. 1, July 1950, pp. 6-12; No. 2, August 1950, pp. 10-13.

GRADING AND CLASSIFICATION

CANADA AND VERMONT

Vermont classification is the same as the Canadian, covered in the following pages. Canadian asbestos is graded into nine major groups, most of which are divided into several subgroups. Group 1 consists of Crude No. 1, and Group 2 of Crude No. 2, Crude Run-of-Mine, and Crudes, Sundry. Groups 3 to 7, milled fibers, are classified according to tests made with a Quebec standard testing machine. A description of the machine, essentially as given by Ross,[1] follows:

The machine consists of a nest of 4 aluminum boxes measuring 24½ by 14¾ inches and 3½ inches in depth. The boxes, which are superimposed one above the other, are numbered, from the top down, 1, 2, 3, and 4. The bottoms of boxes 1, 2, and 3 consist of bronze screens of the following specifications: Box 1: 1½-inch opening, diameter of wire—0.105 inch. Box 2: 4-mesh opening, wire—0.063 inch. Box 3: 10-mesh opening, wire—0.047 inch. Box 4 is a receptacle for the fines that fall through the three other boxes. The nest of four boxes or trays rests on a table to which an eccentric with a throw of 25/32 inch gives a movement of 1 9/16-inch travel.

To make a test, 16 ounces of fiber is put on the top tray, which is covered. The machine is run at the rate of 300 revolutions per minute at the shaft of the eccentric, giving the nest a rapid horizontal shaking movement. By automatic control it is kept running exactly 2 minutes. At the end of this time the fiber that remains on each tray is weighed, and these weights give the grade of the fiber. The longest fiber naturally stays on the top tray, whereas the shorter fibers, according to their length, remain on screens 2 or 3 or drop into the pan or lowest tray. The more fiber retained on the first screen and the less fiber in the pan, the higher the grade and therefore the greater its value. If, for instance, a customer buys spinning fiber of the specification 4–7–4–1, it means that, in a sample of 16 ounces, representing the average of the lot shipped, 4 ounces will remain on the top screen, 7 on the second, and 4 on the third, and 1 ounce will go through all the screens into the pan. This, of course, is a more valuable fiber than paper stock, for example, testing 0–0–10–6. Such a designation indicates that, out of 16 ounces tested, nothing is retained on the first 2 screens, 10 ounces remain on the third, and 6 ounces go through all the screens into the pan. It is evident that the figures of the test represent the proportion, in ounces, of the different lengths of fiber in a pound of asbestos.

Samples for control testing usually are taken at the bagging machines every half hour or oftener. Owing to unavoidable variations in fiber as it comes from the pit the quality of mill-run fiber usually is maintained a little higher than its designation.

For many years each Canadian company graded its fiber according to its own standards and sold the products under its own trade designations. This practice led to much confusion in marketing, because different mills employed similar marks for grades unequal in quality and value. It was frequently necessary for buyers to have samples tested before placing orders. In 1931 producers in Quebec agreed upon a uniform classification of fibers whereby, they were divided into nine groups, and each group was subdivided into grades. Crude asbestos was defined as "hand-selected cross-vein material essentially in its native or unfiberized form," and milled asbestos as "all grades produced by mechanical treatment of asbestos ore." Except for the very lowest grades, which are based on the weight per cubic foot, all milled grades are based on the results of tests in the standard testing machine previously described.

"Shipping test" is the average, for each carlot or smaller shipment, of tests of representative samples taken at the time of shipping. "Guaranteed minimum shipping test" is that below which the actual shipping test shall not fall.

The standard grades as agreed upon in 1931 and revised effective January 1, 1949, are as follows:

Group 1:
- Crude No. 1—Consists basically of crude ¾-inch staple or longer.

Group 2:
- Crude No. 2—Consists basically of crude ⅜-inch staple to ¾-inch.
- Crude Run-of-Mine—Consists basically of unsorted crudes.
- Crudes Sundry—Consists of crudes other than above specified.

[1] Ross, J. G., Chrysotile Asbestos in Canada: Canada Dept. of Mines Bull. 707, 1931, p. 49.

Mill fibers

Standard designation of grades:	Guaranteed minimum shipping test, Canadian standard testing machine
Group 3:	
3F	7 – 7 – 1.5 – 0.5
3K	4 – 7 – 4 – 1
3R	2 – 8 – 4 – 2
3T	1 – 9 – 4 – 2
3Z	0 – 8 – 6 – 2
Group 4:	
4H	0 – 5 – 8 – 3
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 5:	
5D	0 – .5 – 10.5 – 5
5K	0 – 0 – 12 – 4
5M	0 – 0 – 11 – 5
5R	0 – 0 – 10 – 6
Group 6: 6D	0 – 0 – 7 – 9
Group 7:	
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
Group 8: 8S	Under 75 pounds per cubic foot loose measure
Group 9: 9T	More than 75 pounds per cubic foot loose measure

The suffix "F" designates "floats" in all subsections of Group 7. Floats consist of dust, collected in chambers and bagged. It may be sized by screening before bagging.

Following are the qualities and uses of the various groups:

Group 1 (*Crude No. 1*).—Asbestos fiber greater than three-fourths inch in length. It should be silky and have enough tensile strength to permit its use for making asbestos yarn, tape, cloth, carded fiber, and other textiles.

Group 2 (*Crude No. 2*).—Generally referred to as fiber that has not been milled and that has a length of ⅜ to ¾ inch. It must have good tensile strength. Unsorted and Sundry crudes are included with Group 2.

Group 3.—Milled spinning or textile fiber that tests 0–8–6–2 and over.

Group 4.—Known as shingle fiber; includes fiber suitable for the manufacture of asbestos-cement products, such as pipe, shingles, and siding, compressed sheet packing, and 85-percent magnesia and high-temperature molded pipe covering. These fibers are also used with portland cement for manufacturing asbestos corrugated and flat interior and exterior sheets, wallboard, switchboard panels, and other products. This grade tests below 0–8–6–2 and includes 0–1½–9½–5. The better known grades for asbestos-cement shingles are 4H, 4M, 4T, 5R, and 6D.

Group 5.—Known as paper stock; includes fibers testing below 0–1½–9½–5, including 0–0–10–6. They are used chiefly for the manufacture of asbestos paper and millboard and sometimes are mixed with higher grades for the manufacture of asbestos-cement shingles.

Group 6.—Known as stucco or plaster fiber; has only one grade (namely 6D), testing 0–0–7–9.

Group 7.—Includes all fibers having a minimum shipping test of 0–0–5–11 and below. These are known as refuse and shorts and are used in manufacturing asbestos boiler and roofing cements, roofing paints, asphalt floor tile, and occasionally for making millboard.

Groups 8 and 9.—Known as sand and gravel and stone, respectively. They contain a preponderance of rock and sand. These materials are used chiefly in manufacturing asbestos flooring, wall tiles, and similar products.

ARIZONA

In Arizona the fiber-bearing rock is reduced in jaw crushers and rolls, and the fiber is separated by screening into the following grades: No. 1, ¾ inch long and longer; No. 2, ⅜ to ¾ inch; No. 3, ⅛ to ⅜ inch; No. 4, less than ⅛ inch long. Filter fiber consists of grades 3 and 4, further processed. Grades 1 and 2 are classed as spinning fibers.

UNION OF SOUTH AFRICA

CHRYSOTILE

In general, the chrysotile produced in the Union is marketed as a milled run-of-mine fiber. It is said to have less talc associated with it than is present with Canadian asbestos, and fibers from the two countries, possessing comparable end-use characteristics, may not necessarily yield similar or compatible results in a standard testing machine. Various publications on asbestos include the classification of the New Amianthus and Munnik-Myburgh mines in the Barberton district; but, as these mines were idle for many years, such classification has been omitted. They have recently been reopened, but a classification of their output has not appeared. There are several chrysotile producers in the Union, but the grading of their products is not available at this time.

CROCIDOLITE

Following is the classification of Cape blue (crocidolite) recognized by the Cape Asbestos Co., Ltd.

Grade:	*Length of fiber, inches*
X	Minus ¼.
No. 3 or S or MS	¼ to ⅜.
No. 2 or A	⅜ to ¾.
No. 1 or B	¾ to 1½.
Long or C, D, and E	Plus 1½.

Almost all of the imports are of Grade S or MS (mixed short).

Grades of Transvaal blue, as given by the Department of Mines, Union of South Africa, are as follows:[2]

Crude, grade	Fiberized	
	Grade	Length of fiber, inches
TX	TDX	Plus 1½.
T1	TD1	⅞ to 1½.
T2	TD2	½ to ⅞.
T3	TD3	¼ to ½.
T4	TD4	Minus ¼.

AMOSITE

The following classification was in effect until 1952. B–1 was the longest and best grade. The second grades were B–3 and D–3. They were virtually the same grade but came from different sources, the B–3 originating in the Penge mine and the D–3 in the Amosa mine. However, it has been stated recently that material formerly classed as B–3 is no longer produced. Other designations applied to this grade are 3/B, 3/D, 3/BX, and 3/DX. Another grade nearly as good as B–3 or D–3 was designated 3DMI. Although called 3DMI, it was really 3 D Mi, the "Mi" meaning "mixture." It consisted chiefly of D–3.

In 1952 an entirely new classification was set up by the Cape Asbestos Co., as follows:[3]

Symbol	Range of average fiber lengths, inches	Designation
D3	2–6	Long.
D11	½–2	Medium.
MD	½–2	Do.
DX	½–2	Do.
M	½–2	Do.
S2	3/16–1	Shorts.
R	⅛–½	Residue.
K3	½–2	Medium.
SK	3/16–1	Shorts.
RK	⅛–½	Residue.
W3	½–2	Medium.
SW	3/16–1	Shorts.
RW	⅛–½	Residue.
WEG	⅛–3	Medium.

The fibers range in color from brown to gray.

SOUTHERN RHODESIA

CHRYSOTILE

Milled fiber:

- C. & G. 1—high-grade textile fiber (equivalent to Canadian Crude No. 2).
- C. & G. 2—high-grade textile fiber (equivalent to Canadian 3F).
- C. & G. 3—shingle stock.
- C. & G. 4—shingle stock.
- VRA 2—comparable but not equivalent to C. & G. 2.
- VRA 3—comparable but not equivalent to C. & G. 3.
- VRA 4—comparable but not equivalent to C. & G. 4.

SWAZILAND

CHRYSOTILE

Havelock mine

Milled fiber:

- HVL 1—long-spinning fiber.
- HVL 2—short-spinning fiber.
- HVL 3—comparable but not equivalent to C. & G. 3.
- HVL 3XX—comparable to C. & G. 4 (by 1 manufacturer).

[2] Asbestos. Asbestos Grades in South Africa: Vol. 30, No 6, December 1948, p. 16.

[3] Data furnished by Mineral Development Office, Dept. of Mines, Geol. Survey, Union of South Africa.

SOVIET RUSSIA

CHRYSOTILE

Crude: AA—not less than 18 mm. in length.
Milled fiber:
- O–1—textile fiber (comparable to Canadian 3F or 3K).
- O–2—textile fiber (comparable to Canadian 3R).
- 1–2—textile fiber (comparable to Canadian 3Z).
- G–3—textile fiber (comparable to Canadian 3Z).
- O–3—shingle fiber (comparable to Canadian 4H).
- O–4—shingle fiber (comparable to Canadian 4Z).
- I–4—shingle fiber (comparable to Canadian 4R).
- G–4—shingle fiber (comparable to Canadian 4Z).
- WS—shingle fiber.
- R–5—paper fiber (comparable to Canadian 6D).
- I–5—paper fiber (comparable to Canadian 6D plus).
- S–4—paper fiber (comparable to Canadian 5D).
- R–6—shorts.
- I–6—shorts.
- 6A—shorts.

NOTE.—Grades S-4 and WS are completely opened fibers; grades marked I are soft but not completely opened; grades marked G contain more unopened crudes; grades marked O and R contain much hard, crude fiber

INDIA

CHRYSOTILE

Crudes:
- Special A—comparable to Canadian Crude No. 1.
- Regular A—comparable to Canadian Crude No. 1.
- Regular B—comparable to Canadian Crude No. 1.

STOCKPILE GRADES AND SPECIFICATIONS

In 1953 low-iron chrysotile, South African amosite, and Bolivian crocidolite or its equivalent were the only types designated for stockpiling.

CHRYSOTILE

Chrysotile for stockpiling is the low-iron type. It must conform with National Stockpile Specification P–3–R1, dated June 10, 1953, and must be equal to that obtained at the Shabani mines, Southern Rhodesia. The Rhodesian grades designated are C. & G. 1, C. & G. P. 1, C. & G. 2, and C. & G. P. 2. The use of the letter P simply indicates a processed rather than a crude fiber. The fiber-length requirement of C. & G. 1 and C. & G. P. 1 is that a minimum of 15 ounces shall be retained on the first and second screens of the Quebec standard testing machine. The requirement of C. & G. 2 and C. & G. P. 2 is that a minimum of 13 ounces shall be retained on the first and second screens of the Quebec standard testing machine. Arizona Crude No. 1 and No. 2, as well as nonferrous crudes from other sources, are acceptable for stockpiling when strong and "silky." The Arizona "harsh" type is not acceptable.

It is presumed that Canadian fiber will satisfy the specification if the iron content can be reduced enough. Accordingly, the fiber lengths of acceptable Canadian fibers are also specified as follows:

Crude No. 1, consisting of fibers at least 85 percent of which shall be three-fourths inch in length or longer.

Crude No. 2, consisting of fibers at least 85 percent of which shall be ⅜ to ¾ inch in length.

Spinning fibers of the following grades, according to Canadian standard tests:

3F	7.0 – 7.0 – 1.5 – 0.5
3K	4.0 – 7.0 – 4.0 – 1.0
3R	2.0 – 8.0 – 4.0 – 2.0
3T	1.0 – 9.0 – 4.0 – 2.0

On the basis of iron content, the fiber shall be commercially nonferrous and conform with the following limitation: Total iron, maximum percent by weight 3.5; magnetic iron, maximum percent by weight 2.0. The specification includes items on impurities, moisture content, sampling, methods of test, etc.

Five-pound samples shall be inspected by commercial users whose manufacturing requirements represent at least 50 percent of the total United States consumption of the grades of asbestos covered by these specifications and, in any event, by not less than 3 users. Acceptance shall be based upon the written statements from a majority (normally 2 out of 3) of these users that the lot of asbestos conforms to the applicable requirements.

AMOSITE

Amosite for stockpiling must conform with National Stockpile Specification P–4–R dated September 14, 1953. The specification simply states that the material shall conform to the standard commercial Grade D–3, D–X, or D–11.

Inspection is made under the same conditions as specified for chrysotile.

CROCIDOLITE

Crocidolite (blue asbestos) shall conform with National Stockpile Specification P–80–R, dated April 17, 1952, which designates that the material purchased shall be Bolivian crocidolite asbestos or its equivalent. Three grades are covered, as follows: Crude No. 1, a minimum of 85 percent (by weight) of which shall be in fibers ¾ inch in length, or longer; Crude No. 2, a minimum of 85 percent of which shall consist of fibers ⅜ to ¾ inch in length; and Run-of-Mine (crude or milled), a minimum of 90 percent of the lumps and fibers of which shall be retained on a No. 16 sieve. The material shall contain not more than 2 percent of moisture and not more than 5 percent of foreign matter. The specification includes items covering sampling, marking, methods of test, etc.

The supplier of the material shall submit, before or with his bid, a 25-pound representative sample of the material he proposes to furnish. This sample shall be tested by either the Chief Technical Command, Army Chemical Center, Edgewood, Md., or the Director, Naval Research Laboratory, Washington 25, D. C., to determine whether the material is suitable for the purpose intended. If the material is suitable, the contractor at the time of signing a contract will guarantee that material he furnishes is of the same quality as the sample submitted for test.

If the material contains moisture, foreign matter, or fines in excess of that stipulated in the specifications, the material may be accepted at the option of the Government, but payment therefor shall be adjusted according to the amount of acceptable material actually contained in the lot.

MARKETING

GENERAL FEATURES

Asbestos is used in so many diverse products that its markets are numerous and widespread and its marketing complex. It is employed ex tensively in the United States, England, France, Germany, Belgium, Italy, Soviet Russia, Japan, and Australia. Soviet Russia at one time exported most of its production but later became an important manufacturer of asbestos products. Exports from the Soviet Union are erratic but at times are substantial. Many other countries use small quantities. Latin American demands are increasing and have attained substantial proportions. With growing diversity in use and great expansion in long-established uses, the consumption of asbestos is increasing steadily.

Some fiber is handled by agents or jobbers, but most of it is shipped direct from mine to consumer. Fiber length and quality are usually established by standard tests. The larger manufacturers of asbestos products have their own testing machines and can check a producer's classification. The producer is generally so familiar with manufacturing conditions that he can prepare the material to suit each particular use.

Asbestos is sold in 100-pound or, rarely, 125-pound bags on a short-ton basis, bags included. Canadian quotations are f. o. b. mines. Quotations on African fibers are usually f. o. b. port of embarkation, such as Beira or Laurenco Marques. The weight of a given volume varies with fiber length; the longer fibers are bulkier. The volume of a short ton ranges from 60 to 90 cubic feet. A minimum carlot of fiber is 20 tons and of refuse and shorts 30 tons.

Market requirements are based principally on length of fibers, but strength, flexibility, color, chemical composition, and cleanliness may have an important bearing on use. The principal market outlets are indicated in the following brief summary of uses.

The longer and more valuable crudes and mill fibers are employed in manufacturing woven brake linings, electrical insulation products, textile fabrics, packings, and gaskets. The next lower grades are used in making asbestos-cement products, such as pipe for underground use, fluepipe, roofing and siding, shingles, lumber, and corrugated sheathing. Other important uses are for molded friction products and filtering. Shorter fibers are used for paper and millboard manufacture and the lowest grades for heat-insulating cements, molded articles, and fillers in such products as asphalt tile. There are multitudes of other uses.

Most of the world supply of raw asbestos is in strong hands and is distributed to asbestos-products manufacturers, most of whom are also well-organized concerns.

Most of the large producers, such as Johns-Manville Corp., Bell Asbestos Mines, Vermont Asbestos Mines, Turner & Newall, Ltd., and the Cape Asbestos Co., are of the vertical type; that is, they mine and mill the raw materials and fabricate the finished products. The asbestos from these so-called captive mines provides, first of all, raw materials for the company-owned manufacturing plants; and the surplus, with grades that cannot be used, is sold to other consumers. These companies also purchase fibers from other producers, because generally they do not produce the full range of fibers in the proportions that they use. Some important producers, however, such as Asbestos Corp., Ltd., and Johnson's Co., are producers only, having no asbestos-product-manufacturing facilities.

NECESSITY FOR A BALANCED MARKET

In any asbestos deposit the length of the fibers varies considerably. Thus, when the total fiber recovered is classified into grades according to length, quite a number of grades may result. Canadian asbestos, for instance, falls into seven major grades, ranging from the longest (Crude No. 1) to the very short fibers in the classification "Refuse and Shorts." Most of the major groups are divided into several subgroups. The proportions falling in the several grades are fairly constant for any one deposit; and, as the miner has to take the rock as it comes, he has little control over the proportions of the various grades in his mill product. The demand for certain grades may be stronger than for others; during some periods in the past, when the supply of most grades exceeded the demand, producers were obliged to stock up on the less salable types or let them go to waste. Success in an asbestos-mining enterprise under such conditions depended to some extent upon developing a balanced market that would absorb all grades, roughly in the proportion in which they were produced. When heavy demand arises for some grades, while others are overabundant, specifications should be modified as much as possible toward easing the pressure on those most in demand. For certain uses grades are interchangeable to some extent, and in such instances the maximum use of the most plentiful grade is to be encouraged. Where grades are interchangeable, a price differential favoring the more abundant type will tend to keep demand in step with supply.

For several years up to 1952, however, the demand for all grades exceeded supply, and marketing problems were therefore simplified; but such conditions are unlikely to be sustained over long periods. In 1952, 1953, and 1954 the demand for some of the shorter grades declined and became more selective.

DISTRIBUTION PRACTICES

Virtually all of the important asbestos deposits of the world, except those in Soviet Russia, are within the political orbit of the British Commonwealth of Nations. Deposits in this category are those of Canada, Southern Rhodesia, Union of South Africa, Swaziland, Australasia, India, and Cyprus. British Commonwealth needs naturally receive first attention, but large quantities of asbestos are shipped to outside countries. During recent years demand has exceeded supply. Many new plants for manufacturing asbestos products have been built throughout the world. Even though production of asbestos has made enormous gains, the available supply of certain grades for United States industry has not increased proportionally. The inadequacy of supply has been most in evidence for low-iron chrysotile of spinning grade from Southern Rhodesia. Supplies of amosite from the Union of South Africa and of spinning grades of chrysotile from Canada have been in short supply at times.

Some years ago marketing problems pertained primarily to finding adequate outlets for raw asbestos; but, with changing conditions, the problem evolved into one of finding supplies of asbestos large enough to satisfy the demands of customers wholly or in part. Statistics of international trade indicate that, during the postwar stringency, Great Britain and central European countries received proportionally larger quantities of Rhodesian and Canadian spinning fibers than they received during World War II. The United States receives at all times a large proportion of the shorter grades of Canadian asbestos.

Canadian Johns-Manville Corp., Ltd., is the leading producer in the Quebec area, but there are four other large and several smaller independently owned companies. The Quebec Miners' Association is an industry organization.

The distribution of Canadian asbestos is strongly influenced by control of individual companies. Most of the output is from captive mines whose products are used partly in the manufacturing plants of the mine owners. The unused fiber from these mines and the output of independent producers enter normal distribution channels. The way in which customers' orders are filled may seem arbitrary at times; but the rejection of orders, or allocations on a reduced basis, has been due in large measure to the shortage of supply that has characterized recent years. One authority in the asbestos-production field claimed late in 1950 that world production of Canadian Group 4 or its equivalent was less than two-thirds of that needed to supply plants in the world then using these grades, even for operation at 85 percent of capacity. During this stringency of supply, the establishment of new asbestos-products industries was difficult, because new customers were at a disadvantage in having orders filled for raw asbestos as producers customarily gave preference to old customers, and when supplies were short the newcomers received nothing.

African asbestos distribution is controlled more rigidly than Canadian. Southern Rhodesian production is mainly in the hands of a single company—Turner & Newall, Ltd., of Manchester, England. This company has large asbestos-products plants in Great Britain and several other countries, and the needs of these plants receive first consideration when raw asbestos is allocated. As the requirements of these plants are constantly increasing, the United States has been receiving progressively smaller quantities of the better grades.

Similarly, the major production of amosite and blue asbestos in the Union of South Africa is in the hands of a single firm, the Cape Asbestos Co. of London, England, which also has its own manufacturing plants and allocates its surplus asbestos to customers throughout the world. At times, supplies of amosite have been inadequate to satisfy United States requirements.

There is some prospect of a change in the African situation. Several new companies have begun or are about to begin production in Southern Rhodesia and the Union of South Africa, hence increasing quantities of asbestos may become available from independent sources.

Continental European demands have become important factors in asbestos marketing. The asbestos-products industries of France, West Germany, Italy, Netherlands, and other nearby countries that were virtually paralyzed during World War II were reestablished during postwar years. As there are little or no fiber resources in these countries except in Italy, they depend chiefly upon Africa and Canada for supplies. Russian asbestos is imported at times, especially by the Scandinavian countries. Imports from all sources were inadequate for several years. Canada allocated available supplies on the basis of the prewar consumption of

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each plant. Obviously, this condition discouraged the building of new plants. Enlarged demands for raw asbestos to supply newly created manufacturing facilities in Canada, Australia, and Latin America have also placed an additional load on the producing mines. As a result, the United States supply situation has become difficult at times, even though world production has made substantial gains. Supply and demand were, however, in approximate balance for most types and grades by 1954. Uses are expanding so rapidly, however, that, even with increasing production facilities, shortages may occur in the future.

SAIAC (Switzerland Société Anonyme Internationale de l'Asbestos Cement) has been mentioned as an organization that exerts some influence over asbestos distribution. According to a press report,[1] this international organization, established in the 1920's, had among its objectives a provision for mutual assistance among its members in procuring the necessary raw materials on the best terms. The organization is said to be concerned primarily with the grades of asbestos used in making asbestos-cement products.

[1] Rock Products, Great European Asbestos Cartel Formed: Vol. 33, No. 21, Oct. 11, 1930, p. 48.

HISTORY

Prices of Canadian asbestos fluctuated greatly for several years after the close of World War I. In 1920, because of war stimulation, prices attained unprecedented heights, Crude No. 1 selling for more than $3,000 a ton. In 1921 the price dropped to less than half that amount, and by 1925 the highest grades were selling for only about one-eighth of the price received in 1920. Since that time, except for the depression years of the early 1930's, the price trend has been generally upward. The advances have been most pronounced since 1945.

Figure 14 shows graphically the price history of Canadian asbestos, by principal grades. Table 39 shows average prices per short ton of Canadian fiber f. o. b. mine from 1926 to 1953. Table 40 gives prices of Vermont asbestos (f. o. b. Hyde Park or Morrisville, Vt.) during recent years. The recent wide demand for all grades of chrysotile and the general inadequacy of supply during recent years have tended to elevate prices to high levels.

Chrysotile from Southern Rhodesia and amosite and crocidolite from the Union of South Africa are not quoted in the open market. Contracts are made by negotiation at unpublished prices. In 1950 Rhodesian C. & G. No. 1 was selling at $418 and No. 2 at $385 per ton f. o. b. U. S. port.

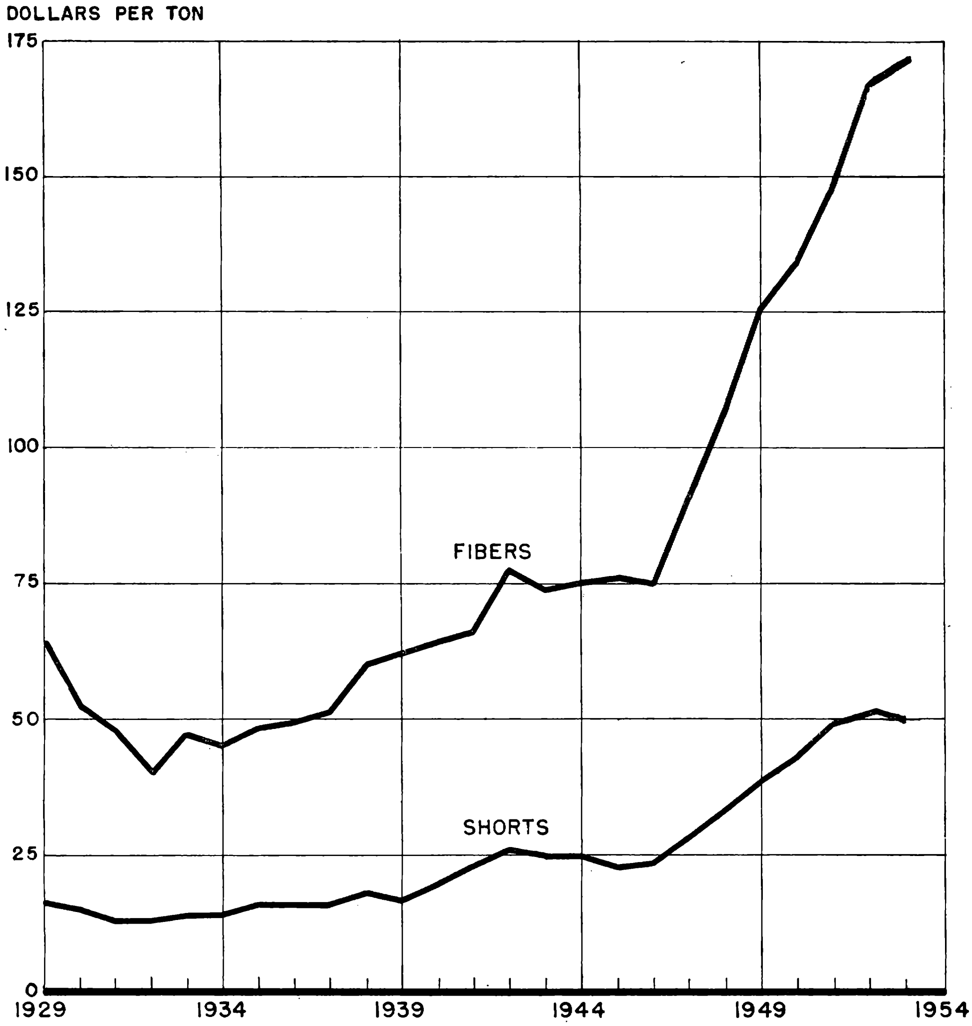

FIGURE 14.—Price History of Canadian Asbestos

TABLE 39.—*Price history of asbestos sold in Canada, 1926–53, in dollars per short ton* [1]

Year	Crude No. 1	Crude No. 2	Spinning fibers	Shingle fibers	Millboard and paper fibers
1926	$504. 16	$289. 58	$185. 00	$65. 00	$45. 00
1927	525. 00	312. 50	193. 75	70. 83	39. 17
1928	575. 00	375. 00	225. 00	80. 00	35. 00
1929	575. 00	375. 00	225. 00	80. 00	35. 00
1930	570. 83	362. 50	216. 67	78. 33	34. 17
1931	466. 67	241. 67	135. 00	65. 00	30. 00
1932	450. 00	200. 00	110. 00	60. 00	30. 00
1933	450. 00	200. 00	110. 00	60. 00	30. 00
1934	450. 00	200. 00	120. 00	60. 00	32. 50
1935	500. 00	200. 00	120. 00	60. 00	32. 50
1936	545. 83	200. 00	120. 00	60. 00	32. 50
1937	725. 00	250. 00	155. 00	66. 75	42. 50
1938	725. 00	250. 00	155. 00	67. 75	42. 50
1939	725. 00	250. 00	155. 00	67. 75	42. 50
1940	725. 00	250. 00	155. 00	71. 25	44. 75
1941	725. 00	250. 00	155. 00	71. 25	44. 75
1942	700. 00	275. 00	178. 75	72. 50	46. 75
1943	700. 00	275. 00	178. 75	72. 50	46. 75
1944	700. 00	275. 00	178. 75	72. 50	46. 75
1945	700. 00	275. 00	192. 00	76. 25	48. 50
1946	800. 00	385. 00	220. 50	88. 75	55. 75
1947	800. 00	423. 75	262. 50	104. 75	65. 75
1948	928. 00	447. 50	291. 25	106. 25	73. 75
1949	1, 005. 00	475. 00	328. 50	118. 25	83. 25
1950	1, 005. 00	475. 00	337. 50	130. 00	91. 00
1951	1, 300. 00	692. 50	362. 50	143. 00	107. 00
1952	1, 300. 00	750. 00	412. 50	175. 00	120. 00
1953	1, 300. 00	750. 00	412. 50	175. 00	120. 00

[1] Figures for 1926–36 from Dominion Bureau of Statistics. Yearly averages for 1937–53 are from the magazine, Asbestos, and are furnished by Canadian producers, they are averages of December range for each year.

TABLE 40.—*Prices of Vermont asbestos, 1931–53, in dollars per short ton* [1]

Year	Shingle fibers	Paper fibers	Cement stock [2]	Year	Shingle fibers	Paper fibers	Cement stock [2]
1931	$45. 00	$35. 00	$20. 00	1943	$64. 00	$49. 00	$33. 00
1932	42. 50	32. 50	20. 00	1944	64. 00	49. 00	33. 00
1933	45. 00	35. 00	23. 00	1945	64. 00	49. 00	33. 00
1934	45. 00	35. 00	23. 00	1946	79. 00	55. 75	39. 00
1935	37. 50	35. 00	23. 00	1947	97. 50	69. 00	48. 50
1936	47. 50	35. 00	23. 00	1948	102. 00	76. 75	56. 00
1937	57. 00	40. 00	25. 00	1949	117. 75	87. 75	59. 00
1938	57. 00	40. 00	25. 00	1950	135. 55	96. 50	64. 90
1939	57. 00	40. 00	25. 00	1951	148. 50	98. 25	71. 40
1940	58. 50	44. 00	30. 00	1952	164. 50	121. 00	78. 00
1941	58. 50	44. 00	30. 00	1953	164. 50	121. 00	78. 00
1942	64. 00	48. 50	33. 00				

[1] Quotations, E&MJ Metal and Mineral Markets, 1931–38; Asbestos, 1939–53, average of December range for each year.
[2] "Cement stock" classification changed to "Waste" since 1940.

PRICES IN 1953

According to a consular report,[1] prices of Rhodesian and South African chrysotile closely approximated those of similar Canadian grades in 1953. Table 41 shows a comparison of certain typical grades. Late in 1953, however, lack of demand led to a strong downward trend in prices, and in 1954 several marginal mines in the Union of South Africa and Southern Rhodesia suspended operation.

The average value per ton of the total output of Rhodesia and the Union of South Africa can be determined from the tonnage and value given in tables of production appearing in the discussion of asbestos in the several countries.

[1] Parsons, Marselis C., Jr., Current Prices for Chrysotile Asbestos, Southern Rhodesia and Union of South Africa: Johannesburg, June 24, 1953, 2 pp.

TABLE 41.—*Comparable prices per short ton of African and Canadian chrysotile in 1953*

Grade	African chrysotile, f. o. b. Beira and Durban	Canadian chrysotile, f. o. b. mines
Crude No. 1	[1] $1, 260–$1, 400	$1, 300. 00
3F	630	514. 00
3Z	350–364	321. 00
4H	200	200. 00
4T	182	156. 00
5K	126	122. 50

[1] Pounds converted to dollars on basis of 1£=$2.80.

SUBSTITUTES FOR ASBESTOS

A fibrous material resembling cotton, silk, or wool but having the added quality of nonflammability satisfies a multitude of needs so admirably that it is difficult to find satisfactory substitutes therefor. A shortage of asbestos is a strong incentive for seeking substitutes. Germany's virtual isolation from sources of asbestos during World War II prompted a great deal of experimentation on possible substitutes. Materials tested included glass wool, steel wool, iron wire, synthetic rubber, organic plastics, cellulose, and treated paper. Some of the so-called substitutes were so unsatisfactory that no further mention will be made of them. The worldwide shortage of asbestos during and after World War II led to extensive research on possible substitutes in the United States and other countries. Consideration is given to individual substitutes as follows:

SODA-LIME-SILICA-GLASS FIBERS

The development of a fiber-glass industry opened up a promising field for substitution because glass fibers, like asbestos, will not burn. However, as will be pointed out later, glass fibers may lack certain physical or chemical characteristics inherent in asbestos and consequently fail to satisfy the exacting specifications that must be met for most uses. For other uses they may be satisfactory. Glass and related fibers are manufactured in two basic forms—a wool-like material and a filament. Rock wool, glass wool, and slag wool are used primarily as lightweight thermal insulation, such as house fill. Such applications in general are not substitutes for asbestos. Glass filaments made by more refined processes, involving the use of platinum dies, are of high quality and uniform size. Some are less than one-half micron in diameter and are adaptable to highly specialized uses, such as weaving into fabrics. Attempts have been made to use glass fibers in place of asbestos in asbestos-cement products; but such tests have given unsatisfactory results, chiefly because of a chemical reaction between the glass and cement, which decomposes the fibers and destroys their effective strength.

Neither glass filaments nor cloth woven from them resists high temperatures. The fibers will not burn, but they will soften and coalesce when the temperature reaches a certain point, and this point varies, depending upon the composition of the glass. The organic film used on woven-glass textiles will decompose and volatilize at about 300° C., and its loss impairs the effectiveness of the fabric to some extent. Normally, glass resists weathering very well. Windowpanes generally show no weathering effects, even after many decades of use. However, the surface area per unit volume of very fine glass fibers is so great that exposure to water vapor results in relatively rapid deterioration.

Glass and mineral-wool fibers are efficient thermal insulators in various types of equipment, such as stoves and refrigerators, where temperatures are moderate and corrosive conditions are not encountered. The high tensile strength, the greater thermal stability compared with organic fibers, and the electrical resistance of glass fibers make them suitable for electrical insulation, such as sleeving for wire and tapes for the construction of some types of motors. Fiber glass is used to some extent in conjunction with, or as a substitute for, asbestos in Navy cable insulation. It is claimed, however, that asbestos insulation permits greater flexibility in finished cables than can be obtained with fiberglass insulation. Glass fibers are said to be unsatisfactory for cable filler (material that fills in the spaces in a group of insulated cables), but recent improvements in glass fibers promise future satisfactory use. Very thin glass-fiber paper may find advantageous use in condensers for electronic equipment; for instance, its use may make it possible to reduce the size of the condensers.

A glass-asbestos cloth was designed during World War II to extend the supply of asbestos textile fibers. It has continued in use as a covering on thermal insulation applied to piping on naval vessels. It is woven with a plied yarn having one strand each of glass and asbestos yarn.

United States Rubber Co. has announced production of a new fabric named "Asbeston," consisting of interwoven glass and asbestos yarns. It is said to be well adapted for theater curtains as well as for fireproof draperies in schools, hospitals, libraries, hotels, and ships.[1]

Coarse glass fibers compressed into batts are efficient lightweight air filters that are used extensively for cleaning large volumes of air. Asbestos is not widely used in this field, but blue asbestos has found important use in gas-mask filters. The Naval Research Laboratory has found that glass fibers make superior gas filters. In recent gas-mask tests in a smoke-filled room, only 1 particle in 100,000 passed through the filter; at the same time, the mask caused no increase in normal breathing resistance. Glass filter paper is said to be "5,000 times more effective than present commercially

[1] Asbestos, Draperies of Asbestos Glass Fabric: Vol. 31, No. 10, April 1950, p. 8.

available filters." The filter paper can be made in any ordinary paper mill.[2] Fiber glass may, therefore, displace blue asbestos in Navy gas masks. It has been claimed, however, that blue asbestos is more satisfactory than glass fibers for civilian gas masks and for those used by the Army.

A considerable part of the present production of fiber glass is being applied to military uses. Many manufacturers of electric insulating materials are listed as users of fiber glass, for instance, manufacturers of asbestos cloth and tapes, laminates, varnished tubing, magnet-wire covering, and mica insulating products. Fiber glass was widely used during World War II for heat, sound, and electric insulation on aircraft. Over 90 percent of the output during World War II was used for military or essential civilian use.

The use of fiber glass as a substitute for asbestos in friction equipment has, in general, given unsatisfactory results. No published information on comparative tests of fiber glass and asbestos in brakebands appears to be available, but verbal statements by those who have made such tests indicate that the principal objection to fiber glass is its rapid abrasion of brake drums.

As fiber glass can replace asbestos in certain fields of application, its future availability is of first importance. It had been claimed that the process of manufacturing fiber glass is controlled by a single company—the Owens-Corning Fiberglas Corp. Such a claim is not now correct. Glass Fibers, Inc., Waterville, Ohio, has its own process for making fibers suited for glass-fabric manufacture, and Glass Floss Corp., Long Island, N. Y., has developed a process for making bonded mats and air filters. In addition to these independent concerns, the following companies operate under license from Owens-Corning Fiberglas Corp.: Gustin-Bacon Manufacturing Co., Kansas City, Mo.; Libbey-Owens-Ford Glass Co., Parkersburg, W. Va.; Pittsburg Plate Glass Co., Shelbyville, Ind.; and Ferro Corp., Nashville, Tenn.

The parent company, Owens-Corning Fiberglas Corp., has increased its capacity greatly. It now has plants manufacturing fiber-glass textiles at Ashton, R. I., Huntingdon, Pa., and Anderson, S. C., the latter plant came into production in July 1951. The company also has four plants making nontextile fiber-glass products, such as block and blanket insulation and pipe covering. These plants are at Newark, Ohio; Kansas City, Kans.; Santa Clara, Calif.; and Sarnia, Ontario, Canada.

The expansion in fiber-glass manufacture indicated in preceding paragraphs would indicate a growing capability of the industry to provide for prospective future needs.

A question has been raised as to the limitations on fiber-glass manufacture imposed by the need for platinum. At one stage in the principal process of fiber-glass manufacture, the molten glass is drawn through perforations in a platinum-bottomed cell or bushing, and it appears that no other substance can be substituted for the platinum so used. Because platinum is produced in limited quantities—a world production of about 500,000 troy ounces a year—and has wide scientific and industrial uses, its availability for wider application in this industry deserves careful consideration. Platinum is a critical material during war periods. Three important circumstances tend to relieve, to some extent, the threat of a possible shortage.

1. There is very little loss of platinum during fiber-glass manufacture. The holes through which the fibers are drawn will gradually enlarge, and the platinum bushing will accordingly have to be rebuilt, using the same platinum. Care is taken to recover any dust or fragments of platinum. The first installation is the important consideration, but subsequent replacement of losses is very small.

2. Research is being conducted constantly to find ways of reducing the quantity of platinum required in each bushing. Presumably some saving will be accomplished.

3. Research is also underway on possible substitution of some less costly and more abundant substance for platinum. Limited progress has been made, and there is at least some promise of success.

Another raw material essential to fiber-glass manufacture that may be in short supply in times of emergency is cryolite, sodium-aluminum fluoride (Na_3AlF_6), which is mined only in Greenland. The supply, however, is augmented by artificial cryolite manufactured from fluorspar. If supplies of both these materials are limited, sodium silicofluoride may be substituted; but, as this commodity also is a derivative of fluorspar, it may likewise fall in the category of scarce materials.

Under normal industrial conditions the supply of both fluorspar derivatives and platinum would appear to be adequate for a moderate expansion in fiber-glass manufacture. Most of the raw materials used are plentiful.

HIGH-SILICA GLASS FIBERS

Glass fibers approximating vitreous silica in composition are superior to soda-lime-silica glass fibers in resistance to deterioration from the action of water vapor and to high tempera-

[2] Office of Public Information, Department of Defense, Glass-Fiber Filter Insulator Developed by Naval Laboratory: Dec. 7, 1950.

tures, but their manufacture is a difficult problem. Fused silica is so viscous, even at temperatures as high as 1,700° C., that its manufacture into thin filaments is almost impossible. To overcome this high viscosity, fluxes are added, the fibers are made, and the fluxes are then removed. Several methods are used, but they are similar in principle. First, filaments are formed from an easily workable composition, such as an alkali silicate. Second, the alkali or flux in the filament is removed by leaching or ionic substitution. The resulting fibers are relatively porous and of high silica content. They will withstand, with little deterioration, temperatures exceeding 1,000° C. The minimum diameter of high-silica fibers on which data are now available is about 2 microns, and the average is much greater. On the other hand, natural asbestos fibers are only a fraction of 1 micron in diameter. Correspondingly, the silica fibers are much less flexible than natural chrysotile. If finer fibers can be made by improvements in processing, this difficulty may be overcome to some extent. Because of their high moisture resistance and ability to withstand high temperatures, the vitreous silica filaments undoubtedly can be substituted for asbestos in some applications, but it is doubtful that they can replace asbestos where flexibility or elasticity is a prime consideration. Furthermore, the cost of manufacture is very high.

Dr. Rudolf Leutz claimed to be the inventor of a process for making synthetic asbestos in Germany. His product, however, could not be called synthetic asbestos because its base was sodium silicate, and an analysis of the final product indicated that it consisted of over 97 percent SiO_2. It was, in fact, a silica-glass fiber. Three companies were licensed to manufacture this product in 1943, but because of the military reverses suffered by Germany no progress was made.[3]

OTHER SILICEOUS FIBERS

A new series of aluminum silicate fibers, made by the mineral-wool process after fusion by means of an electric arc, has been developed. This process has the decided advantage of eliminating the use of platinum. The products, which are available under various trade names, have thermal stabilities in the order of 2,300° F. They have been successfully employed where extremely high temperatures are encountered and where glass fibers are unsatisfactory, as in jet aircraft. Possible substitution of these new fibers for asbestos in cable coverings and electronics is being explored. Uses extensive enough to justify commercial production have been established.[4]

Both high-silica glass (quartz) and ceramic (aluminum silicate) fibers have been used successfully by the Naval Research Laboratory, Washington, D. C., for making paper that has superior properties for electrical insulation. A regular papermaking machine can be used if the fibers are of fine sizes and properly purified. Quartz paper is said to withstand temperatures up to 3,000° F. and ceramic paper 2,500° F., whereas the upper limit of asbestos paper is not more than 1,000° F.[5]

Hydrous calcium silicate is another insulating material used to quite an extent during the past 10 years, particularly as an alternate for 85-percent magnesia where high temperatures are involved. It will give satisfactory service up to 1,200° F.

It was reported in February 1952 that Glass Fibers, Inc., Toledo, Ohio, had developed a process for making pure quartz fibers in submicron sizes.

ORGANIC SUBSTITUTES

German scientists attempted to manufacture yarn using short-fiber asbestos mixed with long organic fibers such as cotton, cellulose, or synthetics, but the product obtained was very weak.[6] Cardboard with an organic plastic was used in Germany as a substitute for asbestos packing in flanges of steam and water pipes. This packing was satisfactory for pressures up to 5 atmospheres and temperatures up to 160° C. It is stated that substitutes for asbestos in high-pressure packings have not been successful and that all substitutes developed and used up to 1944 were inferior to asbestos.[7]

A diaphragm of Perlon paper coated with barite paste was tried by I. G. Farbenindustrie as a substitute for asbestos cloth as a diaphragm in a Siemens-Billiter cell in the manufacture of NaOH by electrolysis of NaCl solution. It failed within 30 minutes. Perlon is a German synthetic fiber similar to nylon. However, a polyvinyl chloride diaphragm gave results equal to those obtained with asbestos cloth.[8]

Although reports are somewhat conflicting, polyvinyl fibers appear to be inferior to asbestos in asbestos-cement products. Silicone rubber has been used successfully as a wire covering in certain applications.

[3] FIAT, Technical and Scientific Developments Related to the Asbestos Industry in Germany: Final Report 1070, 1947.

[4] Chemical Engineering, Ceramic Fiber Resists 2,300° F.: Vol. 59, No. 9, September 1952, p. 198.

[5] Chemical Engineering, Insulating Papers vs. Asbestos: Vol. 59, No. 7, July 1952, p. 248.

[6] Blakely, J. D., Dawson, E. L., Gaze, R., and Henderson, M. B., BIOS Final Report 404 PB 34022, 1945.

[7] Krannich, W., I. G. Farbenindustrie A.-G., Ludwigshafen, PB 52025, 1944, pp. 176–181.

[8] Liebenwirth, I. G. Farbenindustrie A.-G., Ludwigshafen, PBL-70305, FIAT Reel—, B-31 Fr 40694–5.

SUBSTITUTES FOR AMOSITE

As indicated elsewhere, an important use for amosite is for the manufacture of light, fluffy insulation for use on marine turbines and jet planes. The fluffiness appears to be a function of fiber diameter; the finer fibers show the higher degree of thermal efficiency per unit weight. Accordingly, it has been found that fiber glass having diameters of less than 1 micron has a thermal efficiency comparable with that of amosite. However, an ordinary lime-soda glass has too low a thermal efficiency for the specialized insulation uses of amosite. Aluminum silicate fibers mentioned in a previous paragraph have melting points as high as 2,300° F., which is much higher than the temperature at which amosite disintegrates. Such fibers, now being made in submicron sizes, are said to be satisfactory substitutes for amosite, but their cost is 5 or 6 times as great.

Some progress has been made in substituting fiber glass for amosite in making 85-percent magnesia insulation.

SUMMARY OF CONCLUSIONS ON SUBSTITUTES

Other materials may be substituted for asbestos in some fields of use. Glass fibers are satisfactory thermal insulators for low-temperature equipment and other applications in which the fibers are not exposed to water vapor or continued flexure. Glass fibers are good electric insulators and therefore are used to some extent for wire covering and similar applications. Vitreous silica fibers will withstand more severe weathering conditions and higher temperatures than the soda-lime-silica glass fibers, but their manufacture is difficult. Moreover, their flexibility is much inferior to that of asbestos but is improved as processes for making finer size fibers are developed.

Glass fibers are now substituted to some extent for long-fiber chrysotile in cable coverings and fabrics, and more extensive substitution is anticipated. Shortage of platinum might, in an emergency, limit the available supply of fiber glass. The glass fabrics, or the combined glass-asbestos fabrics, have some advantages over asbestos fabrics in lighter weight per square yard and in strength, but they are generally inferior to asbestos fabrics in resistance to high temperatures, flexure, and chemical action. The processing of combined glass-asbestos fabrics introduces problems affecting the comfort of workers, because glass fibers cause skin irritation. Extremely fine fibers create less irritation than the coarser ones.

Glass fibers in submicron sizes are much more costly than asbestos. With improvement in quality and substantial reduction in cost of manufacture, a wider substitution of fiber glass for asbestos is forecast.

In some applications where the temperatures encountered are low and where chemical resistance is not important, organic fibers are satisfactory substitutes.[9]

[9] Data on substitutes included in this discussion were supplied in part by Jay E. Comeforo, Electrotechnical Laboratory, Bureau of Mines, Norris, Tenn.

BENEFICIATION OF ASBESTOS

A critical situation existed during and after World War II owing to a short supply of chrysotile low enough in iron to satisfy the requirements for uses involving high dielectric resistance. For instance, electric cable coverings on shipboard must not only be fireproof but must have insulating qualities high enough to obviate the risk of current leakage or short circuit. Asbestos of spinning length is a satisfactory cable covering if the iron content is low. The National Stockpile specification for low-iron chrysotile calls for material containing not more than 3.5 percent total iron and not over 2.0 percent magnetic iron. The principal supply of asbestos that will satisfy this specification originates in Southern Rhodesia, and supplies from this source during and for a few years following World War II became smaller year by year. The softer varieties of Arizona asbestos are satisfactory, but the supply is small. The iron content of Canadian or Vermont asbestos is too high to conform with the specification.

REDUCTION OF IRON CONTENT

A logical approach to the problem of obtaining adequate supplies of the low-iron type is to find a way to reduce the iron content of Canadian fiber to a point low enough to meet the requirements. Sporadic attempts were made some years ago to remove magnetite from the Canadian fibers, but with small success. Recently the asbestos industry has conducted extensive research on this problem.

QUINTERRA PROCESS

The Johns-Manville Corp. has obtained results in its laboratories promising enough to justify the erection of a special plant at Tilton, N. H., for manufacture of an asbestos-base, inorganic, electric-insulating paper or tape named "Quinterra" paper. Tilton was chosen because it has a dustfree atmosphere, is within easy reach of the Canadian asbestos mines, and is favorably located for marketing. Another reason was an abundant water supply. Water is a prime necessity, as 7,500 pounds is required in the manufacture of each pound of Quinterra paper. Short-fiber Canadian asbestos is beaten and agitated in water to separate the magnetite from the fiber. The purified asbestos, blended with clay, is fabricated by a special papermaking process. The paper has a closed structure; that is, it has neither holes nor interstices, such as are present in woven products. It is said to withstand temperatures as high as 800° C. The severe mechanical treatment required to free the magnetite tends to weaken the asbestos fibers considerably. To give additional strength, the paper is reinforced with an open fiber-glass fabric or grid. The resulting product is a satisfactory substitute for Rhodesian fibers in various nonferrous applications. Silicone-treated Quinterra paper is now applied to electrical-insulation uses.[1]

TERRATEX PROCESS

The General Electric Co. has conducted much research on developing thin fiber-glass sheets of high dielectric strength. It was found, however, that asbestos fibers are more flexible than those of glass, but are relatively impure. Means were found for separating the asbestos into extremely fine filaments and removing the impurities. The resulting paper, known as "Terratex," has satisfactory thermal and electrical resistance for many uses. The research work paralleled the Quinterra process already described.[2]

NOVABESTOS PROCESS

Raybestos-Manhattan, Inc., is also conducting experimental work on a wet-process method that differs from that employed by Johns-Manville in that longer fibers, even up to spinning grade, are used. To free the magnetite from the fibers, a method has been devised whereby fibers are separated with a dispersing agent. Many agents were tried, and several were finally found that would disperse or separate the fibers from each other with minimum mechanical force. In other words, a chemical process for separating fibers is substituted for the mechanical beating or crushing method. Thus, the magnetite is set free so that it can be removed magnetically, with very little damage to the fibers. The fine fibers are made into papers and tissues known as "Novabestos." Some are reinforced with fiberglass. They are employed commercially for several nonferrous uses.

VORTRAP PROCESS

The Naval Research Laboratory has demonstrated the ability of a papermaker's Vortrap to remove free magnetite from a wet slurry of asbestos. Essentially the separation is effected by the swirling action that arises when rapidly flowing water is introduced into a pipe tangentially. The concomitant centrifugal action tends to throw the heavy magnetite against

[1] Asbestos, Quinterra Type 3: Vol. 33, No. 3, September 1951, p. 6. The Quinterras: Vol. 33, No. 5, November 1951, pp. 10–20.

[2] Walters, T. R., "Terratex"—A Thin Flexible Inorganic Insulation: Trans. Am. Inst. Elec. Eng., vol. 67, May 1948, pp. 452–454.

the walls, while the asbestos fibers, freed from magnetite, remain suspended and ultimately pass up and out of the instrument to a decker or other fiber-recovery apparatus. Fibers of spinning length have been cleaned with fair success in a laboratory-size Vortrap (1¾-inch). As the magnetite grains tend to be intimately attached to the fibers, some asbestos is carried away with the heavy fraction; on the other hand, some fibers to which fine grains of magnetite are attached are light enough to be carried upward with the iron-free asbestos.

In accordance with plans formulated by the Naval Research Laboratory and the Bureau of Mines, larger scale tests with Canadian asbestos were made in 1952, but the results were inconclusive. This preliminary work indicated a need for a more comprehensive study of the problem. The Bureau of Mines has undertaken a program of research in this field, including petrographic studies, fiberization by selective grinding, and possibly supersonic vibration and iron separation by Vortrap or magnetic means.

FAULTY SPECIFICATIONS

Some investigators believe that the actual quantity of total iron and magnetic iron present in asbestos or its products is a faulty criterion of its electrical resistance because much depends upon the condition of the iron present. For instance, a large fragment of magnetite would be more detrimental than the same quantity of magnetite in the form of numerous small fragments, because the large mass might constitute an uninterrupted path for the electric current, whereas the small particles, separated from each other by comparatively resistant materials, would provide a less ready pathway along which the electric current could travel. Accordingly, removal of the larger fragments would improve the electrical resistance of the product more than removal of the same quantity of iron in the form of small fragments only. It is recognized in the specifications that magnetic iron is more detrimental than the nonmagnetic forms, but the actual quantities of each may still be a faulty measure of electrical resistance.

MEANS OF MODIFYING INCLUSIONS

It has been pointed out that, if the iron-bearing asbestos were carried between the terminals of an electric arc, the short circuit created when a relatively large piece of magnetite reaches the space between the terminals would not only break up the fragment into small particles but would reduce the magnetite to ferrous forms, which are less harmful. Methods of modifying the form and particle size of the iron minerals present in asbestos have not yet been fully explored. Possibly the best results can be obtained by combining processes of iron removal with methods of modifying the form and grain size of the iron particles that remain.

About 1925 the Jeffrey Manufacturing Co. developed a method whereby woven asbestos tapes were passed between electrodes, with the result that the larger particles of magnetite were volatilized or converted to nonmagnetic compounds of iron. The resulting perforations in the tape were sealed by a following treatment with resins. When nonferrous tape became available, this practice was discontinued, but recently it has been applied successfully to Novabestos sheet made by Raybestos-Manhattan, Inc.[3]

It is pertinent in this connection to point out the desirability of a more complete investigation of types of asbestos that may be high in iron but in which the iron is present in silicate forms that are relatively resistant to the passage of electricity. Crocidolite, for instance, is high in iron, but little free iron oxide is present. The possibility of using crocidolite for fabrics suitable for wire covering has not been fully explored, chiefly because supplies of crocidolite of spinning quality are relatively small.

ELONGATION OF SHORT FIBERS

During recent years there has been great need for a larger supply of long spinning fibers of both the low-iron and the higher iron types. As pointed out elsewhere in this report (p. 62), spinning fibers produced in Canada constitute only about 4 percent of the total production. If some method could be devised for converting short fibers into long ones, the situation might be relieved. To make short fibers out of long ones is easy; all mill operators wish that it were not so simple, but elongation of short fibers is much more difficult. Fortunately, the research scientist is not terrified by apparently insurmountable barriers, and some investigations have already been conducted in this field.

Driscoll and Bruce [4] claim that an improved product can be made by mixing a slightly soluble metal compound, such as lime, with the short asbestos fibers. A soluble silicate is then used to impregnate the asbestos mass and cause precipitation of a bonding agent such as calcium silicate.

Lüdke [5] claims that short fibers can be converted into long fibers. The fibers are oriented by some means, such as electrostatically, into

[3] Data supplied by Jesse M. Weaver.
[4] Driscoll, James, and Bruce, Donald S., Treated Fabric and Process of Making the Same: U. S. Patent 2,033,928, Mar. 17, 1936.
[5] Lüdke, W., Asbesten mit längeren Fasern aus Kurzfasrigen synthetischen Asbesten: German Patent 740,911, Nov. 1, 1943.

parallel position and are then exposed to water and fluorine vapors at elevated temperatures.

Callinan [6] has devised a method of improving the structural and mechanical properties of asbestos. It is claimed that the reaction between asbestos and silicon tetrachloride results in a product that has a higher silicon content and greater tensile strength. It is postulated that the silicon tetrachloride reacts with the terminal hydroxyl groups of chrysotile and causes a condensation which leads to a substantial increase in chain length.

Brandenberger et al.[7] found that, when sepentine synthesis was conducted in the presence of natural serpentine fibers (chrysotile), no enlargement in the grain size of the natural fibers took place.[8]

[6] Callinan, T. D., Mineral Products and Method of Preparation: U. S. Patent 2,394,040, Feb. 5, 1946.

[7] Brandenberger, E., Epprecht, W., and Niggli, F. [The Serpentine Minerals and Their Synthesis, II]: Helv. Chim. Acta, vol. 30, 1947, pp. 9–14 (trans. by Frank Riordan, Jr.).

[8] Data on treatment of short fibers supplied by Jay E. Comeforo, Electrotechnical Laboratory, Bureau of Mines, Norris, Tenn.

SYNTHESIS OF ASBESTOS

Mineral synthesis is a well-established art. Synthetic sapphires and rubies have been used as jewel bearings for many years. Recently remarkable success has been attained in making synthetic quartz crystal, and some progress has been made in synthesizing mica. As the United States mines only a small fraction of its total requirements of asbestos and an even smaller fraction of its needs of the spinning grades, the development of a process for making long-fibered chrysotile is highly desirable, for it would tend to overcome our major dependence upon foreign countries in times of emergency. Some progress has been made in synthesizing amphibole asbestos, but chrysotile synthesis appears to be much more difficult. Following is a review of the status of the problem. Acknowledgement is made to Dr. Jay E. Comeforo, Electrotechnical Laboratory, Bureau of Mines, Norris, Tenn., for a substantial part of the data presented herein.

SYNTHESIS OF CHRYSOTILE

In 1929 Wells [1] synthesized "a hydrous magnesium silicate very similar to serpentine" by the interaction of a sodium silicate solution with $MgCO_3$ at 375° to 475° C. under pressures of 200 to 230 atmospheres. Under similar conditions, Ipatiev and Muromtseff [2] claim to have prepared chrysotile from a silica gel and magnesium salt solutions.

Using MgO and an alkali-free silicic acid, Jander and Wuhrer [3] synthesized serpentine at temperatures below the critical point of water. Nothing was said concerning the fibrous character of the synthesized serpentine.

Noll [4] reduced the number of nuclei formed during the synthesis by carefully introducing the reactants into nickel or silver tubes in the form of solutions in two layers or strata. One layer was composed of waterglass and caustic soda while the other consisted of a magnesium salt, such as $MgCl_2$. A gel soon formed at the interface, which served as a diffusion membrane and hindered the rapid mixing of the solutions. The tube and its contents were rapidly heated to 300° C. under a pressure of 100 atmospheres. By this means, groups or pockets of chrysotile fibers were formed. The greatest length of the filaments was 0.2 mm., which is longer than the fiber length of the product obtained without the diffusion process.

Recent studies of the $MgO-SiO_2-H_2O$ system by Bowen and Tuttle [5] have shown that chrysotile can be synthesized at temperatures below 500° C. and at pressures of 2,000 to 4,000 p.s.i. The chrysotile fibers formed, however, were very small.

O'Daniel and Hahn-Weinheimer [6] have reported the synthesis of a long-fibered material by recrystallization of chrysotile, antigorite, or mica from an ammoniacal solution. The properties determined on samples of synthetic chrysotile are found to be similar to those reported for the naturally occurring mineral. For example, both exhibit similar dehydration curves, X-ray patterns, and refractive indices.[7]

Recently Bates and coworkers [8] have reported chrysotile fibers to be actually hollow tubes. Electron micrographs show synthetic chrysotile to have the same tubular structure.[9] Noll and Kircher [10] have synthesized garnierite, a mineral in which the divalent magnesium ions are isomorphically replaced by divalent nickel. The synthesis was carried out in a similar manner to chrysotile, except that $NiCl_2$ was used in place of $MgCl_2$. On the basis of crystal evidence, the structure of garnierite is also believed to consist of curved double layers, analogous to those of chrysotile.

The hydrothermal synthesis of chrysotile is being studied at the New Jersey Ceramic Research Station, Rutgers University. A primary objective is to determine the factors that will promote growth of the fibrous habit. Best results have been obtained with gels. The effects of variations in pressure, temperature, duration of run, and composition were investigated. The chrysotile filaments made were of submicroscopic size.[11]

The universal difficulty to date has been the inability to develop crystals of chrysotile in sizes suitable for commercial utilization.

SYNTHESIS OF AMPHIBOLES

As early as 1935, Dr. Werner Lüdke claimed to have made synthetic amphibole asbestos.[12]

[1] Wells, F. G., The Hydrothermal Alteration of Serpentine: Am. Jour. Science, vol. 18, 1929, pp. 35–52.

[2] Ipatiev, W., and Muromtseff, B., Bull. Soc. Chim. Er., vol. 41, 1927, pp. 1, 588–1, 591.

[3] Jander, Wilhelm, and Wuhrer, Josef, [Hydrothermal Reactions, the Production of Magnesium Hydrosilicates]: Ztschr. anorg. u. allgem. Chemie, vol. 235 (4), March 1938, pp. 273–294.

[4] Noll, W., [Serpentine Asbestos, $Mg_6(OH)_6Si_4O_{11}.H_2O$)]: I. G. Farbenindustrie A. G., June 30, 1942. Inorganic Scientific Laboratory, Leverkusen, Germany, PB L74889, FIAT microfilm reel T-14, Frames 58–67.

[5] Bowen, N. L., and Tuttle, O. F., The System $MgO-SiO_2-H_2O$: Bull. Geol. Soc. America, vol. 60, 1949, pp. 439–460.

[6] O'Daniel, —, and Hahn-Weinheimer, P. [Fiber Growth in Serpentine]: Neues Jahrb. Mineral. Monatsh., 1952, pp. 213–16.

[7] Noll, W. [Synthesis in the System $MgO-SiO_2-H_2O$]: Ztschr. anorg. Chem., vol. 261, 1950, pp. 1–25.

[8] Bates, T. F., Sand, L. B., and Mink, J. F., Tubular Crystals of Chrysotile Asbestos: Science, vol. 3, May 12, 1950, pp. 512–513.

[9] Noll, W., and Kircher, H. [The Morphology of Chrysotile Asbestos]: Naturwissenschaften, vol. 37, 1950, pp. 540–541.

[10] Noll, W., and Kircher, H. [Synthesis of Garnierite]: Naturwissenschaften, vol. 39, 1952, pp. 233–34.

[11] Communication from Shaw, Myril C., 1953.

[12] Lüdke, Werner [The Scientific Basis of the Lüdke Asbestos Synthesis, and Properties of Synthetic Asbestos]: Reichber. Chem., vol. 1, No. 2 (Prüf-Nr 015); PB. 52025, 1944, pp. 121–40.

Lüdke's process was a type of pneumatolitic synthesis; that is, it involved the reaction resulting from the passage of heated vapor over compounded mixtures. Gerd M. Bloomfield,[13] who made a thorough review of all attempts to make synthetic asbestos in Germany, was present at a meeting in 1935 at which the representatives of the asbestos industry expressed the opinion that Dr. Lüdke's product, at the current state of development, was an unsatisfactory replacement for natural asbestos. Faced with a shortage of asbestos, however, the Anhaltische Studiengesellschaft supported Dr. Lüdke; and a pilot plant was built in Bernburg in 1940, where attempts were made to develop the process to a commercial scale. The synthetic asbestos fibers produced, however, were of inferior quality and were never improved. An attempt was made to manufacture high-pressure gaskets, but the synthetic material was chemically unstable and did not withstand the mechanical handling necessitated by quantity production. The requirements demanded for these gaskets could not be satisfied by the experimental samples made of synthetic asbestos. Asbestos paper and millboard made of Lüdke's synthetic amphibole asbestos did not compare favorably with those made of natural asbestiform minerals.

Sitz [14] has described Lüdke-process asbestos, which, in a somewhat later stage of development, came from the furnace in the form of a large plate about 300 mm. thick. He states that it was broken up, shredded, and used in high-pressure packings, brakebands, insulation, airplane coverings, and paints. Sitz's report shows no improvement over the previously stated results attained by Dr. Lüdke.

Lüdke's most successful experiments are being reinvestigated at the Electrotechnical Laboratory of the Federal Bureau of Mines to determine more precisely the effect of variations in the conditions during synthesis on the quality of the product. This research has resulted in the synthesis of an alkali-containing amphibole at a temperature as low as 400° C. in an open system.

A review and critique of previous syntheses of amphiboles by both reactions in the solid state and by crystallization from melts are given by Comeforo and Kohn.[15] In the synthesis of amphiboles, a promising technique is to replace the hydroxyl normally present in natural amphiboles by fluorine, just as in the more familiar phlogopite-mica synthesis. By this means, it is possible to produce large amounts of synthetic amphibole by crystallizing a melt of the amphibole composition in a closed container to retard volatilization of fluorides. Unfortunately, all synthetic amphibole fibers are weak and brittle. To improve the flexibility of synthetic amphiboles and to determine the most satisfactory compositions for crystallizing them relatively free of impurities, an extensive study of the isomorphism of synthetic fluor-amphiboles has been made at the Electrotechnical Laboratory of the Bureau of Mines. This work has resulted in the synthesis of amphiboles of widely varying chemical compositions, many of which are unknown in nature.

Controlled thermal gradients can be used to induce alinement of the crystals, first, by cooling the melt from the bottom, and second, by varying the shape of the container so that cooling will begin at one small area. Figure 15 shows the definite vertical orientation of amphibole crystals that may be obtained by these techniques (scale on photograph in millimeters).

Except for their fibrous habit, the properties of synthetic amphiboles are almost identical to those of their naturally occurring analog. The replacement of hydroxyl by fluorine does not result in any appreciable change in its X-ray or optical properties.

A study of well-formed, single crystals of synthetic fluor-tremolite showed that the indices of refraction of the synthetic mineral were slightly lower and the extinction angle slightly higher than those of the natural mineral. To show how closely the crystal structure of the synthetic compares with that of natural tremolite, the unit cell dimensions are compared in table 42.

SYNTHESIS OF ANHYDROUS ASBESTIFORM MINERALS

In addition to research on the synthesis of chrysotile and amphiboles—the two naturally occurring asbestiform minerals of commercial interest—experimentation is in progress on the synthesis of other inorganic, crystalline fibrous materials. Progress is being made on the synthesis of a potassium-lead silicate which has appreciable flexibility and crystallizes in a fibrous habit. The method of synthesis and chemical and certain physical properties of this promising material have been recently discussed.[16] The potassium-lead silicate has been shown to be isomorphous with lead-aluminum silicate, which also crystallizes in a fibrous habit. Aside from possible practical uses, these minerals should prove valuable in the general theoretical study of inorganic, crystalline fibers.

[13] Bloomfield, Gerd M., Technical and Scientific Developments Related to the Asbestos Industry in Germany: FIAT Final Rept. 1070, 1947.

[14] Sitz, G., The Technical Development of the Lüdke Asbestos Synthesis: PBL 52025, 1941, pp. 141-147.

[15] Comeforo, J. E., and Kohn, J. A., Synthetic Asbestos Investigations, I: Study of Synthetic Fluor-Tremolite: Am. Mineral., vol. 39, Nos. 7 and 8, July-August 1954, pp. 537-548.

[16] Shell, H. R., and Brown, D. L., Synthetic Asbestos Investigation, II: Synthesis and Properties of Fibrous $K_2Pb_4Si_8O_{21}$ and Isomorphs. (In press.)

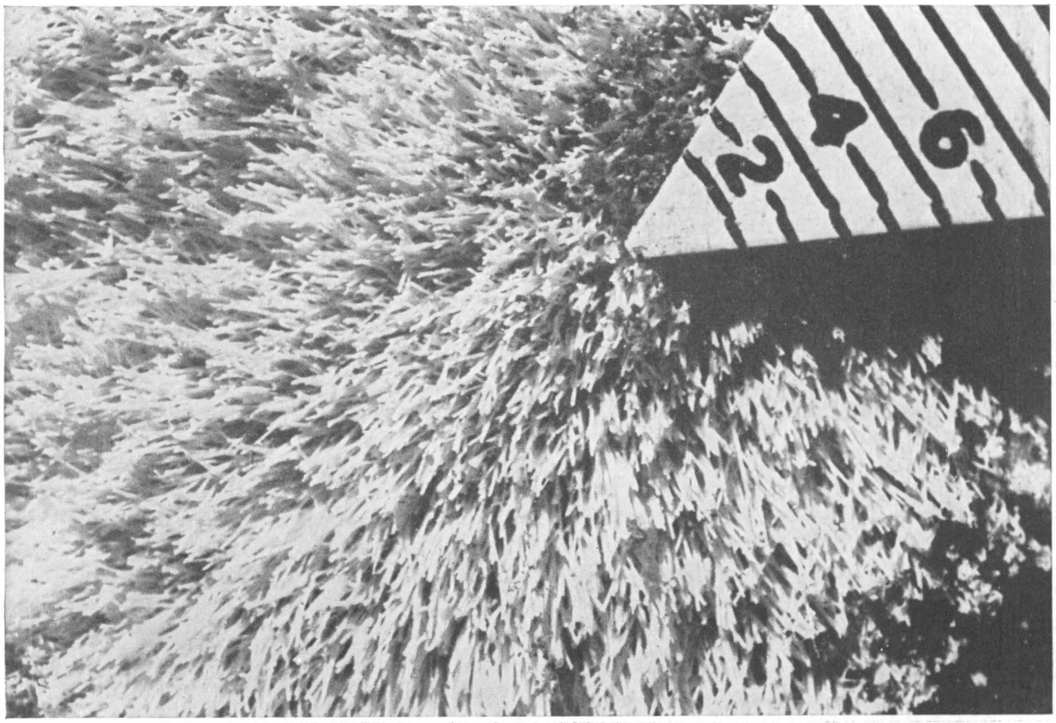

FIGURE 15.—Synthetic Amphibole Asbestos Made at Electrotechnical Laboratory, Bureau of Mines, Norris, Tenn.

TABLE 42.—*Cell dimensions of natural and artificial tremolite*

	Natural tremolite (Warren)[1]	Artificial tremolite (Comeforo and Kohn)[2]
a_0	9.78A°	9.781A°.
b_0	17.8	18.007.
c_0	5.26	5.267.
B	73°58′	75°29′.

[1] Warren, B. E. [The Structure of Tremolite, $H_2Ca_2Mg_5(SiO_3)_8$]: Ztschr, Krist., vol. 72, 1930, p. 44.
[2] See footnote 15 (p. 102).

SUMMARY OF ASBESTOS SYNTHESIS

Research on asbestiform minerals since the early 1930's has firmly established the fact that chrysotile and amphibole can be synthesized. However, a product of commercial value as a replacement for the natural minerals has not yet been made. With chrysotile a means of increasing the length beyond a few tenths of a millimeter has been a major difficulty, while with synthetic amphiboles excessive brittleness has made them unsuitable except for limited applications.

All results to date indicate the need for finding ways of increasing the length of the fibers and, in the case of synthetic amphibole, of increasing the flexibility.

One of the promising new developments in the search for a new type of inorganic, crystalline fiber is a potassium-lead-silicate compound that exhibits flexibility, can be produced in lengths of several millimeters, and has good dielectric properties.

The synthesis of an asbestiform material is a problem that must necessarily be approached from the long-range viewpoint. Most of the work to date has been in the establishment of fundamental facts upon which the ultimate development research will be built. Those who have worked in this field are uniformly convinced that a suitable product will eventually be synthesized, but success will demand unremitting and vigorous pursuit.

MANUFACTURE OF ASBESTOS PRODUCTS

A WIDESPREAD AND DIVERSIFIED INDUSTRY

The fire resistance of asbestos, combined with its fibrous character, adapts it admirably for the manufacture of flexible, heat-insulating products, packings, and gaskets for use in places where fabrics of animal or vegetable origin would be less enduring and would create fire hazards. The addition of asbestos to various fireproof building materials gives them strength and flexibility; furthermore, manufacturers of many miscellaneous products find that asbestos, when used as an ingredient, imparts superior qualities. The United States leads all countries in the manufacture of products of which asbestos is a major or an essential constituent. The industries are centered chiefly in North Atlantic, Southern, Midwestern, and Pacific Coast States. The value of asbestos products manufactured in the United States during recent years is indicated in table 43. The articles listed as "other products" are very numerous; some manufacturing companies sell more than 200 different articles. Most of the output enters the domestic market; less than 4 percent, in value, is exported. Nevertheless the export trade is of considerable magnitude, as indicated in table 44.

Although Canada uses less than 5 percent of the asbestos produced within the country, its asbestos-products industry is expanding. According to an official report,[1] there are 4 companies making asbestos-cement products, 14 manufacturers of molded asbestos automotive products, 3 asbestos-paper companies, and 3 manufacturers of asbestos textiles.

TABLE 43.—*Value of asbestos products manufactured in the United States, 1950-52*

[Data from U. S. Department of Commerce]

Product	1950	1951	1952
Asbestos textiles	$22, 088, 000	$30, 303, 000	$28, 648, 000
Asbestos friction materials	76, 239, 000	96, 935, 000	85, 180, 000
Asphalt floor tile	(1)	87, 634, 000	86, 194, 000
Asbestos-cement shingles and clapboard	66, 433, 000	57, 589, 000	70, 077, 000
Asbestos-cement flat and corrugated sheets and wallboard	23, 177, 000	32, 125, 000	28, 859, 000
Other products	88, 748, 000	29, 877, 000	33, 245, 000
Total	276, 685, 000	334, 463, 000	332, 203, 000

1 Data inadequate; value included under "Other products."

FABRICATION OF ASBESTOS PRODUCTS

The manufacture of asbestos products involves many diversified and complex processes. Only a brief summary of the principal operations is presented herein because this report pertains primarily to raw materials.

TABLE 44.—*Value of manufactured-asbestos products exported from the United States, 1950-52*

[Data from U. S. Department of Commerce]

Product	1950	1951	1952
Brake blocks	$396, 654	$680, 989	$454, 537
Brake lining and clutch facing	3, 592, 291	7, 614, 860	6, 078, 614
Construction materials	1, 755, 149	2, 526, 784	2, 822, 802
Pipe covering and cement	205, 185	453, 367	655, 254
Textiles yarn and packing	1, 814, 105	2, 391, 982	2, 428, 123
Other	333, 808	652, 407	588, 409
Total	8, 097, 192	14, 320, 389	13, 027, 739

FABRICS

The preliminary treatment of asbestos before it is made into textiles has been described in the chapter on Milling Methods (see p. 82). The processes involved in manufacturing fabrics follow, in general, those employed in spinning and weaving cotton, wool, or silk. The asbestos fibers are generally shorter than those of organic origin, but they differ from them mainly in the nature of the surface. Wool fibers are covered with scaly bands known as imbrications, and cotton fibers are rough, twisted, and irregular. On the other hand, asbestos fibers have no nodules, twists, or irregularities on the surface that will enable one fiber to cling to another. They are more nearly akin to silk but are smoother and more rodlike. This smooth, slippery condition creates such difficulties in spinning that the manufacture of a 100-percent asbestos yarn is slow and costly; therefore a percentage of some other fiber, usually cotton, is added to act as a vehicle to carry the asbestos through the manufacturing process. The proportion of cotton added varies with the character of the asbestos and with the nature of the finished product.

Asbestos used in the manufacture of fabrics may consist of a mixture of varieties from different localities. The proportions depend upon the cost and quality of raw materials and the requirements of the finished product. Most manufacturers in America prefer Canadian fiber as a base, although many products now are made of African fiber alone. The blended fibers, with the necessary addition of cotton, are mixed thoroughly with revolving beaters. Some manufacturers, however, introduce the cotton at a later stage.

Carding is the next step in the manufacturing process. Carding rolls are covered with leather and fitted with sharp steel bristles. They comb

1 Foreign Trade, Dept. of Trade and Commerce, Ottawa, vol. 14, No. 340, July 1953, pp. 17-20.

the fibers parallel and remove short fibers, bits of rock, and dust. After passing a succession of carding rolls the fiber emerges as a loose blanket, which may be turned 90° and passed through another carding machine. The blanket then is separated into rovings, which are gathered in a roll on a Jack spool and spun into yarn, as in ordinary textile mills.

Yarns are made in various sizes; a "5-cut" yarn measures about 500 yards to the pound and a "30-cut" yarn about 3,000 yards. When twisted exceptionally hard, it is known as asbestos thread, which is used in sewing gas mantles, asbestos theater curtains, and asbestos clothing. The spindles of single-ply yarn are transferred to twisting machines and twisted into 2- or 3-ply yarn, which is wound on spools. Asbestos cord and rope are made by twisting a greater number of strands together.

Where yarn is to be used for brake bands or packings, it usually is reinforced with fine copper, brass, or lead wire. Thus, for brake bands, 3 strands of single-ply yarn and 2 strands of brass wire of gage Nos. 0.006, 0.007, or 0.008 may be twisted together. For packings, a single lead wire or 1 to 3 strands of brass wire are twisted with 2 or 3 strands of asbestos yarn. Products prepared in this way are known as "metallic yarns."

Yarns are woven into fabrics by well-known processes employed in cotton- or woolen-textile mills. Asbestos cloth is used for theater curtains, fireproof clothing, and many other textile products. Single-ply asbestos yarn also is braided into tape. For electrical insulation, it should contain not more than 7 percent carbon and not more than 14 percent cotton. Metallic yarn containing about 16 percent cotton is woven into strips for brake-band linings. Standard widths range from 1 to 6 inches and standard thicknesses from ⅛ to ⅜ inch. They are processed with rubber and other ingredients. The manufacture of woven brake linings for automobiles is an important branch of the asbestos-products industry, but it has become relatively less important since molded brake linings have been introduced.

Asbestos packings are made in various ways. The yarn may be twisted or braided into valve-stem packings, the braided forms may be compressed into rings, or asbestos cloth may be cut into gaskets or other desired forms. They may be coated or impregnated with rubber compounds, oil, or flake graphite. Metallic yarn is used in some packings. Further details on the uses of asbestos in fabrics have been published.[2]

[2] Asbestos Textile Institute, Handbook of Asbestos Textiles: New Brunswick, N. J., 1953, 78 pp.

SHINGLES AND LUMBER

Asbestos roofing shingles and sidings consist of portland cement to which is added about 15 percent of shingle-grade asbestos and coloring matter as desired. When manufactured by the so-called "dry process," the cement, asbestos, and coloring agent are mixed dry in a cylindrical mixer provided with paddles. The mixture is spread evenly on an 18-inch conveyor belt and sprayed with water at 180° F. Rollers compress it to the required thickness, and a rotary cutter separates it into individual shingles. The shingles are piled in stacks separated by steel pallets and squeezed in a hydraulic press at a pressure of 20,000 pounds per square inch, after which they are cured, trimmed, and punched for nailing.

Asbestos lumber, sidings, and shingles are also made by a wet method known as the laminated or "Hatschek" process first used in Austria. Cement, shingle-grade fiber, and coloring matter are mixed with a large quantity of water, agitated thoroughly with a beater, and pumped to a so-called Hatschek machine (named after the inventor) that builds up sheets in successive laminations to the desired thickness. Portland cement thus mixed with a large quantity of water does not lose its capability of setting at a later stage when most of the water is removed. Steam curing hastens the setting. For shingle manufacture, thin sheets are made. Lumber consists of thicker and larger sheets. Corrugated sheets are made by crimping flat sheets. The laminated process is also used for making cement-asbestos pipes, but the building up of tube-shaped articles is more complicated and requires special equipment.

Asbestos lumber is also made by the dry process described previously, but more time is needed for compression and curing than is required for the thin sheets used for roofing.

PAPER AND MILLBOARD

Asbestos of paper-stock grade is mixed with a large amount of water to make a thin slurry, which is agitated thoroughly in 5-foot drums covered with slats. Starch, flour, or size and sodium silicate, derived partly from the overflow squeezed out of the paper at a later stage, are added to the slurry. This is then conveyed to a paper machine similar to that used in manufacturing paper from rags or wood pulp. All particles of stone or other impurities are eliminated in a sand-catching and knot-removing machine. The sheets of paper pass between rollers to remove most of the water, are dried on hot cylinders, and are wound in rolls. If a 2-ply paper is desired, 1 side of a sheet is coated lightly with sodium silicate, and the 2 sheets are run together over several hot rolls. Crimped paper is made by passing it over corrugated rolls. In the manufacture of air-cell pipe covering, the tips of the corrugations are coated with sodium silicate, and a flat sheet is added. When this process is repeated, a 2-ply, 3-ply, or thicker air-cell covering may be made.

Millboard is generally classed with paper because it is manufactured by the same general process. It is simply a thick paper; it bears the same relation to asbestos paper that cardboard bears to wrapping paper. The board usually is built up on rectangular screens rather than on drums.

The manufacture of millboard gaskets is important. The high speeds, temperatures, and pressures attained in modern automobiles and other machinery demand very exacting qualities in the millboard used. It must have uniform density and high strength, and variations in thickness in any part of the sheet must not exceed 0.002 inch.

ASBESTOS-CEMENT PIPE

In one method of pipe manufacture a slurry of asbestos, cement, and water is collected on a felt-covered belt and the water removed by suction. The sheet is then wound on a rotating metal cylinder having an outside diameter equal to the inside diameter of the pipe to be made. After it has been built up to the desired thickness, it is steam-cured. Such pipe is used extensively for water and oil lines, as it resists corrosion, compression, traction, or shock. An admixture of sulfur and asbestos is also used for making pipes or for lining steel pipes. Sulfur has remarkably high resistance to chemical action, and the asbestos fiber supplies the desired strength.

ASBESTOS-MAGNESIA INSULATION

A light, fluffy form of magnesium carbonate combined with asbestos fibers makes an effective heat insulator for steam pipes. The magnesium carbonate is commonly recovered from dolomite, which is a double carbonate of calcium and magnesium. By means of a complex chemical treatment, the magnesia is separated in the form of a light, fine-grained, basic magnesium carbonate. Magnesium carbonate is also obtained from bitterns (the residual brines at salt works) and from sea water.

About 15 percent, by weight, of asbestos is added to the magnesium carbonate and the mixture agitated thoroughly in water. The solids are collected on a filter press and cast in the form of pipe insulation, generally 1 to 4 inches thick. Such products are designated "85-percent magnesia."

The asbestos used is commonly a mixture of Canadian chrysotile and amosite. The proportions may be 40 to 60 percent amosite and the remainder chrysotile of Group 4 or 5. When fibers of fair length are used, the proportion of fiber may be reduced—possibly as low as 11 percent. If shorter fibers are used, the percentage must be increased, possibly to 15 percent or more. The shorter the fibers, the greater the breakage loss in the finished product. Amosite furnishes long fibers at lower cost than those obtained by employing Canadian chrysotile. One product, "Unibestos," consists almost entirely of amosite. The 85-percent magnesia is used for temperatures up to about 550° F., above which the magnesia disintegrates. Unibestos is used for temperatures of 550° to 900° F. Another high-temperature insulating material, named "Calsilite," consists of amosite, Canadian 3Z, and a siliceous binder. It is said to withstand temperatures up to 1,200° F.

COMPOUNDED PACKINGS

Packings are used to prevent the escape of steam or compressed air around the moving parts of machinery. Compounded packings are made of asbestos mixed with fillers and binders. Ordinary fillers are clay, barite, magnesia, iron oxide, graphite, and cellulose. The binding materials are gums, resins, lac, or rubber dissolved in a volatile solvent. High-grade packings contain about 2 parts of asbestos to 1 part of filler. The mixture is molded into sheets of any desired thickness and may be reinforced with copper or lead foil.

ASBESTOS CEMENT

A covering used widely for boiler insulation consists of short-fiber asbestos. Cementing material such as plastic clay is sometimes used. The ingredients are mixed with water to form a paste, which is applied with a trowel. The fibers employed for such cements are the shortest and lowest priced grades.

MOLDED ARTICLES

Increasing quantities of short-fiber asbestos are used in manufacturing electrical fittings and household appliances. Mixtures of asbestos, gilsonite, cement, and oil are ground together and compressed in molds; these are baked in ovens, polished, and lacquered. Gilsonite imparts a brown color; if gray is desired, the gilsonite is omitted. Short-fiber asbestos mixed with synthetic resins, vegetable oils, or other ingredients may be compressed in molds to make so-called "asphalt" floor tile. Such tiles may contain 40 percent or more of short-fiber asbestos, and the industry has grown to such proportions that it has created a market for large quantities of the shorter fibers that formerly were discarded as waste.

NONCORROSIVE FILTERS

Amphibole asbestos, which, in general, is more resistant to chemicals than chrysotile, is washed, thoroughly fiberized, acid-treated to remove soluble impurities, and otherwise prepared for use in Gooch crucibles or for other filtering processes that employ strong acids and alkalies.

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