SEELEY W. MUDD SERIES

INDUSTRIAL MINERALS and ROCKS

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The Seeley W. Mudd Series

Industrial Minerals and Rocks
Edited by The Committee on the Industrial Minerals Volume

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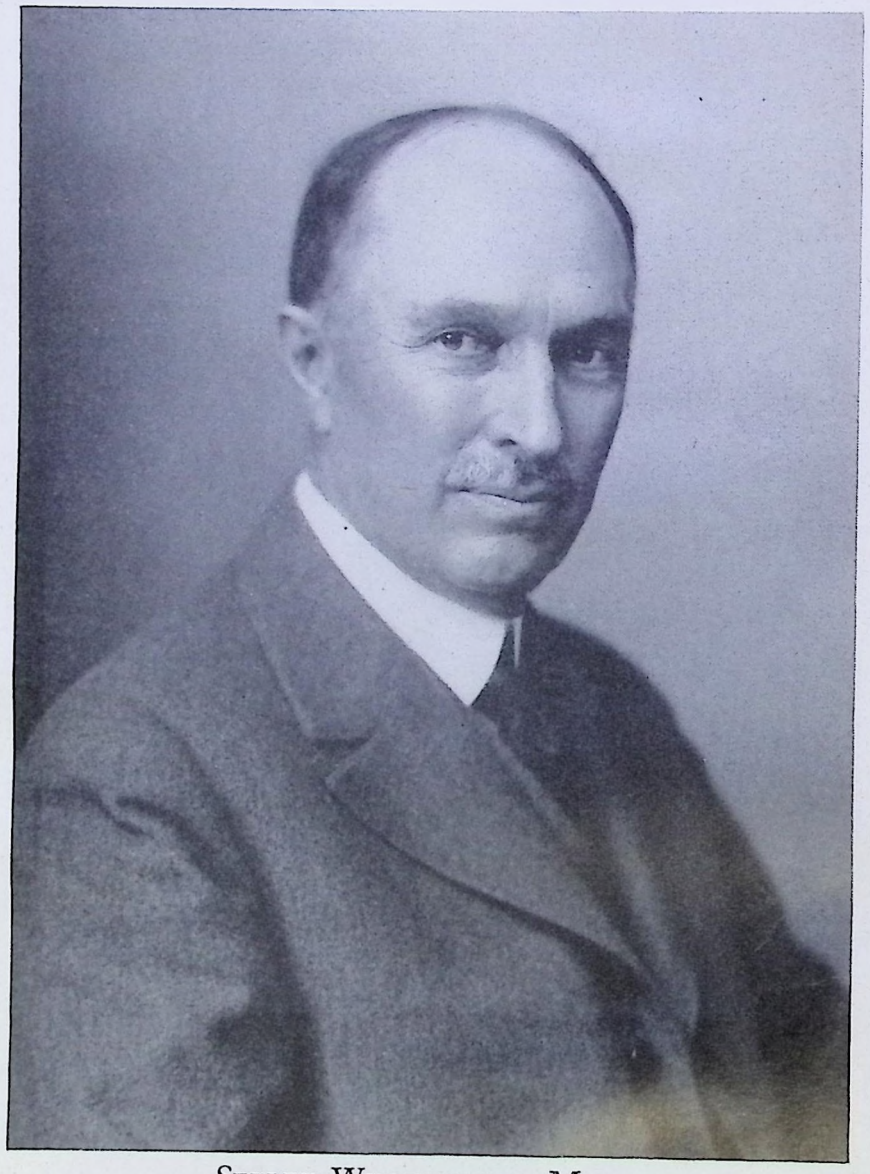
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SEELEY WINTERSMITH MUDD

INDUSTRIAL MINERALS AND ROCKS

(Nonmetallics other than Fuels)

SECOND EDITION
COMPLETELY REVISED

The Committee on Industrial Minerals Volume

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INTRODUCTION

The first edition of Industrial Minerals and Rocks was published in 1937. The growing demand, both in industry and for classroom use in colleges, led to a second printing a few years later. Now, after a lapse of ten years, it has been considered desirable to completely revise this work, to incorporate important technical developments in the intervening decade, and to bring statistical information up to date. This has resulted in the present edition II.

This work is composed of 51 chapters written by recognized specialists in the respective fields. Because of death, or for other reasons, several of the authors whose names appeared in the first edition have had to be replaced by others. In no other publication is there available so complete a collection of data on the so-called industrial minerals—a term which has now largely replaced "nonmetallic minerals" in technical usage.

As pointed out in the earlier edition, here is not only a large but a particularly fertile field for the engineer and technologist in the mineral industries. Only in recent years, and then only to a limited extent, have the search for, and the exploitation and beneficiation of, these minerals been conducted by men having professional engineering training. But more and more those who finance these operations are realizing the advantages of employing such men to manage and superintend their operations. The gradual exhaustion of surficial deposits and the consequent more elaborate mining methods; the need for mining ores of lower grade, resulting in the introduction of mechanical dressing and other types of processing; and the competition between materials, which demands that these things be done with the maximum efficiency —all these things require the highest possible skill, knowledge, and resourcefulness. The trend is distinctly toward the employment of technically educated men. The growing use of this work in technical schools is further evidence of the increasing demand for young engineers with specific training in this field.

Problems in the production of industrial minerals may differ in important respects from those found in metal or coal operations. Often such factors as color and other physical aspects are of high importance, whereas chemical analysis may or may not affect the utility of these materials.

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Publication of this volume has been made possible by an appropriation made in 1946 by the Seeley W. Mudd Memorial Fund, administered by a committee composed of H. Foster Bain, Wilber Judson, and H. DeWitt Smith, with Louis S. Cates and A. B. Parsons ex-officio. In the Deed of Gift by which the fund was established, mention is made specifically of projects that would be of particular benefit to young engineers. The interest of Colonel Mudd in aiding younger men, particularly young engineers, has been taken into account by the Fund Committee, the Editorial Board, and the many authors and others who have contributed so freely of their time and knowledge in the preparation of this book.

To Oliver Bowles, Vice Chairman of the Editorial Board, is due much credit for organization and critical reading of manuscripts. The Institute is also indebted to other members of the Editorial Board and to the 49 individual contributors.

The U. S. Geological Survey, the U. S. Bureau of Mines, and the Canada Department of Mines and Resources have cooperated freely in this work in supplying statistical and other data. Many of the authors are specialists on the staffs of these organizations.

In view of the reception accorded the first edition, there can be little doubt of the usefulness of this work to those engaged in the production and use of industrial minerals and to those rising engineers and students who desire to take advantage of the growing field for engineers trained in these subjects.

New York, N. Y.
February 1, 1949

Samuel H. Dolbear.

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CHAPTER 2

ASBESTOS

BY G. F. JENKINS*

ASBESTOS is a general term embracing the fibrous varieties of a number of minerals. Of these, the hydrous magnesium silicate, chrysotile ($H_4Mg_3Si_2O_9$), a variety of serpentine, is the most abundant and useful to industry.

All other types of asbestos belong to the amphibole group of minerals and are classified as: crocidolite, $NaFe(SiO_3)_2\ FeSiO_3$; anthophyllite, $(MgFe)SiO_3$; amosite, also a ferromagnesium silicate but with iron content higher than that of anthophyllite; tremolite, $CaMg_3(SiO_3)_4$; and, actinolite, $Ca(MgFe)_3(SiO_3)_4$.

PROPERTIES

The commercial value of asbestos depends largely on the physical property that permits it to be readily separated into fine filaments of high tensile strength and flexibility, which, coupled with the fact that it has the quality of incombustibility of a mineral—in distinction to vegetable and animal fibers—makes it of unique usefulness for many purposes. To some extent, the value depends upon the length of the fiber, although extreme length is neither necessary nor desirable for most purposes.

Chrysotile occurs as cross-fiber veins, in which the asbestos fibers are approximately at right angles to the vein walls, with vein width—or fiber length—seldom exceeding 2 or 3 in.; also as slip-fiber, in which the fibers lie in the same plane as the vein or on slippage planes. A cleanly broken vein of cross-fiber has a pearly luster and may range from a deep green or brown color to light shades of yellowish green or cream. When of good quality, the fiber filaments forming the vein may be easily drawn away from their neighbors and exhibit a fine silkiness and pure white color. They may be twisted into a thread and when flexed between thumb and fingers are found to be strong and pliable. Chrysotile withstands comparatively high temperatures without breaking down completely or fusing but begins to lose water of crystalliza-

* General Manager, Asbestos Corporation Ltd., Thetford Mines, Quebec.

The author wishes to acknowledge the help and advice given him by A. L. Penhale, President, Asbestos Corporation Ltd., also the assistance of I. C. Campbell, P. E Breton and M. K. Senicie, of the same company.

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tion at about 450°C and becomes brittle. It is readily attacked by acids. Fibers of highest quality generally contain more than 13 pct water of crystallization.

Slip-fiber chrysotile may be equally strong and flexible but is unsuitable for spinning, although useful for other purposes.

Crocidolite has a characteristic deep dusty blue color in the fiberized as well as in the crude state. This variety is less resistant to heat than chrysotile, fusing at a comparatively low temperature. On the other hand, it withstands the effects of acids and alkalies much better and is said to have a higher dielectric strength. Its spinnability is inferior to that of chrysotile.

Amosite usually is of a yellowish gray shade. The fibers, while having good tensile strength and greater average length than chrysotile or crocidolite, are relatively harsh and do not spin well. Its resistance to acids and alkalies is fairly high, though lower than that of crocidolite. It is superior to crocidolite in withstanding heat.

Of the three remaining fibrous amphibole minerals, actinolite, tremolite, and anthophyllite, the two last named, because of their resistance to attack by acids, are especially suitable for use in filtration. The fibers lack tensile strength and those of anthophyllite, in particular, are brittle.

DISTRIBUTION OF DEPOSITS

United States

Asbestos deposits in the United States are very limited in extent and distribution. The largest known reserves are in northern Vermont, where the asbestos-bearing serpentine zone of Quebec extends into that state. The developed ore is chrysotile, almost entirely of the slip-fiber type. It is reported, however, that diamond drilling has recently revealed cross-fiber of good quality in the same zone as that of the slip-fiber ore body being currently mined.

In Arizona, chrysotile occurs in veins following the bedding of serpentinized dolomites near diabase intrusions. The fiber is of high quality and is particularly suitable for insulation of electrical equipment because of its low iron content; unfortunately, however, it cannot be considered a potentially important reserve.

Some cross-fiber chrysotile occurs also in Montana and California but of insufficient grade or extent to have been actively developed to date.

Anthophyllite is mined in Georgia and North Carolina. Further occurrences of this mineral and other varieties of amphibole asbestos have been found in the southern Appalachian Mountains, also in California, Oregon, Washington, Idaho, and Alaska.

Canada

By far the most important asbestos deposits of the North American Continent are in the southern part of the Province of Quebec, Canada, in the area known as the Eastern Townships. Here, chrysotile of good quality has been produced for nearly three quarters of a century and there are known and indicated reserves sufficient for many more years at the present rate of exhaustion. There are two main deposits, one near Danville and the second some 40 miles to the northeast in the Thetford mines, Black Lake, area. On the fringes of these main centers are producing mines at Nicolet, near Danville, and at East Broughton, a further 20 miles northeast of Thetford mines.

Elsewhere in Canada, notably in northern Ontario and northern Quebec, occurrences of chrysotile asbestos have been found, although, to date, no deposits of commercial importance have been developed.

Russia

Russia possesses chrysotile deposits of considerable size and economic importance. Previous to the war, the locality being most actively exploited was at Asbest, in the district of Bajenova (Bazhenova) on the eastern slope of the Urals, where reserves were reported as being very extensive. Other large asbestos-bearing serpentine areas are north of the Asbest district. In 1938, production was second only to that of Canada. Since that year, however, no statistics have been available.

Africa

Africa ranks third in the importance of known deposits. In addition to its large reserves of chrysotile, it has the distinction of being the only important producer of crocidolite and the sole producer of amosite. Chrysotile is mined in substantial tonnages in the Shabani district of Southern Rhodesia and in recent years the Havelock area, which is in Swaziland near the Transvaal border, has become an important source of supply. The more accessible deposits of the Barberton and the Carolina districts of the Transvaal have apparently been largely depleted.

Crocidolite, "Cape Blue," is actively exploited in the Union of South Africa's Cape Province, in an extensive belt in the Kuruman district that continues into the districts of Vryburg and Mafeking, this variety being the only asbestos mined in the province. Crocidolite also occurs and is mined from numerous small workings in the Pietersburg district of northeastern Transvaal.

Amosite also is found in the Pietersburg district, where in some places it is quite closely associated with the crocidolite; it occurs alone in the neighboring district of Lydenburg. These are the world's only known sources of amosite.

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Kenya and Uganda have been reported as minor producers of asbestos, presumably the anthophyllite variety of amphibole only.

China

The possible asbestos ore reserves of China may be substantial. Very little information is available except that production figures have risen since 1939 to around 20,000 tons annually. The location of the mines from which this increased production is derived has not been reported. It is known, however, that small-scale mining operations have been carried on for many years in the Laiyuan district of Hopei, where chrysotile occurs in altered limestone near the contact with an intrusive granite. Chrysotile asbestos is known to occur also in several other provinces. The problem of transportation has been a handicap to more active development.

Italy

Northern Italy, the cradle of the asbestos industry, continues to produce an important tonnage of fiber. This country has been almost the sole supplier of a good grade of tremolite asbestos, some of which has been of sufficiently high quality to have been used for spinning in the past. This fiber is mined in the vicinity of Turin in the Lanzo, Susa and Aosta valleys as well as near Sondrio, east of Lake Como. Slip-fiber chrysotile, also, is mined in the Lanzo valley, where it is recovered from a highly sheared serpentine similar to that worked at East Broughton in Canada.

France

France has continued to produce a small tonnage from a chrysotile deposit in the western Alps, and in Corsica has deposits of short-fibered chrysotile, in which there is revived interest due to the world shortage of asbestos.

Minor Production

A small production has been obtained from French Morocco and also from Egypt. Turkey has produced slightly more on the average, and is reported to have a potential source of supply in the Province of Kara in Turkish Armenia.

The production of Finland, which is several thousand tons of fiber yearly, is derived from the eastern part of the country and consists of anthophyllite.

Cyprus probably still has moderately large reserves of short-fibered chrysotile. Asbestos has been mined on the island, it is believed, since the ancient Greeks and Romans made use of long-fiber amphibole for lampwicks and cremation sheets. Amphibole deposits still exist, although modern production is entirely from the serpentine areas.

Several South American countries produce asbestos fibers in minor

quantities. In Venezuela a small plant has been constructed to exploit the chrysotile occurring in serpentinized basic rocks west of Tinaquillo. Some asbestos is also mined in Brazil. In Bolivia there is an occurrence of crocidolite from which a small production has been derived.

In Western Australia crocidolite deposits, similar in origin to those of South Africa, are in process of development in the Hamersley Range. Some production of chrysotile and anthophyllite has been reported from Western Australia, together with chrysotile from New South Wales, South Australia and Tasmania. Occurrences of the latter variety have also been recorded in Victoria and Queensland, although apparently not in commercial concentrations.

In New Zealand there has been some revived interest in the chrysotile deposits of the Flora district, Northwest Nelson.

India and Indochina produce a few hundred tons of asbestos annually. The potential reserves are doubtful, but in the Addapah district of Madras Presidency small quantities of a very fine grade of chrysotile have been mined from a narrow band occurring in dolomitic limestone, close to the contact of a dolerite sill.

The asbestos reserves of Japan apparently are quite limited. Stimulated by requirements during the war, production rose to nine thousand odd tons in 1944. The locale of production is not known. Deposits are known to exist, however, in the island of Kyushu near Nagasaki and Kumamoto and there are occurrences in Korea. The mines at Chinchow, Manchuria, were worked by a Japanese company for many years.

Asbestos occurs in a number of places in Newfoundland. In the Lewis Hills area near Port-au-Port, where good quality chrysotile has been known to exist for many years, work has been done recently but nothing of commercial importance has been developed.

POLITICAL AND COMMERCIAL CONTROL

From the foregoing, it is apparent that all the known major asbestos deposits, except those of Russia, are in countries of the British Empire. English capital controls the majority of Rhodesian and South African mines, also one important property in Canada. Several of the Canadian properties, including the largest single producer, are controlled by United States companies while Canadian capital has controlling interest in others. Russian mines, of course, are exclusively state-owned.

PRODUCTION AND CONSUMPTION

The demand for asbestos in recent years has greatly exceeded supply. This situation is world-wide and few, if any, industrial nations have been able to procure sufficient fiber to satisfy the requirements of manufacturers using asbestos in their products. Production of the

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raw material by the mines, particularly in Canada, has increased steadily over the past three years and is continuing to increase. Much of the added output has been in the shorter grades, however, and has not been of much real assistance to the manufacturer of asbestos cement products using so-called shingle-fiber grades.

Countries in which manufacturing had been curtailed during the war years are again in the market. In the meantime, the consumption of asbestos in the United States, where peak figures were reached in the period from 1941 to 1943, has continued to increase, so that in 1946 the amount used was nearly double the 1938–1940 average and was still greater in 1947. Previous to World War II, the United States consumed about one half of the world's production.

In 1946 Canadian mines accounted for over half a million tons of the raw product, representing about 77 pct of the world's total from all sources outside of Russia.* When statistics for 1947 are complete, undoubtedly they will show this figure to have risen to approximately 80 pct. Of this, 83 pct by weight in 1946 was exported to the United States, which constituted over 94 pct of the asbestos imported by this country in that year. Domestic sources supplied the United States with less than 3 pct of its total requirements.

Statistics indicate that Africa, the only other major producer aside from Russia, had 14.9 pct of the world's total in 1946 (Russia again excluded) comprised of 8.3 pct from Rhodesia, 3.7 pct from Swaziland and 2.9 pct from the Union of South Africa.

The accompanying graphs (Figs 1 and 2) show asbestos production from Canada, Rhodesia and the Union of South Africa for the years 1936 to 1947 in short tons and Canadian dollars respectively.

Canada consumes a very small but growing percentage of its production. The other principal consuming countries, aside from the United States, are: Great Britain, Russia, Belgium, France, Italy, South American countries collectively, Australia and Mexico. Consumption in the three last named has expanded considerably in recent years. Germany and Japan, which were large users of asbestos before the war, have received little or no asbestos in recent years.

PROSPECTING AND EVALUATION

Chrysotile asbestos, as described earlier, is a form of serpentine and occurs in association with this mineral. All of the extensive and more important deposits of this variety are found in large bodies of serpentinized olivine-rich ultrabasic igneous rocks, such as dunite and peridotite. Outcrops of these rocks usually are recognizable by the yellowish or reddish brown appearance of their weathered surface, although

* The latest figures on production of asbestos in Russia is 86,000 metric tons in 1938. This represented 19 pct of the world's total at that time.

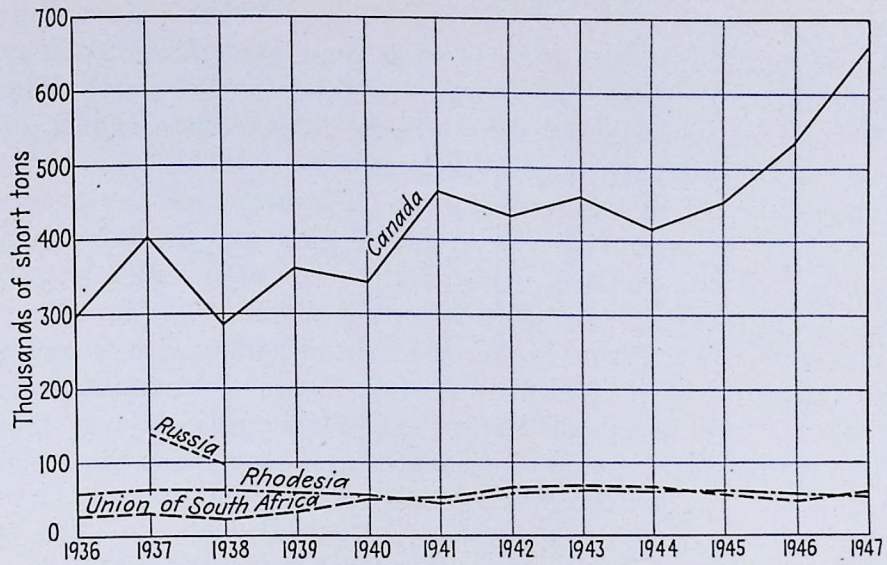


FIG 1—PRODUCTION OF ASBESTOS IN CANADA, RHODESIA, RUSSIA, AND UNION OF SOUTH AFRICA.

Canadian figures do not include sand and gravel. South Africa figures include Swaziland from 1939.

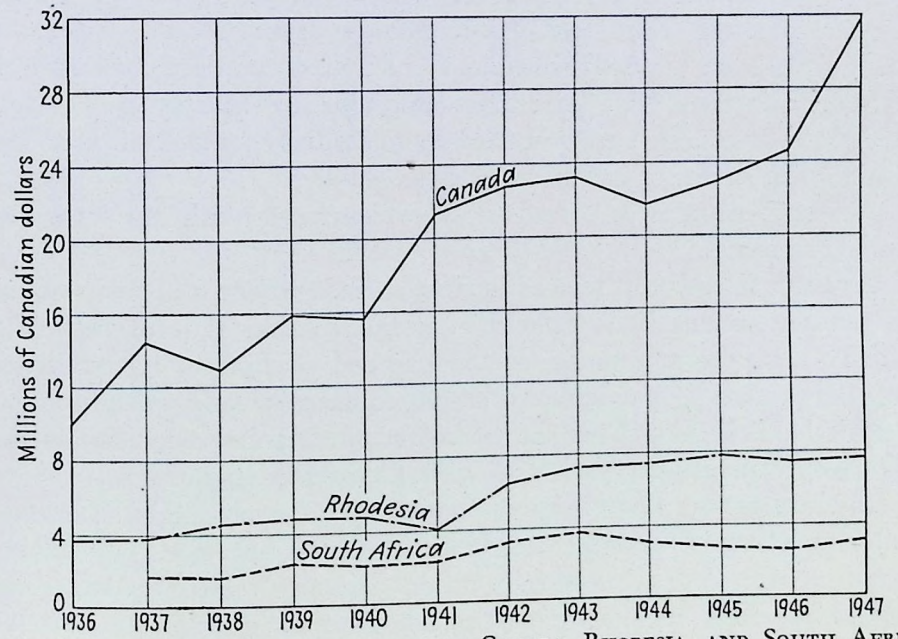


FIG 2—VALUE OF ASBESTOS PRODUCTION IN CANADA, RHODESIA, AND SOUTH AFRICA.

South African figures based on domestic and export sales.

Rhodesia: figure of $4.33 per pound used for conversion of pounds sterling to Canadian dollars.

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where less weathered or of lower iron content, the color may be greenish or of lighter shades. Associated rocks generally found intruding the serpentinized ultrabasics are granite or other acidic phases such as aplite, alaskite, or feldspar porphyry in the form of dikes or sills. High-grade deposits often are found quite close to these intrusives.

Chrysotile is found in serpentinized dolomitic limestone, as in Arizona, where the association is with diabase sills, and the veins, instead of being disseminated throughout great masses of the rock, generally occur in relatively narrow bands following the bedding. Another type of occurrence in dolomite is that where the veins are arranged concentrically in a band of serpentine surrounding a spheroidal core of serpentine, much as the shell of an egg. This type is of very limited economic importance but is of academic interest at least. Examples of the spheroid type are common in the Grenville limestone east of Ottawa, Canada, and in the Flora district, northwest Nelson, New Zealand. A somewhat similar occurrence, also to be found in the last named district and in the Lewis Hills of Newfoundland, is where asbestos veins form a peripheral zone surrounding lenses of gabbro or boulder-shaped differentiates in serpentinized peridotite.

Crocidolite, the blue variety of asbestos as found mainly in Cape Province and the Transvaal, South Africa, occurs as cross-fiber veins in highly folded banded ironstone, which may be described as a ferruginous quartzite. The productive horizons are mainly in the lower part of the ironstone series not far from underlying dolomite or lying close to thin sheets of intrusive dolerite.

Amosite asbestos is found closely associated with the crocidolite in the Transvaal.

Asbestos is resistant to weathering, so that where a deposit outcrops the prospector has little difficulty in recognizing it, and may make a fairly accurate evaluation of the exposed portion by visual inspection. Serpentine is particularly stable chemically and, although relatively soft, is likely therefore to be found forming the intermediate features of topography such as low knolls or less rugged hills.

In addition to a knowledge of the actual host rock of asbestos, those exploring for new deposits would be well advised to direct their attention to the rocks commonly found associated with existing commercial deposits, as, for instance, the granites and aplites, such as those of the Thetford district of Canada or the Shabani district in Rhodesia.

Asbestos fiber that has been removed from its host rock by natural processes of weathering and erosion may be found intermixed in clay or other overburden, or in the talus of a steep hillside, and thus assist in the discovery of a deposit. Boulders in which the asbestos veins are still intact may be traced in stream beds and serve to guide the searcher.

In some cases the use of magnetometer observations may be of assistance in exploration for asbestos, but this method has been little used. Where the initial examination of outcrops indicated favorable conditions, further exploration is generally conducted by conventional methods of stripping, trenching, diamond drilling and test pits.

In diamond drilling, the larger diameter cores are favored for better recovery. Normally, however, the diameter need not be larger than the $1\frac{1}{8}$ in. Good core recovery is difficult where intense shearing is encountered but the better grade portions of a deposit, where the more valuable cross-fiber veins are found, are generally sufficiently solid for good recovery. The usual practice is to evaluate the diamond-drill cores visually. A reasonably accurate estimate of the percentage of fiber content can be made mathematically by taking the sum of vein widths over measured lengths of core. In addition to this, the unit value of the fiber itself per ton will depend on its quality and length. It is necessary therefore to assess the quality and grade and arrive at an estimated value of the average grade that would be expected to be recovered. The latter value, in terms of per ton of fiber, multiplied by the percentage content will give the value per ton of ore.

An engineer making an evaluation would normally have at least part of the core treated in a laboratory equipped to separate fiber from the rock, and would determine the grade of the fiber by standard testing methods for asbestos. The results thus obtained can be used as a guide but care must be taken to make due allowance for the general attitude of the veins intersected: a section of core containing a vein running lengthwise could obviously give very misleading results.

For more accurate evaluation it is necessary to take large representative bulk samples and have these treated in a commercial asbestos mill or pilot plant.

MINING METHODS

To date, by far the greatest proportion of asbestos ore has been extracted by opencast mining methods. Obviously, however, some deposits are worked more economically by underground systems even in the initial stages. Some of the older mines, where open-pit operations have been continuous for many years, are now changing over to underground systems as greater depths are reached.

Several of the larger Canadian mines are classic examples of the varied methods used; having progressed stage by stage from simple open quarries with boom or overhead cableway derricks, where boxes or skips were loaded by hand, to mechanized loading on a larger scale by power shovels into cars or trucks, with equipment ranging up to 6-yd and 8-yd shovels and standard-gauge railway cars, although the largest equipment mentioned is the exception rather than the rule.

Other means have been, and are being, used to suit special condi-

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tions. Glory-hole mining has been quite successfully employed in Canada although better suited for milder climates where snow and ice do not block the draw points in winter operations. Shrinkage and sub-level stoping systems have been discarded for more economical methods in mining some of the larger ore bodies, although satisfactory in particular cases. Deposits such as the flat-lying beds of Arizona, which outcrop on steep canyon sides, must be worked from adits with extraction by room-and-pillar or longwall methods.

In some of the larger Canadian deposits where open-pit mining has been pursued to the economic limit, a system of block caving has been very successful. By this method development is carried to a considerable depth below the surface and large blocks of ore are extracted with a minimum of drilling and blasting, by undercutting and allowing the ore to cave and crush from its own weight. Space does not permit a detailed description but the accompanying drawing (Fig 3) shows the development of a typical block with grizzly drifts and raises, through which the broken ore is drawn into chute raises and thus into cars that are hauled to a shaft. As caving proceeds it breaks through eventually to the surface and then, as the plug of broken ore descends, backfill of mill tailings is brought in by conveyor and the hole is kept filled to minimize subsidence of the walls (Fig 4). No pillars are left between blocks but the practice is to allow the backfill of a worked-out block to consolidate before caving is started in an adjacent one.

At one mine, which is currently being prepared for block caving, the grizzlies are being supplanted by scram drifts and raises for use with scrapers.

In asbestos mining, steel and concrete are generally used instead of timber where support of the workings is required, and all forms of wood are kept out of the mine as far as possible, the reason for this being that wood splinters are difficult to separate from asbestos fiber when once admixed with the rock. Better practice, therefore, is to keep it out.

PREPARATION FOR MARKET

In the early days of the asbestos-mining industry, production was mainly by hand methods, in which the veins of longer fiber only were selected and cobbed to remove adhering gangue. The grades thus prepared for market were called crudes and, in fact, the designation is still used for the small proportion that continues to be produced in this way. As uses developed for other than the longest fibers, mills were built in which the ore was crushed to free the smaller veins from the enclosing rock, and the fiber was separated by screening and other means. As markets continued to expand and new uses were progressively found for shorter grades of fiber, mills grew in size, so that at present there are a number with capacities of from 2000 to 4000 tons per day, and

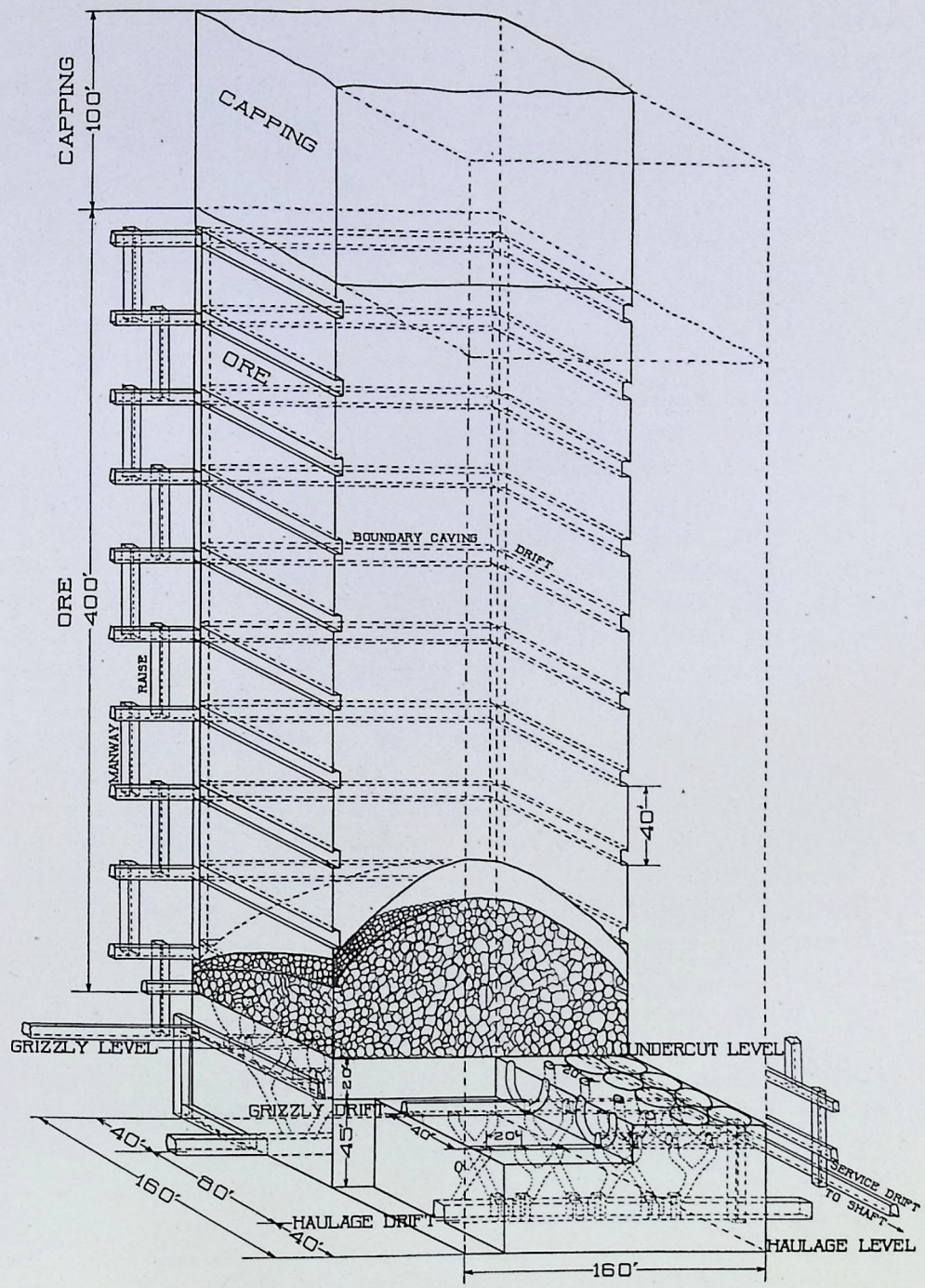


FIG 3—DEVELOPMENT OF A TYPICAL BLOCK OF ASBESTOS FOR CAVING.

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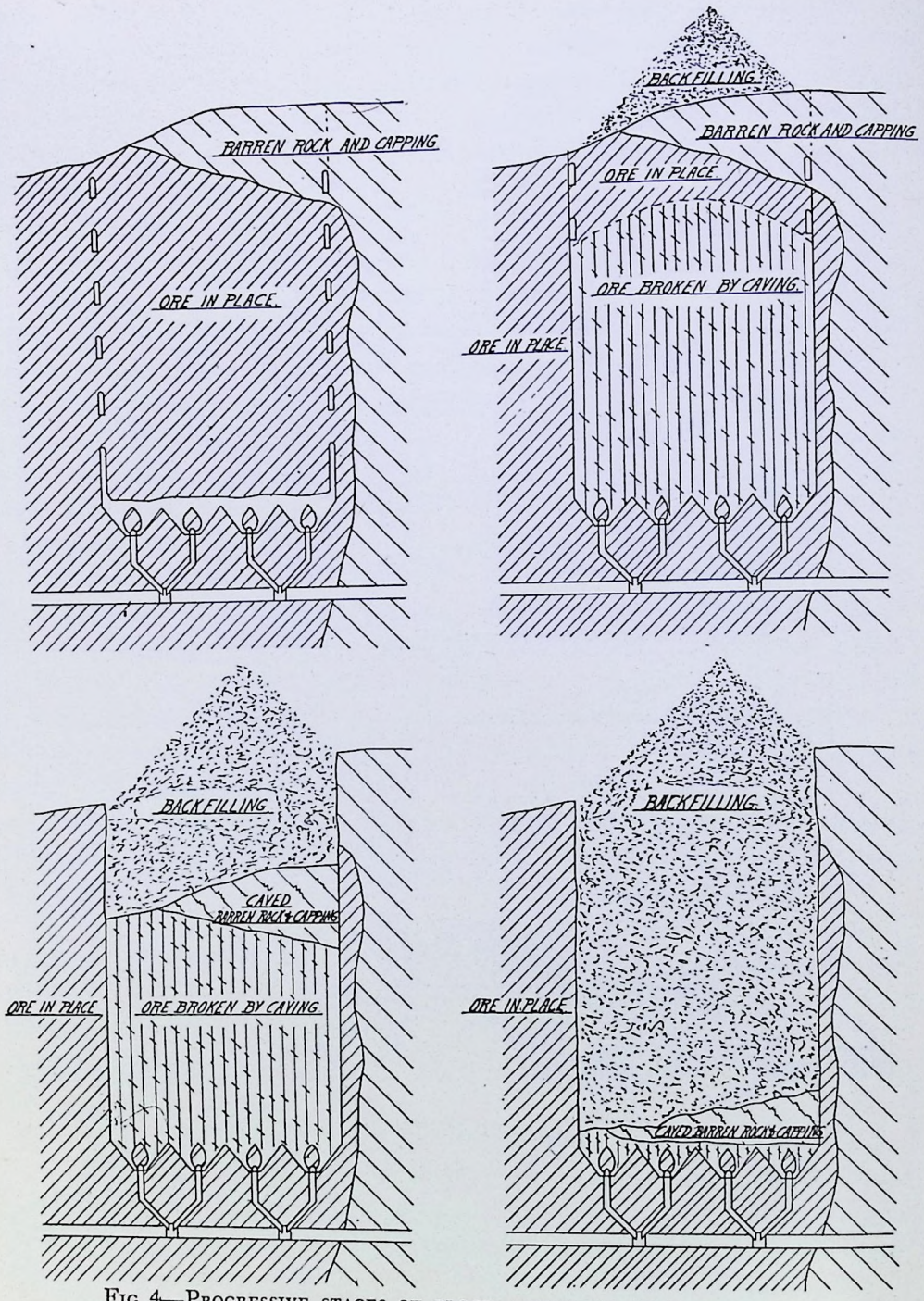


FIG 4—PROGRESSIVE STAGES OF BLOCK CAVING IN MINING ASBESTOS.

one operation has a single mill capable of treating 10,000 tons of ore daily.

Asbestos fibers are strong and tough, and can be separated comparatively easily from the rock or gangue by a crushing action, which causes the more brittle material to shatter and leave the fibers free. Their removal from the accompanying barren material can then be

effected by currents of air or water. All existing mills operate on a dry process in which the separation is largely by air suction. The usual application of this principle is by means of hoods, in effect very much like oversized vacuum cleaners, installed over the lower end of shaking screens: the screen removes fine sand and dust and the suction lifts the fiber away from the crushed rock.

While, as stated, asbestos fiber is strong and tough, the action of crushing and, to a greater extent, grinding, does to some degree cut and otherwise damage the filaments. For this reason it is the aim of operators to select milling equipment that will effect the necessary reduction with the least amount of abrasive action, within the economic limits for the particular ore being treated. The trend in asbestos milling is toward the use of machines giving more positive particle-size reduction by straight crushing action in the primary and secondary stages of milling, and moving the fiberizers—the machines that fluff or "open" the small bundles of fibers—farther along in the flow where mainly the very short grades only, and those more difficult to "open," are affected. Because of this, fewer hammer crushers, cyclone mills and disintegrators are being used, and more of the work is done with cone crushers or other types of modified gyratories. One comparatively recent installation in South Africa employs pan crushers, which work on the principle of a chaser, with good results. At one time rolls were in great favor because of their almost ideal action in releasing fiber with minimum damage. Low capacity and high maintenance cost, however, has relegated these machines to a minor role, such as the preparation of some grades of crude.

In the accompanying flowsheet (Fig 5), an attempt has been made to give a generalized representation of present Canadian milling practice in a somewhat simplified and abbreviated form.

Milling Machines

No detailed description of the equipment used in asbestos milling will be given herein but it may be of interest to note certain features and to describe briefly some of the machines peculiar to the industry.

Primary jaw crushers are generally 36 by 42 in. in size but some operations are using 48 by 60-in. machines requiring 200 to 250 hp and with a capacity of 250 tons per hour on average ore. For the most part, they are of standard design, although it is preferable to have a smaller angle of nip than usually is possible with a standard frame and, at the same time, retain full size of opening. It is considered that the nip angle should be 21° to 23°. Most manufacturers of jaw crushers build machines with a special deep frame to attain this smaller angle between the fixed and the swinging jaw. The desirability of this feature arises from the fact that often there is a tendency for pieces

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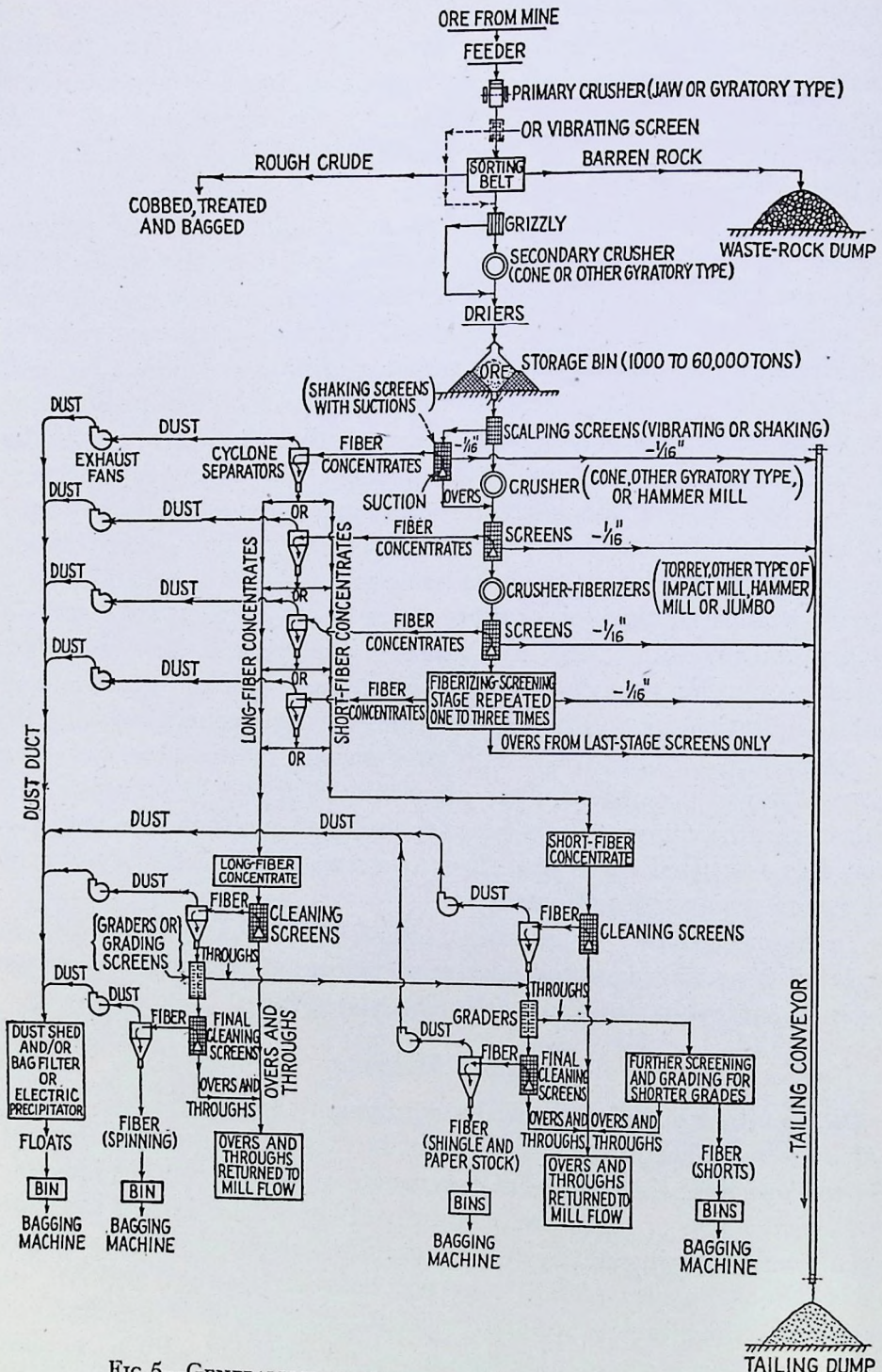


FIG 5—GENERALIZED FLOWSHEET OF CANADIAN ASBESTOS MILL.

of serpentine ore to slip as the crusher jaws apply pressure, resulting in a jumping action by the rock and therefore decreased efficiency.

Driers may be either the conventional rotary kiln type or the vertical stack. The former is of standard design, consisting of a rotating cylinder 40 to 60 ft long by 4 to 6 ft in diameter. The drier may be installed so that the hot furnace gases pass out along the outer shell before returning through the cylinder itself where they are in contact with the ore. For increased efficiency and to lessen the tube-mill action of the larger pieces of ore on the fiber-bearing fines, the drier cylinders sometimes are divided into segments, or smaller cylinders or tubes are built within the main shell, so that the ore and gases are confined to spaces of smaller cross-sectional area, in which there is a better mingling of the two as well as less grinding action on the fiber.

The vertical drier consists of a square stack, generally 7 by 7 ft in cross section by 50 ft high. Ore is introduced at the top and falls through a rising current of heated air together with the gases of combustion from a coal-fired furnace. It is retarded and dispersed in its fall by a gridwork of cast-iron bars throughout most of the height of the stack, requiring about 20 sec to reach the discharge chute at the bottom. Forced draft is introduced under the furnace grates and the gases are drawn from the top of the drier by an induced-draft fan through a cyclone collector, where a small amount of dried fiber and dust is caught, before exhausting into a smokestack.

Storage bins to which the dried ore is conveyed, in addition to serving the normal purpose of a uniform supply of mill feed, allow time for the ore to cool and to lose up to one per cent of the remaining moisture. The bins often are made by depositing two high parallel ridges of mill tailings and constructing a reinforced-concrete tunnel with draw points in the valley between the ridges. The angle of repose of the tailings forms the bin bottom; a steel-frame structure covered with corrugated asbestos provides cover.

Screens, so widely used in an asbestos mill, serve a dual purpose—the normal one of sizing and secondly as planes from which the fiber can be lifted away from the rock by aspiration. For the latter reason a shaking action is preferable to a vibrating action, as it permits the fiber to bed above the rock and to be more effectively separated. Screens usually are constructed in the mine shops. They are made with wooden frames, reinforced where necessary with steel, and actuated by roller-bearing eccentric, although where a long stroke at slow speed is desired ordinary bearings and even a crank-type eccentric may be used. In size they are generally either 4 or 5 ft in width by 11 ft or more in length. The support usually is by pieces of hardwood shaped to allow the necessary degree of flexibility. Screens often are arranged in pairs, back to back, with one eccentric shaft serving both.

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Suction hoods are made with an opening of from 2 to 5 in. and are sufficiently long to extend across the full width of the screen. They are suspended above the lower end of the latter and are adjustable as to height. The tapered upper section of the hood converges into an air duct, commonly 15 in. in diameter, which conveys the air to a cyclone collector where the fiber is dropped, and thus through the exhauster fan. One fan may serve a number of suctions, approximately 15 hp being required for each 15-in. pipe and suction.

DUST COLLECTION

As a considerable amount of dust escapes collection, the air discharged from the fans is conducted usually to a settling chamber, often constructed in the form of a large shed in which there are burlap baffles to assist in the removal of the dust, before the air is exhausted to the atmosphere. These so-called dust sheds, however, are insufficiently effective and in the more populated areas are being supplemented by more positive means of filtration or precipitation. A system of electrical precipitation has proved quite efficient at one large plant but others have favored the use of bag filters. The latter are built in units in which there are commonly 144 to 224 fabric tubes 8 to 10 in. in diameter by 18 ft or more in length per unit. Air is introduced into the tubes from below and filters through the fabric, depositing the dust on the inside surface. Multiple units are built, so that the air supply can be diverted periodically by a timed mechanism and, at the same time, the bags or tubes are shaken mechanically to dislodge the layer of accumulated dust. Accepted practice is to have sufficient fabric area so that not more than 4 to 5 cfm of free air is being filtered per square foot of fabric. For this reason a mill treating 3000 to 4000 tons per day and exhausting some 500,000 cfm of free air requires an extensive filter installation.

CRUSHING AND GRADING

Several other machines are named in the flowsheet (Fig 5), which are little used except in asbestos milling and therefore should have some further mention.

The Torrey cyclone is a machine in which ore previously crushed to 2 in. or less is further reduced by impact. The machine consists of a vertical cylindrical shell 54 in. in diameter by 5 ft high, enclosing a central upright shaft. Ore, fed on the top, falls onto a circular table or "spider" bolted around the shaft and in turn supporting four radiating vanes of manganese steel. Since the whole assembly is revolving at high speed, the material is thrown outward by centrifugal force and is caused to impinge against heavy grooved castings. As the ore falls, it is caught in a conical hopper, which, in turn, guides it to a lower spider

and vane assembly on the same shaft, for a second stage of crushing by impact in the same way.

The Jumbo has a horizontal cylindrical body 3 ft in diameter by 6 ft long. The inside periphery is lined throughout with serrated chilled iron castings. A central horizontal shaft supports a number of arms with heavy detachable wearing tips cast with a beveled face on one side. The feed entering the upper part at one end is subjected to a rubbing and grinding action, as it is moved the length of the machine by the propeller-like action of the beveled tips, and it is discharged through an opening in the bottom at the opposite end.

Graders may be either conventional trommels, or, as the name is generally applied, a modification of this machine in which the cylinder of perforated plate remains stationary and the material (fiber in this case) is moved from one end to the other by arms, clamped to a revolving central shaft and twisted to give the necessary forward pitch. In size these generally are about 7 ft long by 26 in. inside diameter.

TESTS AND SPECIFICATIONS

Canadian asbestos fibers are graded within definite limits and production is controlled by means of the Quebec Standard Testing Machine, which has become the accepted measure of fiber length by which milled asbestos is sold. All grades except crudes, sand and gravels, are controlled by this standard. The machine consists of a nest of four rectangular cast-aluminum boxes clamped onto a table that is shaken by an eccentric. The bottom box serves as a pan and the three superimposed sieves have screens of successively larger meshes. From the top, down, the mesh sizes are: $\frac{1}{2}$-in. opening, 4-mesh and 10-mesh. All screens and dimensions are to exacting specifications.

To make a test, 16 oz of asbestos is placed on the uppermost tray, which is then covered and tightly clamped. The machine is started and allowed to run at 328 rpm for exactly 600 revolutions, when it is stopped by an automatic device. At the end of this time, the asbestos remaining on each sieve is weighed and the test is recorded to the nearest tenth of an ounce.

The Canadian classification of chrysotile asbestos specifies the minimum shipping test for each grade; i.e., the minimum number of ounces of fiber there shall be on each of the upper screens and the maximum there shall be in the pan. For conveniences of designation, fibers have been divided into numbered groups and each group has been subdivided into grades, identified by letters of the alphabet. Space does not permit an itemization of all the recognized grades but, by way of explanation, in the following list of groups there are a number of grades, each with its minimum guaranteed test, under each group heading. In group No. 3, for example, there are five grades, the longest of which

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is 3F with a guaranteed test of 7-7-1½-½ (i.e., ounces on screens of ½-in., 4-mesh, 10-mesh, and pan, respectively, the whole adding up to 16 oz). The shortest grade in this group is 3Z with a test of 0-8-6-2.

Group No. 1. Crude No. 1 (¾-in. staple and longer).
Group No. 2. Crude No. 2 (⅜-in. staple up to ¾-in.).
Group No. 3. Textile and spinning fibers (testing 0-8-6-2 and over).
Group No. 4. Shingle fibers (testing below 0-8-6-2 and including 0-1½-9½-5).
Group No. 5. Paper fibers (testing below 0-1½-9½-5 and including 0-0-10-6).
Group No. 6. Waste, stucco, or plaster fiber (testing 0-0-7-9).
Group No. 7. Refuse or shorts (testing 0-0-5-11).
Group No. 8. Sand—a mill product weighing less than 75 lb and more than 35 lb per cu ft.
Group No. 9. Gravel and stone—a mill product weighing more than 75 lb per cu ft.

MARKETING

A great part of all raw asbestos produced is from the mines and mills of companies that also manufacture asbestos products. Independent producers, meaning those that deal in the raw products only, are in the minority. For much of the output, therefore, the producer is likewise the chief consumer, and marketing is less of a problem than for many commodities. It would be misleading, however, to confine ourselves to this generalization, since, in fact, there are still substantial tonnages sold to other manufacturers by the mine-to-finished-product companies, as well as by the independent companies that produce the raw fiber only.

Agencies and representative firms handle part of the business of marketing and often act as jobbers for the distribution of small lots. With this exception, nearly all fiber is shipped direct from mine to consumer.

The asbestos as it is produced is packaged in jute or heavy paper bags containing 100 or (occasionally) 125 lb, and generally is shipped in boxcars of 30 to 50 tons.

Sales are made on the guaranteed test as previously described, which is the accepted, although empirical, method used as a measure of fiber length, prices being based largely on length. In this connection there is also to be considered, however, what may be called the potential test as well as the actual test of the fiber at time of shipment. To illustrate, we might compare crude with a milled fiber, as an example. Crudes are not sold on test and if we were to determine the value of, say, a No. 2 crude by the relative amount retained on the upper sieve of a testing machine, it would fall much lower in the price scale than its actual value. The difference is that the crude is still in lumps, many of which can pass through the ½-in. screen opening. On the other hand, when this crude is received at the consumer's plant, it is further processed so that the individual fibers are pulled apart, converting the product from a collection of lumps to a fluffy fibrous mass, which would then virtually

all remain on the top box of the testing machine. Now this same principle may be applied to a lesser degree in comparing mill fibers, since these may be in some cases recovered under conditions that will leave the fibers in a relatively less "opened" or "harsher" state. The classification and test under which two grades of asbestos are sold may therefore be identical but one may contain more pieces of "crudy" fiber. The result is that when the fiber in the less opened state is received at a consumer's plant, it can be further processed and, in the final state of preparation, it will be equal in test to that of a higher grade. Because of this "potential," the more "crudy" fiber may therefore command a price premium above the average mill fiber of that grade. At some mines it is practical to produce fibers in this way, particularly the shingle grades. European users generally prefer these more "crudy" fibers, partly because of the lesser bulk and consequent saving in ocean freight. Consumers in the United States, on the other hand, generally prefer grades that are ready to use with a minimum of handling and preparation at their plants.

USES OF ASBESTOS

There are many characteristics, of course, which affect the usefulness and value of asbestos. In the longer grades for spinning purposes, the fine, silky chrysotile fibers of high tensile strength are most in demand, while coarser, more brittle fibers may have but a limited use. Even what is generally considered high-quality chrysotile from serpentine deposits is not entirely suitable for insulation of electric equipment because of a small percentage of adhering magnetic iron oxide, and, for this reason, chrysotile occurring in dolomite, such as the Arizona fibers, is more suitable for this purpose. Some grades of tremolite and other amphibole fibers are particularly suited for filters and similar applications where a high degree of resistance to acid is required. In the short grades of chrysotile, when these are for compounding with oils or resins, the relative ability to absorb oils, and the wet bulk, are often characteristics examined by the plant chemist.

The uses for asbestos are many and diverse and space will not permit enumeration except of a summary nature. Much of the longer fiber is spun into yarn for the weaving of cloth, brake lining and other articles. Some is also used for special packings, gaskets, and insulating materials. The building trades, led by asbestos cement products, consume by far the greatest tonnages. Fibers of medium length, to the extent of 15 pct or more by weight, are mixed with portland cement to manufacture shingles, corrugated and flat sheets, and pipe. To this may be added asphalt asbestos shingles and siding, which generally are made with a somewhat shorter fiber than the cement products. Further,

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asphalt asbestos floor tiles, in which large quantities of short fibers are now being absorbed, may be included.

In the automobile industry, clutch facings and brake linings account for large quantities of the medium length and shorter fibers as well as the smaller percentage used for the woven linings. Other important uses are for gaskets, packings and asbestos paper.

In the insulating field, much paper-stock asbestos goes into air-cell steam-line insulation, while in 85 pct magnesia block insulation approximately 15 pct of a longer grade of fiber is mixed with magnesia and molded and cut to required shapes. A type of sprayed insulation, which was used in ships during the second World War, is finding new application for acoustic insulation.

The war developed a tremendous demand for high-grade spinning fibers for use in ship, tank, and aircraft construction, and markets for these were under close government control. Special compounds in which asbestos was incorporated were developed for waterproofing vehicles taking part in beach landings and crocidolite fiber was required for gas-mask filters.

With the progress of industry, more short-fiber asbestos is being used than ever before. Much is compounded with various synthetic resins in the manufacture of molded articles, also with asphalts and oils for cements, tiles, and linoleum; with plastics, paints, and greases.

In recent years, the glass industry has made progress in the production of fiber-glass and the manufacture of attractive fabrics from this synthetic fiber. Blended with asbestos, fiber-glass is finding application for insulation of electrical equipment. Mineral and slag wool has become a useful commodity, which is widely used as space insulation in the building trades and in other industries, where it is particularly suited because of its nonhygroscopic nature. These products, and some of the vegetable fibers and wood flour, may be thought of as asbestos substitutes, but, in fact, they are for the most part simply substances for which somewhat similar uses are found, and each has its place and usefulness.

PRICES

Prices of the numerous grades of fiber cover a very wide range. At the first of this year (1948) floats and other very short grades were selling at $27 or less per ton; cement stocks from $31 to $46; paper stock at $70 to $80. Shingle fibers range between $100 and $130 and spinning grades are generally between $200 and $300 a ton.

Canadian crude prices for the past 10 years have remained relatively stable; No. 1 crude, for example, from 1938 through 1945 was $700 per ton in Canadian dollars, although having risen to $800 in 1946.

On the whole, prices for asbestos fiber maintained a gradual increase throughout the period 1936–1946. During the war years, Canadian asbestos was placed under federal price control and from 1942 through 1945 prices were frozen. It was inevitable that, in the face of greatly increased costs, the Canadian producers were forced to raise prices in 1946 and again in 1947. Meanwhile prices for African asbestos have also risen.

The graph of Fig 6 shows average values based on annual sales for Canadian No. 1 crude, spinning and shingle fibers according to statistics published by the Quebec Bureau of Mines. The price range of Rhodesian No. 1 is estimated from available data.

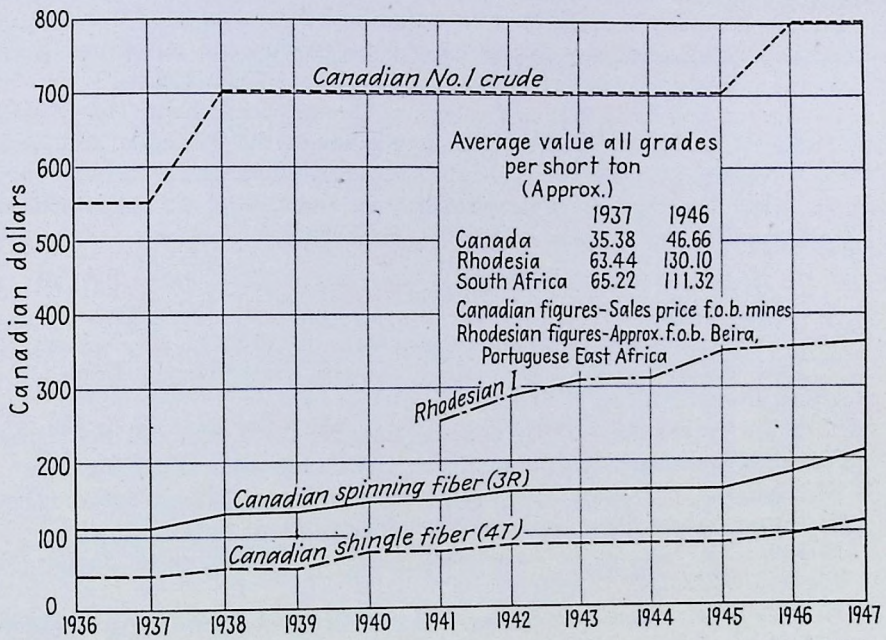


FIG 6—YEARLY AVERAGE VALUE PER TON OF VARIOUS GRADES OF ASBESTOS FIBER, IN CANADIAN DOLLARS.

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