Asbestos Fiber

compliments of D. Wolochow

INDUSTRIAL MINERALS SECTION

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Asbestos and its Utilization

By David Wolochow*

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FORTY years ago, at one of the earliest meetings of the Institute, it was stated (1): "The production of asbestos is now a firmly established industry and large quantities of fibre were extracted in the Thetford and Danville districts". Today, with an approximate 25-fold increase in production, it can indeed be said that asbestos fibre production is not only "firmly established" in Canada, but that it has become a very important unit of the mining industry of this country. It has, in fact, the highest value among the non-metallic minerals (excluding coal).

This alone would perhaps justify the frequent references (2, 3, 4) to asbestos found in the *Transactions* of the Institute, but there are other reasons why this mineral deserves attention. Some have described it as "the most wonderful non-metallic mineral", as "the most important non-metallic mineral", and as "an absolute necessity in our modern life". Though these appellations may have been applied to asbestos by enthusiasts, there is no doubt whatsoever that its value, especially in the control of heat and motion, is being increasingly recognized and its products are, as a result, constantly receiving wider industrial application.

Varieties of Asbestos

Before discussing in detail the utilization of asbestos, and where and how it is obtained, it is necessary to point out that 'asbestos' is a general term that is now applied to the following fibrous minerals:

I. Serpentine Group.—Hydrated magnesium silicate, $3MgO.2SiO_2.2H_2O$, characterized by high magnesia and water content.

(1) **Chrysotile**.......Fine silky fibres, mostly white.

(2) **Picrolite**........Coarse, harsh fibres.

II. Rhombic Amphiboles.—Silicate of magnesium and iron with the general composition $(Mg,Fe)O.SiO_2$.

(1) **Anthophyllite**

(2) **Amosite**.........High iron content with variable amounts of aluminium, magnesium, and calcium. Sodium may or may not be present. Yellow to light brown.

* Chemist in charge of Asbestos Research, National Research Labo[ratories]...

(1) Numbers in parentheses refer to references at end of paper.

III. MONOCLINIC AMPHIBOLES:

(1) **Tremolite**......Silicate of calcium and magnesium, $CaO.3MgO.4SiO_2$.

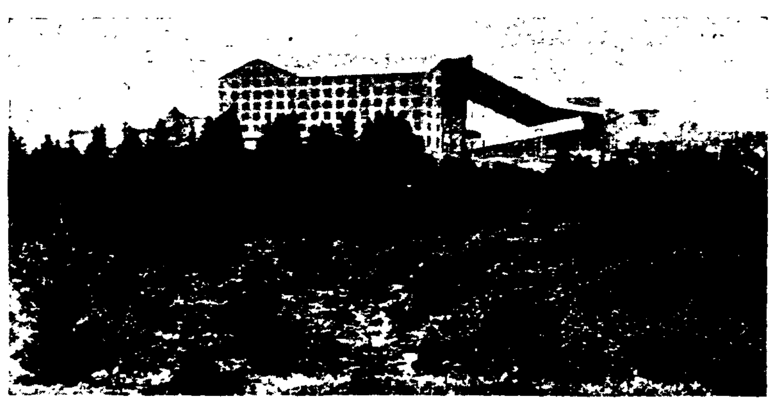
(2) **Actinolite**......Silicate of calcium, magnesium, and iron, $CaO.3(Mg,Fe)O.4SiO_2$.

(3) **Crocidolite**.....Silicate of iron and sodium, $(NaFe''')O_2.2SiO_2.Fe''O.SiO_2$. Sodium is always present. Blue colour.

ORIGIN AND MODE OF OCCURRENCE

The mineralogy of these varieties of asbestos, their origin, mode of occurrence, and geographical distribution, as well as the geology of the deposits in which they occur, have been the subject of several books (5) and of numerous papers (2, 3, 4, 6), and will be dealt with only briefly here.

Chrysotile, industrially the most important member of the asbestos family, usually occurs in massive serpentine, of which it is a crystalline fibrous form, but it is also found associated with serpentinized carbonate rocks. The origin of the serpentine and the formation of the chrysotile veins have been discussed by numerous writers and more recently by Hess (8) and by Cooke (7). The latter has summarized the existing theories as follows (*7c*, p. 362): "Three theories have been advanced to explain the origin of asbestos veins. (1) The veins are replacements; solutions entered along a tight crack which is now the central fissure, and recrystallized the adjacent serpentine to asbestos. (2) The veins are fissure fillings; open cracks were filled with fluid which either contained the components of serpentine in solution, or obtained them by dissolving part of the wall rock, and the dissolved material eventually crystallized as asbestos. (3) Taber's theory; solutions or vapours penetrated through the pores of the wall rock, extracted serpentine, and deposited it as asbestos in tight fissures. The growth of the fibre gradually pushed the walls apart sufficiently to form the existing veins". On the basis of field evidence and other considerations, Cooke dismisses the first two hypotheses as being untenable and accepts the third, which he develops farther than did Taber.



Asbestos mill of Johnson's Company, Thetford Mines.

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Crocidolite and amosite occur only in banded ironstones (sediments) and, according to Hall (5*f*), "amphibole asbestos thus becomes the result, not only of solutions circulating in open fissures, but of recrystallization of material for the greater part already present in the ironstone, and can be described as a growth *in situ*". But after reviewing in some detail the information on the formation of asbestos fibre, available at that time (1930), the same writer concluded that: "Little has so far been achieved in laying bare the whole riddle of asbestos".

Again, it is not known precisely why asbestos fibre is found to occur in three modes of arrangement: cross-fibre, in which the fibres are oriented approximately perpendicular to the direction of the vein; slip-fibre, in which they are disposed along the vein direction; and mass fibre, in which they have no definite arrangement, but may occur in clusters, etc. The largest and most important deposits of asbestos consist entirely of cross-fibre, though there is some production from slip-fibre and mass-fibre deposits.

GEOGRAPHICAL DISTRIBUTION AND CHEMICAL COMPOSITION

Three countries, Canada, Russia, and Rhodesia, supply the bulk of the world's present demand for chrysotile asbestos, which variety constitutes about 98 per cent of all asbestos used commercially. There is some production of chrysotile in the United States (Vermont and Arizona), Cyprus, and the Transvaal, and very minor amounts are produced in a number of other countries. Amosite and crocidolite are produced only in South Africa, the latter in Cape Province, whence its trade name, *Cape Blue asbestos*. Production of other varieties (anthophyllite, actinolite, tremolite) is very limited and has come mainly from Austria, Italy, and the States of Georgia and Maryland, although occurrences of these minerals are fairly widespread.

General view of asbestos milling property, showing tailing dump, Vermont Asbestos Corporation, Eden, Vermont.

Although, as already indicated, each type of asbestos has a fairly definite formula, the chemical composition for any one variety depends somewhat on its source and, in the case of mechanically prepared fibre, on the method of preparation. Table I shows the general range of composition of the several varieties, though samples may be found that are outside the limits indicated and traces of elements other than those shown may be present.

TABLE I.—CHEMICAL COMPOSITION OF ASBESTOS

	CHRYSOTILE	AMOSITE	CROCIDOLITE	ANTHOPHYLLITE	ACTINOLITE	TREMOLITE
Silica	38–43	45–57	50–60	52–58	55–60	57–59
Alumina	0.2–3.5	0.5–9	0–2.0	0.5–2.0	1–1.5	1–5
Iron oxide	0.2–7.0	34–44	35–40	5–12	5–7	0.2–0.5
Lime	0–0.5	0–5.0	0–2.0	1–2	10–14	10–12
Magnesia	38–43	0.5–8.0	1–4	28–30	20–24	22–25
Soda	——	0–2.5	4–7	0–1.0	——	——
Water	13–16	0.5–4	1.5–5.5	1.5–2.5	1.5–5.5	0.5–1.5

MINING AND MILLING PRACTICE

The methods employed in the mining of asbestos are fully described in the literature and it need only be stated here that, in the past, open-pit or quarrying methods have been used almost exclusively, except in South Africa, where a number of underground mines have been worked. In recent years, large-scale underground mining has been undertaken in the King mine of the Asbestos Corporation of Canada, at Thetford Mines. The system of block-caving employed there has been fully described in two papers by Ross and co-workers (4 *g*, *h*). There is reason to believe that this method will in the near future be adopted by other Quebec operators.

Preparation of the fibre for the market consists in the separation of the fibre from the rock by mechanical means. These milling operations, consisting of crushing, drying, and further crushing of the rock, followed by

General view of the asbestos mine and factory operated by the Canadian Johns-Manville Company, Limited, at Asbestos.

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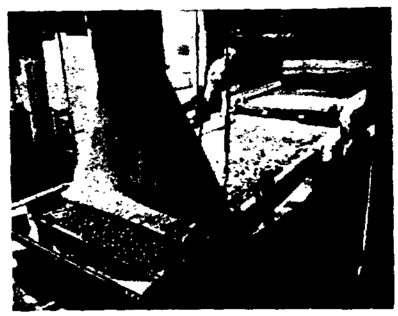
screening and air separation, have been dealt with by Larochelle (4 *d*) and earlier writers.

The value of the fibre depends largely on its length; hence, the milling practice is designed with the object of preserving the fibre length as far as possible. The grading of the milled fibre is based on fibre length as measured by a screen test, the Quebec Standard Asbestos Testing Machine (see p. 433) being practically in universal use for this purpose. A small proportion of fibre, hand-picked in the mine and from picking belts, receives a minimum of mechanical treatment, and, though known as 'crude' fibre, has the highest commercial value.

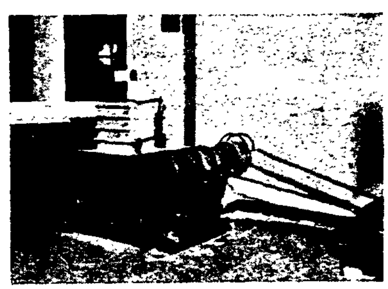
Wet methods and purification by means of acid treatment are sometimes employed in the preparation of the anthophyllite, actinolite, and tremolite varieties.

Fibre is usually classified (according to approximate length) into the following groups: crude, spinning, shingle, paper, cement, and shorts. More precise classification of the grades within each of the groups (except crude) is based on the screen test. For detailed discussion of the classification, see Dufresne and Larochelle (4 *f*).

Shovel used for loading asbestos-bearing rock into cars, which carry the rock to the mill.



Shaking screen on which the fine sand is screened out of the crushed rock and from which the loose fibre is picked up by air suction.



The Quebec Standard asbestos testing machine.

HISTORY OF ASBESTOS PRODUCTS INDUSTRY

The uses of asbestos depend to a large extent on its incombustibility, fineness of fibre, tensile strength, and resistance to deterioration. The fact that it cannot burn or decay was apparently known to the ancients (the word *asbestos*, derived from the Greek, signifying 'not to be quenched'), but whereas the earliest records indicate that asbestos textiles were used to protect the bodies and ashes of the dead and in worship of the gods, in modern times asbestos products are used to protect the living and are dedicated to the spirit of efficiency. For many centuries, however, asbestos remained little more than a curiosity—a 'mineral paradox'.

Early in the eighteenth century, chrysotile deposits were discovered in the Ural mountains, and for several decades various asbestos textile articles were made in Russia. About one hundred years later an asbestos industry was started in Italy, where asbestos, or 'amianti', had been known since the time of the Romans. Textiles, paper, packings, and heat-insulating board were made, but development was slow and commercial utilization of asbestos products, except in a small way, cannot be considered to have begun much before 1860. In that year asbestos was discovered near St. Joseph, Quebec, though it has been stated (2 *k*) that it had been known in the Eastern Townships since 1847. In 1877, the Thetford deposits were discovered, and in the following year shipments began to the outside world; and because regular production in other countries did not commence until much later, it can be truly said that the development of the Canadian deposits and the introduction by Canadian operators (in 1888) of mechanical means of preparing the fibre, laid the foundations of the modern asbestos industry, which has seen its greatest development in the United States, in the United Kingdom, and, recently, in the Soviet Union.

USES OF ASBESTOS

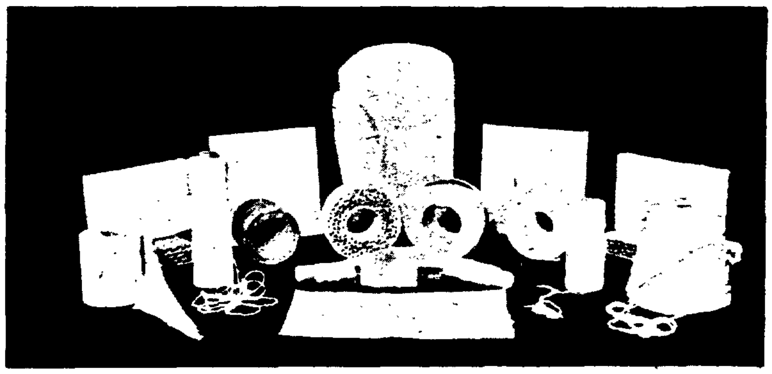
Asbestos fibre is a constituent of so many products (9, 10) that the mere enumeration of all of its uses would require several pages of text. It is used by itself in numerous products, but in very many more it is used in conjunction with other materials, such as Portland cement, metal, rubber, graphite, oil, grease, and bituminous materials. Considered broadly, asbestos products may be divided into the following five categories: textiles and textile products, building materials, heat and sound insulating materials, molded products, and miscellaneous products.

TEXTILES AND TEXTILE PRODUCTS:

Textiles were, perhaps, the first asbestos products, having been made by the ancients; but it was the advent of the steam engine and the automobile that was responsible for this large branch of the industry. The manufacture of automobile brake-linings and clutch-facings is the largest single outlet for asbestos textiles, but very appreciable quantities are used as packings, gaskets, tape, listing, and lagging. Asbestos cloth is used in making fireproof clothing—such as suits, aprons, shoes, and mitts—mail bags, theatre curtains, fire-blankets, hose, conveyor belts for carrying hot materials, laundry roll covers, and awnings. Asbestos roving and yarn are used extensively for insulating electrical conductors (13). Asbestos rope made from yarn finds considerable use, and yarn itself is used as a packing material in flexible metal hose.

Fireproof suit made from asbestos cloth.

In the manufacture of asbestos textiles, the first step is the fiberizing, opening, or fluffing of the fibre until it is as free as possible from bundles, or pencils, of fibre. Then, except when a pure (100 per cent) asbestos textile is required, a proportion of cotton is usually added to facilitate the suc-



Samples of various asbestos products.

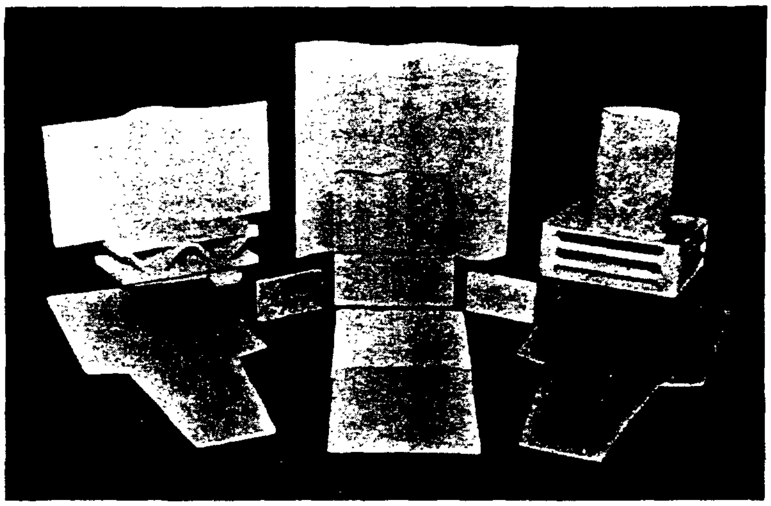
ceeding operations. Though these operations are patterned very much after those employed in the older textile trades (*e.g.*, cotton, wool), numerous problems had to be solved before the large-scale production of asbestos textiles, by means of carding, spinning, etc., became a commercial success.

In the manufacture of woven brake-linings, the asbestos yarn is usually reinforced with a fine metal wire, such as brass, lead, or zinc, and is then woven into listing of the desired width and thickness. The listing is impregnated with various friction, waterproofing, and binding compounds, and finally is baked and subjected to a number of finishing operations. All the larger manufacturers maintain laboratories and fleets of automobiles for testing their products.

The size of asbestos yarn is designated by the term 'cut', which is the number of 100-yard lengths contained in a pound. Thus '10-cut' (which is one of the most popular commercial sizes) means that one pound of the yarn contains 1,000 yards. Very fine yarns (high cut) and very thin tapes are now available. Specifications and standards for roving (the carding product without twist), yarn, and tape have been set up by the American Society for Testing Materials.

BUILDING MATERIALS:

Among fire-proof building materials, products such as shingles, corrugated and plain sheets, lumber, and wallboard, made of asbestos and Portland cement, occupy an important place, it having been stated that "rigid asbestos-cement sheets are probably better than corrugated iron, especially in their resistance to a fire outside the building" (14). Asbestos-cement roofing was first made by Hatschek, in Austria, about 1900, but the manufacture of asbestos-cement products by the original laminated or 'wet' process on what are essentially paper card-board machines, as well as by the 'dry' process, is now carried on extensively in many countries. In fact, this branch of the asbestos products industry has been the most active one during the past few years. With the development of light-weight roofing and siding of very pleasing appearance, and with attractive, permanent colours, public interest in these products has grown to such an extent that the capacity of existing plants had to be increased, and new plants built, to fill the grow-



Samples of asbestos Portland cement building products.

ing demand. Recently, a number of large companies who for years have been manufacturing other roofing and siding materials have built factories for the manufacture of asbestos-cement shingles and siding, products which have proved to be durable and economical. These building materials should be of particular interest to the mining industry.

Also made from asbestos and Portland cement are pipes for carrying water, sewage, and many industrial liquids and gases. These were first made in Italy in 1913, but, as their usefulness has been recognized, factories for making them have been erected in other countries. Made on specially designed machines and consolidated under very high pressure, the pipes are strong, light in weight, and, being resistant to most corrosive agents, are very durable.

Asbestos paper is made on machines which are essentially the same as those used in ordinary paper manufacture, except that they are operated at lower speed, and a binder is usually added. Large quantities of asbestos paper, saturated with asphalt, are used in the construction of built-up roofing, and in building construction generally.

HEAT-INSULATING MATERIALS:

Properly fabricated, asbestos paper is also an effective heat-insulating material. For this purpose, it is used as pipe covering in the form of air-cell, made by cementing together several plies of corrugated paper, or as flat sheets in walls and between floors, as well as in many other applications. The well known heat-insulator, "85 per cent magnesia," contains up to 15 per cent asbestos fibre. Also used as coverings for pipes, furnaces, tanks, boilers, etc., are other products containing asbestos, while short-fibre asbestos will greatly reduce heat losses when applied, in the form of a water paste, to a radiating surface.

Molded Products:

Among molded products, the largest quantities of asbestos are used in the manufacture of molded automobile brake-linings, which have found wide acceptance. These linings are made from a mixture of asbestos fibre and other materials, molded under pressure. Friction blocks for heavy machinery contain a large proportion of asbestos fibre. Used as a filler in articles molded from natural and synthetic resins, or in which bituminous or other materials are the binders, asbestos imparts certain desirable properties; these articles therefore find application in many fields of industry. Mastic flooring and floor-tile usually contain asbestos fibre as a filler.

Miscellaneous Products:

Of the miscellaneous uses of asbestos, only a very few will be mentioned. Asbestos paper, millboard, and lumber, as well as textiles, are used for electrical insulation (13). These materials are being increasingly employed in ship-building. Bonded to steel by means of metallic adhesives or in other ways, asbestos adds many years of service to roofing and culverts. Many sound-insulating materials contain asbestos. Asbestos fibre is sprayed on ceilings and walls for sound-insulation as well as for fire-proofing. The best means of ensuring reasonable protection against fire for woodwork that is fixed near a flame or other source of light or heat is a piece of thick asbestos millboard or asbestos-cement sheeting, so fastened to the woodwork as to leave an air space (14).

Pads made with alternate layers of lead and asbestos fibre on both sides of a galvanized-iron core and placed under machinery are very effective in preventing the transmission of vibration from the machines to the buildings in which they are housed. Added to concrete, asbestos gives a product which can be nailed. Many types of gaskets contain asbestos in the form of paper

Part of exhibit at National Research Laboratories, Ottawa, illustrating asbestos fibre production and showing asbestos products.

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and millboard. Specially selected and purified asbestos is used as a filtering medium for many fluids, especially wines and pharmaceuticals. Asbestos fibre is used in putty and caulking compounds, in paints and greases, and when added to asphalt pavement it improves the road surface. Mats, table covers, and pot holders are also made from asbestos.

Many other ways in which asbestos is used will be found described or listed in the literature. Those mentioned above will have demonstrated that asbestos fibre, because of the unique combination of properties it possesses, has won for itself a permanent place in commerce and industry.

STATISTICS OF THE ASBESTOS INDUSTRY

The statistics of the industry have to be considered from the point of view of the production of the raw material—asbestos fibre—and of the manufacture of asbestos products.

Chrysotile accounts for about 98 per cent of all the asbestos used in the world, and all but 4 per cent or so of this type of fibre comes from three countries—Canada, Russia, and Africa—as may be seen from Table II.

TABLE II.—PRODUCTION OF CHRYSOTILE ASBESTOS
(Short tons)

YEAR	CANADA	RUSSIA*	RHODESIA	S. AFRICA	CYPRUS	U.S.A.
1930	242,113	59,500	37,765	10,519	6,040	4,242
1931	164,297	71,000	24,042	9,938	4,000	3,228
1932	122,977	66,000	15,766	7,715	1,790	3,559
1933	158,367	79,000	30,182	9,572	5,150	4,745
1934	155,980	101,500	32,214	11,025	8,500	5,087
1935	210,467	105,000	42,598	15,620	8,400	8,920
1936	301,287	143,000	56,346	15,085	10,650	11,012

* Figures for Russian production are mainly estimates.

The accompanying graph shows the relative asbestos production of Canada, Russia, and Africa (including all varieties produced in Africa). The average value per ton of fibre produced is considerably higher in Africa (where the proportion of long fibre sold is greater) than in Canada, so that, on the basis of value, Canada's position is not as favourable as would appear from the graph. The value of the Russian production is not known.

The South African production of amosite and of crocidolite, or blue asbestos, is shown in Table III.

TABLE III.—PRODUCTION OF AMOSITE AND CROCIDOLITE IN SOUTH AFRICA
(Short tons)

	1930	1931	1932	1933	1934	1935	1936
Amosite	3,281	2,087	1,391	3,090	3,757	4,684	6,035
Crocidolite	5,481	3,651	2,964	3,225	2,811	2,495	3,309
Total	8,762	5,738	4,355	6,315	6,568	7,179	9,344

For the year 1936, total production of chrysotile from the sources included in Table II amounted to 537,380 short tons, and in the same year the

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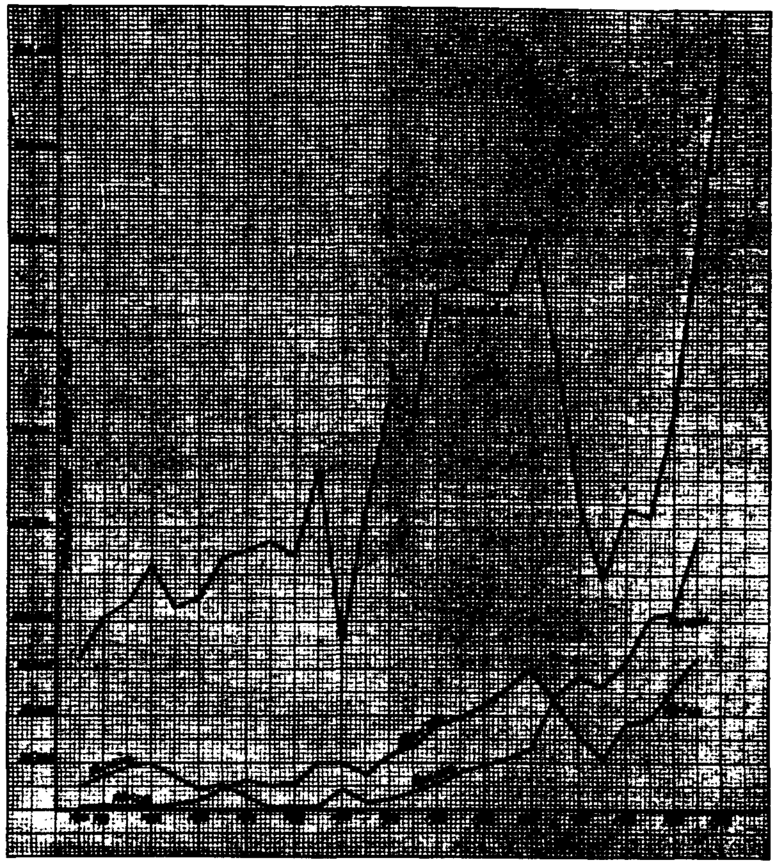

Graph showing production, in short tons, of asbestos fibre in Canada, Africa, and Russia since 1910.

South African output of amosite and crocidolite (Table III) totalled 9,344 tons, giving a combined total for 1936 of 546,724 tons. Production from other countries, or of other varieties of asbestos, would not increase this total by as much as 2 per cent.

Turning to the world consumption of asbestos, we see a very different picture, for, apart from the Soviet Union, the principal asbestos-consuming countries produce very little asbestos, or none at all. Table IV lists the nine countries leading in the use of asbestos fibre.

Table IV.—Consumption of Asbestos, 1934 (Short tons)

United States	123,000	France	11,700
Soviet Union	64,500	Italy	11,200
United Kingdom	28,250	Belgium	10,950
Japan	23,600	Canada (1936)	4,544
Germany	22,000		

The market price of asbestos fibre depends on the grade and variety. However, it is not possible to make a true comparison of the price of apparently corresponding grades from different sources, because methods and standards of grading differ in the several producing countries. As the accompanying figures show, there is a very wide price range between the best 'crude' and the lowest grade 'shorts'. Rhodesian prices are for spinning-grade fibres only:

PRICE RANGE, 1937

Canada	$550	to $ 11 per ton
Rhodesia	$210	" $180 "
Russia	$475	" $ 55 "
Vermont	$ 47.50	" $ 11 "

THE ASBESTOS INDUSTRY IN CANADA (5*g*, 11)

In 1937, according to preliminary estimates made by the Dominion Bureau of Statistics, shipments of asbestos fibre from the mills in the Eastern Townships amounted to 410,026 tons valued at $14,505,791, giving an average selling price at the mines of $35.38 per ton. Asbestos accounted for somewhat more than 3 per cent of the total value of the mineral production of the Dominion and stood seventh in value in the list of products. To produce this large quantity of fibre, about five million tons of rock had to be mined. The capital employed is estimated to be over $20,000,000 and the industry is a progressive one, improvements in mining methods and in the production of fibre being made constantly. Ore reserves are plentiful; drilling to 1,500 feet has shown that fibre, in commercial quantities, exists to that depth at least.

In 1936, there were thirteen plants in Canada engaged in the manufacture of asbestos products. These plants represented a capital investment of some two million dollars, and they produced goods valued at about one and a quarter million dollars. The principal products, with their value, were:

ASBESTOS PRODUCTS MANUFACTURED IN CANADA, 1936

Asbestos brake-linings	$392,309
Asbestos boiler and pipe coverings	162,216
Asbestos packings	113,821
All other asbestos products	257,328

In the United States, production of asbestos products in 1935 was as follows:

UNITED STATES ASBESTOS-PRODUCTS INDUSTRY, 1935

Asbestos textile products	$16,071,754
Asbestos building materials	8,152,264
Other asbestos products	34,591,406
Total	$58,815,424

Comprehensive reports on the asbestos industry are included in annual publications of the Dominion Bureau of Statistics and of the Quebec Bureau of Mines.

Asbestos Research in Canada

In 1930, at the request of the Canadian asbestos producers, an Associate Committee on Asbestos Research was organized by the National Research Council. Under the auspices of this Committee, and with the financial assistance of the producers, a programme of research on various problems of the industry has been carried on in the laboratories of the Council at Ottawa.

One of the first tasks undertaken was the standardization of the Quebec Standard Asbestos Testing Machine, used for grading and testing asbestos fibre. This machine consists of a nest of three screens and a box, or pan, resting on a table that is driven by an eccentric, thereby imparting an elliptic motion to the screens. The standardization, consisting in the elimination of numerous variables and the drawing up of precise plans and specifications for the construction and operation of the machine, has been of considerable benefit to the industry. Recently, the asbestos producers have developed an all-metal machine which is based on the same principle and should still further improve this test method.

In the testing of raw materials, the interpretation of test results is always difficult, and in the case of asbestos fibre, because of its complex physical nature, the problem is particularly complicated. This problem has received much attention and a number of tests have been developed and are being tried.

Considerable work has been done with a view to finding new uses for asbestos, especially for the lower grades and for the waste rock, which, among other things, is a potential source of magnesium metal and magnesium salts. In addition, some fundamental studies are being carried on. Microscopic investigation has shown that asbestos fibre is very probably the finest fibre in existence, a property which, when better understood, may lead to valuable new applications of this material. Knowledge of the physical nature of fibre aggregates, and thereby of the effects of milling processes on asbestos, is being definitely increased and put on a sound basis by this investigation.

Less directly, the research being carried on has been of benefit to the industry because it has fostered a spirit of co-operation and has stimulated the producers to undertake jointly the investigation of technical problems which can be best worked out by the men directly engaged in the industry. The participation of the Quebec Bureau of Mines has been of service in this direction. Finally, there are a number of problems the solution of which will require co-operation between the producers of fibre and those who utilize fibre in the manufacture of asbestos products; the research now under way should be of some help in making this co-operation possible.

References

1. Obalski, J. .... Jour. Can. Min. Inst., II, p. 64, 1899.
2. Jour. Can. Min. Inst. .... (*a*) III, 187 (1900); (*b*) IV, 7, 304 (1901); (*c*) V, 343-356 (1902); (*d*) VI, 372, 454 (1903); (*e*) VII, 167 (1904); (*f*) VIII, 269-271 (1905); (*g*) VIII, 365-367 (1905); (*h*) IX, 19, 219 (1906); (*i*) X, 106 (1907); (*j*) XI, 38, 493 (1908); (*k*) XII, 165-173 (1909); (*l*) XII, 194-204 (1909); (*m*) XII, 618-629 (1909); (*n*) XII, 646-649 (1909); (*o*) XIII, 37, 43 (1910); (*p*) XIII, 408-413 (1910); (*q*) XIII, 414-437 (1910); (*r*) XIII, 438-443 (1910); (*s*) XIV, 93-106 (1911); (*t*) XIV, 107-137 (1911); (*u*) XIV, 138-148 (1911).

3. TRANS. CAN. MIN. INST............(*a*) XV, 36 (1912); (*b*) XV, 84 (1912); (*c*) XVI, 33 (1913).

4. TRANS. CAN. INST. MIN. & MET....(*a*) XXVII, 94-98 (1924); (*b*) XXVIII, 94-97 (1925); (*c*) XXX, 432-466 (1927); (*d*) XXXI, 323-336 (1928); (*e*) XXXIII, 17 (1930); (*f*) XXXV, 224-232 (1932); (*g*) XXXVII, 184-218, 358-364 (1934); (*h*) XXXIX, 441-447 (1936).

5. (*a*) JONES, R. H..................*Asbestos, Its Properties, Occurrences, and Uses;* London, 1897.

(*b*) CIRKEL, F....................*Chrysotile Asbestos, Its Occurrences, Exploitation, Milling, and Uses;* Mines Branch, Dept. of Mines, Ottawa, 1910, 2nd Edition, 316 pp.

(*c*) DRESSER, J. A.................*Serpentine and Associated Rocks of Southern Quebec;* Memoir No. 22, Geol. Survey, Dept. of Mines, Ottawa, 1913, 103 pp.

(*d*) POITEVIN, E., and GRAHAM, R. P. D....................*Mineralogy of Black Lake Area, Quebec;* Mus. Bull. No. 27, Geol. Survey, Dept. of Mines, Ottawa, 1918, 103 pp.

(*e*) BECKER and HAAG.............*Asbestos;* Berlin, 1928, 88 pp., 60 plates.

(*f*) HALL, A. N...................*Asbestos in the Union of South Africa;* Union of South Africa Geol. Survey, Memoir No. 12, 2nd Edition, Pretoria, 1930, 324 pp.

(*g*) ROSS, J. G....................*Chrysotile Asbestos in Canada;* Mines Branch, Department of Mines, No. 707, Ottawa, 1913, 146 pp.

(*h*) BOWLES, O....................*Asbestos;* U.S. Department of Interior, Bur. of Mines, Bulletin 403, 1937, 92 pp.

(*i*) HOWLING, G. E...............*Asbestos;* Imperial Institute, 2nd Edition, 1937, 88 pp.

6. *Asbestos*...........................A list of references to material in the New York Public Library, 1929.

7. COOKE, H. C......................(*a*) Geol. Survey, Dept. of Mines, Summary Report, Part D, 1-24 (1931), 44-55 (1932), 121-138 (1933).
(*b*) Trans. Roy. Soc. Can., XXIX, 1-19 (Section IV, 1935).
(*c*) Econ. Geol., *31*, 355-376 (1936).

8. HESS, H. H.......................Econ. Geol., *28*, 634-657 (1933).

9. SUMMERS, A. L....................*Asbestos and Asbestos Industry;* Pitman & Sons, 114 pp.

10. *Asbestos*...........................A monthly magazine, published by Secretarial Service, Philadelphia.

✓11. MENDELS, M. M..................*The Asbestos Industry of Canada;* McGill University Economic Studies, No. 14, 1930, 85 pp.

12. STENBERG, T. R..................*Brake Linings;* First Edition, 1935, 91 pp.

✓13. (*a*) HUBY, C.....................*Asbestos for Electrical Purposes;* Jour. Am. Soc. Naval Engineers, 47, 543-556 (1935).

(*b*) WARREN, H..................*Electrical Insulating Materials;* Ernest Benn, Ltd., London (1931).

14. WILLIAMSON, J. J., and BUTLER, M..*Common Features of Fire Hazard;* Pitman & Sons, Ltd., London.

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