Information Circular 9036

Asbestos Availability—Market Economy Countries

A Minerals Availability Program Appraisal

By T. F. Anstett and K. E. Porter

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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The Bureau of Mines evaluated the potential availability of chrysotile, amosite, and crocidolite asbestos from 42 properties in market economy countries. This resulted in the development of tonnage-cost relationships indicating the quantity of grades 3 through 7 asbestos at various average total costs of production at 0% and 15% rates of return on invested capital. The availability of grades 2 and 8 was also evaluated, but since each is produced at only one property, no analytical results were given. Total demonstrated recoverable chrysotile fiber potentially available of grades 3 through 7 from the 42 properties evaluated follow: 1.59 million t, 21.00 million t, 16.74 million t, 15.54 million t, and 19.27 million t, respectively. The total amount of crocidolite is 1.69 million t. Owing to the good potential for discovery and development of new deposits, long-term availability of fiber of all three types is not in jeopardy. However, many of the crocidolite properties evaluated in the northern Cape crocidolite field of South Africa have relatively small demonstrated resources, and new deposits will have to be exploited by the late 1990's to sustain projected levels of production.

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PREFACE

The Bureau of Mines is assessing the worldwide availability of nonfuel critical minerals. The Bureau identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availability.

This report is part of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington, DC 20241.

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ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	t	metric ton
km	kilometer	$/t	dollar per metric ton
km^2	square kilometer	t/h	metric ton per hour
m	meter	t/yr	metric ton per year
mm	millimeter	yr	year

ASBESTOS AVAILABILITY—MARKET ECONOMY COUNTRIES

A Minerals Availability Program Appraisal

By T. F. Anstett[1] and K. E. Porter[2]

ABSTRACT

The Bureau of Mines evaluated the potential availability of chrysotile, amosite, and crocidolite asbestos from 42 properties in market economy countries. This resulted in the development of tonnage-cost relationships indicating the quantity of grades 3 through 7 asbestos at various average total costs of production at 0% and 15% rates of return on invested capital. The availability of grades 2 and 8 was also evaluated, but since each is produced at only one property, no analytical results were given.

Total demonstrated recoverable chrysotile fiber potentially available of grades 3 through 7 from the 42 properties evaluated follow: 1.59 million t, 21.00 million t, 16.74 million t, 15.54 million t, and 19.27 million t, respectively. The total amount of crocidolite is 1.69 million t.

Owing to the good potential for discovery and development of new deposits, long-term availability of fiber of all three types is not in jeopardy. However, many of the crocidolite properties evaluated in the northern Cape crocidolite field of South Africa have relatively small demonstrated resources, and new deposits will have to be exploited by the late 1990's to sustain projected levels of production.

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INTRODUCTION

The Bureau of Mines has undertaken this study assessing the availability of asbestos, a commodity that has commercial value for use in various industrial applications. This report addresses the availability of asbestos from 36 foreign and 6 domestic properties in terms of its average total cost of production over the life of each property evaluated. An outline of the procedure followed for this evaluation is shown in figure 1.

The main purpose of this study is to present an estimate of the amount of fiber of various types and grades that is potentially available from the most important producing and undeveloped properties in market economy countries. The results of this study are presented in the form of total and annual available curves, which show the amount of fiber, by grade, that could be produced from each property evaluated. The curves plot availability against average total cost of production over the estimated life of each property.

ACKNOWLEDGMENTS

Production and cost data for domestic properties analyzed in this study were developed at Bureau of Mines Field Operations Centers in Denver, CO, Juneau, AK, Spokane, WA, and Pittsburgh, PA. Production and cost data for all other properties were collected through a Bureau contract with International Mineral Services Associates, Golden, CO, under the direction of Tom Pool, project manager. Robert Clifton, Bureau of Mines commodity specialist, is also acknowledged for his assistance in the preparation of this report.

CHARACTERISTICS AND USES

Asbestos is a term applied to six naturally occurring minerals that are exploited commercially for their desirable physical properties which are in part derived from the asbestiform habit. These minerals are the serpentine mineral chrysotile and the amphibole minerals grunerite asbestos (also referred to as "amosite"), riebeckite asbestos (also referred to as "crocidolite"), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. Individual mineral particles, however processed and regardless of their mineral name, are not considered to be asbestos if the length to width ratio is less than 20 to 1.

The characteristics that render this group of minerals commercially important include their fibrous structure, tensile strength, fiber length, and resistance to high-temperature and chemical attack. Chrysotile is the most important commercially, accounting for over 95% of world consumption (*1*, p. 55).[3] Only chrysotile, crocidolite, and amosite have any significant commercial importance.

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 includes the shorter lengths of these varieties and all lengths of amosite. For some uses, fiber

[3] Italized numbers in parentheses refer to items in the list of references at the end of this report.

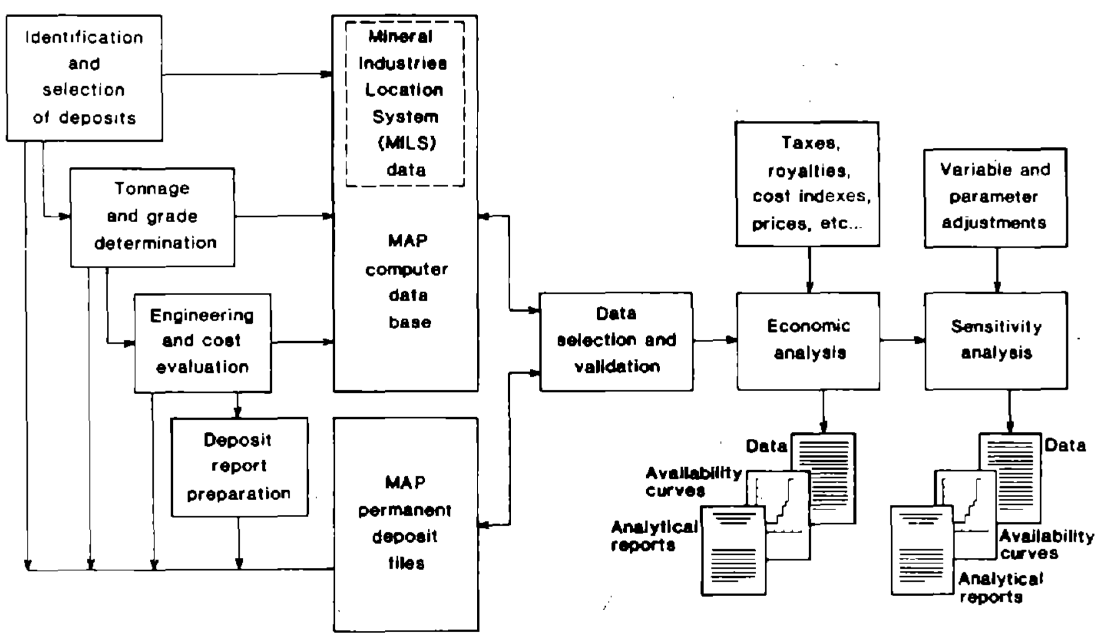

Figure 1.—Minerals Availability Program evaluation procedure.

characteristics must meet stringent standards. For others, fibers of varying quality and character may be satisfactorily used.

The main use of asbestos is in the manufacture of construction materials, primarily in the form of asbestos cement pipe and sheet, flooring products, and roofing products. Other major end uses are in friction materials, paper, coatings and compounds, packing and gaskets, textiles, and plastics. In the United States, the construction sector accounted for 42% of total asbestos consumption in 1982. However, friction products represented the single largest use, 21% of total 1982 domestic consumption (*2*).

For purposes of product grading, the major industry standard was developed by the Quebec chrysotile asbestos industry, whereby asbestos is classified and valued according to fiber length, from the longest (No. 1) to the shortest (No. 9). Table 1 shows the major grading specifications and general product uses by grade classification.

To some extent, grades (i.e., fibers of differing lengths) are interchangeable, and much research effort has been devoted to substitution of more abundant (shorter) grades for less plentiful (longer). For example, in the early days, Canadian grades 3 and 4 were used exclusively in cement production. However, owing to the advent of more sophisticated fiber preparation techniques and incorporation of blue (crocidolite) asbestos in the mixture, it has been possible to use shorter grades of chrysotile in cement products. This is possible because of the high tensile strength and "dewatering" characteristics of the crocidolite fiber.

Table 1.—Quebec standard grades and uses of asbestos

Grade	Length specifications, mm	Uses
Long fiber:		
No. 1 crude . . .	⩾19	Textiles.
No. 2 crude . . .	9.5–19	Textiles; insulation.
No. 3	6–9.5	Textiles; packing; brake linings; clutch facings; electrical, high-pressure, and marine insulation.
Medium fiber:		
No. 4	3–6	Asbestos-cement pipe.
No. 4	3–6	Asbestos-cement pipe and sheets; moulded products; paper products; brake lines and gaskets.
No. 6	<3	Asbestos-cement products; brake linings and gaskets; plaster; backing for vinyl sheets.
Short fiber:		
No. 7	<3	Moulded brake linings and clutch facings; plastics; filler in vinyl and asphalt floor tiles, asphalt compounds, and calking compounds; paints and drilling mud additives.
No. 8	(1)	Do.
Very short fiber:		
No. 9	(1)	Rock ballast; asphalt paving aggregate; landfill.

[1]Weight specifications.
Source: (*1*, p. 58; *3*).

SUBSTITUTION

Owing to the particularly sensitive issue regarding possible health hazards associated with the use of asbestos, a concerted effort has been directed at finding or developing substitute materials for asbestos fiber.

For many years, asbestos has enjoyed a virtual monopoly in the markets in which it is used. Efforts to develop economically and practically viable substitutes have met with varying degrees of success. The following examples indicate the advance of development of viable alternative materials for many uses currently filled by asbestos. In the paper products market, a number of alternative materials, including aramid, carbon, and graphite, have been tried with a reasonable degree of success. In roofing applications, alternatives include organic felt and fiberglass felt. Fiberglass appears to be the main alternative to asbestos in textile uses, although certain ceramic fibers, polymers, and carbon are also competitive. Perhaps the principal area in which substitute materials have not made a significant impact is in asbestos cement sheet and pipe. Because these products constitute the single most important market sector by volume for the asbestos industry, if a viable and economically competitive alternative emerges, given the present climate of opinion regarding the asbestos industry, survival of the industry could be severely jeopardized.

ENVIRONMENTAL HAZARDS, STANDARDS, AND PROBLEMS

The serious health hazards associated with indiscriminate handling of asbestos fiber from mineral extraction to fabrication have long been recognized by the asbestos industry. It is generally accepted that, for the three principal types of commercially used asbestos, there is a greater risk of contracting lung cancer or mesothelioma when exposed to crocidolite than to amosite, and that less risk is associated with chrysotile than with either of the other two types. A definitive assessment of the risks associated with each fiber type does not currently exist and would be extremely difficult to develop, but the general consensus to date is that crocidolite is considerably more carcinogenic than chrysotile (*4*, p. 26).

Despite the paucity of medical and scientific evidence relating to the health risks associated with various levels of exposure to asbestos fiber, there is a high level of concern within the consumer sector. Probably the most controversial aspect of the asbestos and health problem is the claim that even brief exposure may be harmful. In July 1983, the U.S. Environmental Protection Agency (EPA) notified its intention to propose a ban on the use of asbestos in products such as cement pipe, roofing material, and floor coverings. Additionally, the agency will write proposed regulations placing a maximum on the amount of asbestos used for all other products and establish a timetable for phasing out all but a few minor uses over the next few years (*5*, p. 89). Asbestos cement products comprise the most important use of asbestos in the construction and building industry (which asbsorbs about 70% of total asbestos production worldwide). If fiber used for cement products were banned, the result would almost certainly be the demise of the asbestos industry.

PRODUCTION AND CONSUMPTION

Detailed information regarding production and consumption of individual fiber grades by country is difficult to obtain. The following information represents readily available data on world production and consumption of fiber. North American (United States and Canadian) data are presented in more detail. Although separate figures for production and consumption are not available on a world or individual country basis for most countries, a common assumption is that, over the long run, total world production and consumption are in balance.

WORLD

Estimated 1983 world asbestos production and capacities are shown on table 2. Total world asbestos fiber production was 3.92 million t. This figure represents approximately 59% of total world capacity. The leading producer was the Soviet Union which, at 2.20 million t, accounted for 56% of total world production, with output at 72% of estimated capacity. Canada was second in terms of total production at 0.82 million t, followed by the Republic of South Africa at 0.2 million t. Both countries produced at only about half of capacity during the year (54% for Canada, 48% for the Republic of South Africa).

Chrysotile accounts for approximately 95% of world asbestos production, crocidolite, 3%, and amosite, 1.5%, with the remaining 0.5% from other fiber types (e.g., anthophyllite, tremolite). The Republic of South Africa is the only country to produce fiber of all three primary types and is the only international commercial source for both crocidolite and amosite. In 1982, South African production by fiber type was as follows: crocidolite, 49% chrysotile, 33%; amosite, 18% (7, p. 154).

Figure 2 shows world and Canadian asbestos production for 1973–83. Over that period, shipments from Canadian mines averaged approximately 30% of total world production. This percentage is lower than the 45% average during the previous 10-year period (1963–72). Over the 1973–83 period, Canadian production ranged from a high of 39% in 1973 and 1974 to a low of 19% in 1982. Canadian shipments thus have shown a steady decline as a percentage of world production over the past 20 yr.

The Republic of South Africa exports about 93% of its production. However, the country's asbestos industry is being hurt by competition not only from traditional producers such as Canada, the United States, and Zimbabwe, but also from asbestos imports that are entering the world market for the first time from Brazil and Greece. Consequently, crocidolite production has been reduced to about 65% of capacity. At the time of this writing, only the three largest and most productive crocidolite mines are in operation: Pomfret, Klipfrontein, and Elcor (5, p. 89).

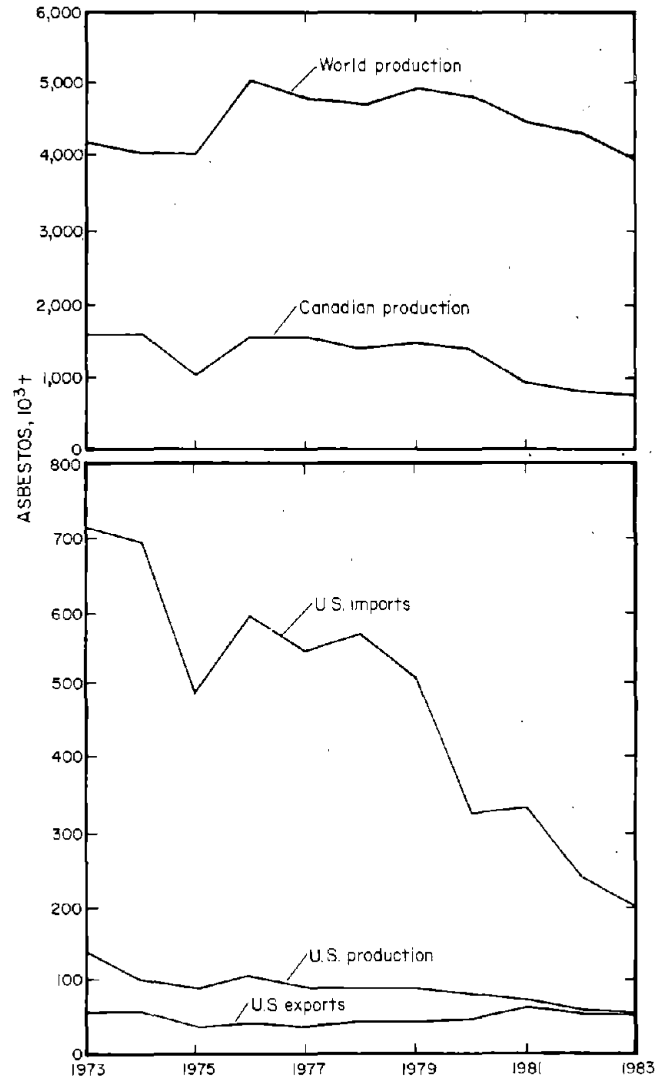

Figure 2.—Asbestos production, 1973-83.

Table 2.—Estimated 1983 world asbestos capacity and production

Country or region	Capacity, 10^6 t	Production, 10^6 t	Production as % of capacity
Canada	1.51	0.82	54
China	.30	.10	33
Europe[1]	.36	.16	44
Republic of South Africa	.42	.20	48
Other Africa[2]	.34	.24	71
South America[3]	.21	.10	48
Soviet Union	3.05	2.20	72
United States	.11	.07	64
Other	.30	.03	10
Total	6.60	3.92	59

[1]Includes Cyprus, Greece, Italy, and Yugoslavia.
[2]Includes Swaziland and Zimbabwe.
[3]Includes Brazil and Colombia.
Source: (4, p. 19; 5, p. 88; 6, p. 13).

World consumption has not declined as dramatically as has consumption in North America and Western Europe. In fact, until recently, consumption of fiber has been rising approximately 4.4% annually in developing nations, largely owing to rapid growth in construction activity.

UNITED STATES

Figure 2 shows production from the United States, which is a relatively insignificant world producer, accounting for less than 2% of world fiber production. U.S. production grew substantially during the 1960's, peaked at 136,000 t in 1973, and subsequently declined by more than 50% to 64,000 t in 1982 and an estimated 70,000 t in 1983.

Over the same period, exports of fiber from the United States grew, to a high of 64,000 t in 1981. Although U.S. net import reliance was 65% in 1983 (*6*), over 85% of U.S. production was exported and about 95% of U.S. consumption was supplied by foreign producers.

Canada is the leading source of fiber for the U.S. market, supplying 95% of all fiber imported by the United States. This proportion has varied little over the past 10 years. The Republic of South Africa accounts for less than 4% of U.S. imports, primarily in the form of crocidolite fiber.

Of U.S. imports by fiber type, 96% is chrysotile, 3% is crocidolite, and 1% is amosite. Nearly half (49%) of U.S. imports in 1974–83 was grade 7, 28% of which was used in flooring products, and another 48% was grades 4 through 6, the primary use of which was in asbestos-cement pipe and sheet. Canada relies heavily on the United States as a market for its exports, and the United States over the past 10 years accounted for an average of 35% of Canadian shipments. However, the U.S. share declined from 42% in 1973 to 27% in 1981 and 1982. Although the United States has become less dependent upon Canadian fiber, the rate of decline in U.S. consumption of Canadian fiber has been slower than the rate of decline of total U.S. imports over the past 10 yr (fig. 2).

In terms of U.S. consumption by fiber grade over the past 10 years, the most dramatic decline has come in the longer grades. Short fiber (grades 6 and 7) constituted 62% of consumption in 1974 and 84% in 1982. In recent years, U.S. consumption of asbestos friction materials and asbestos-based coatings and compounds has remained relatively stable. The products ban being considered by the EPA would have a proportionately larger impact on consumption of longer fiber, especially in the case of asbestos-cement pipe. If the ban is put into effect, the U.S. market would be principally for short fiber.

PRODUCTION AND CONSUMPTION OUTLOOK

In terms of the future trend of asbestos use, industrialized countries can be expected to gradually reduce consumption. The European Economic Community has indicated its desire to implement substitutes as they become viable. Sweden and Denmark have already passed laws banning asbestos, and Japan has passed a law requiring reduction of asbestos in asbestos-cement products to 5% maximum content.

The trend in industrialized countries is toward replacement of asbestos. In addition, the developed countries constitute a "mature" market which, regardless of the health issue surrounding asbestos, could not be expected to provide for substantial future growth in consumption. By contrast, the developing countries can be expected to account for the major growth in world demand, especially for fiber used in construction materials such as asbestos-cement pipe and sheets. Also, environmental and health standards will almost certainly continue to be less stringent in developing countries than in developed countries.

A critical deterrent to increased asbestos consumption in developing countries could be their lack of hard currency and sometimes precarious financial situations. Although the technology to produce asbestos-cement products is relatively inexpensive and not as complex or capital intensive as technologies for other building materials that could compete with asbestos products, developing countries have shown a limited ability to increase their technological capabilities and can be expected to rely heavily on foreign technology for the foreseeable future. However, the ability of these countries as a group to finance the acquisition of this assistance is in doubt.

PRICES

Prices of asbestos fiber are normally negotiated, and the details are seldom available publicly. Absolute prices of a particular grade fiber may vary widely, depending on the market forces relative to supply and demand. However, producer (or "posted") prices, which, until recently, were quoted on a regular basis by some asbestos producers, indicate that the price ratios among the various fiber grades have been fairly constant through time. Depending on market conditions, contract prices may vary considerably from producer prices; it is generally acknowledged that, during the past few years of slack demand, considerable discounting relative to posted prices has occurred.

The f.o.b. mine, Quebec, prices established by a major asbestos mining company acting as price leader historically generally set the pattern for world asbestos prices. There are approximately 29 different fiber grades (classes) and subclasses in the Quebec Asbestos Mining Association standard classification, and within each class there can be 4 or 5 different varieties. Differences between fiber from different ore bodies and mines can result in price premiums or discounts from list prices, depending upon supply and demand and the quality and utility of each grade. Accordingly, fiber bearing the same designation by grade or subclass, but having different physical or chemical characteristics, may be sold at different prices.

The January 1982 posted prices presented in Asbestos magazine (*8*) quoted from Quebec producer price lists were used as the basis for comparing the cost of production for the evaluated properties. Those prices, in terms of dollars per metric ton of fiber, are shown in table 3.

Table 3.—January 1982 Quebec producer prices (*8*)

Fiber grade	Price, $/t fiber
2	2,435
3	1,478
4	974
5	547
6	386
7	175
8	74

GEOLOGY OF ASBESTOS DEPOSITS

Most chrysotile deposits are located in serpentinized ultramafic (peridotite) bodies. In the important producing Thetford Mines area of eastern Quebec, Canada, the fibrous form of serpentine is found in veinlets, mostly less than 1 in wide, in dark green massive serpentine. The veinlets and wall rock have the same chemical composition and vary only in physical character. The chrysotile occurs as silky fiber, referred to as cross fiber when oriented perpendicular to the walls of the veinlet and as slip fiber when more or less parallel to the vein walls. Of the two, cross fiber is much more common.

Of special interest in terms of geological characteristics of chrysotile asbestos deposits is the origin of the fiber-bearing veinlets. The three main possibilities include (1) veinlets are replacement of wall rock, (2) veinlets are fissure filling, and (3) the fiber began to crystallize in minute fractures so tight that they could be bridged by the first formed crystals and wall rocks were subsequently pushed apart as fiber growth occurred. Of the three hypotheses, the last is the one most commonly accepted by geologists.

Among exceptions to the general geologic occurrence (i.e., serpentine hosted) of chrysotile described above are the Arizona deposits, represented in this study by the El Dorado property. The Arizona chrysotile deposits are among the few known occurrences in which the enclosing serpentine was not derived from an ultrabasic rock, but from limestone. The Precambrian Mescal Limestone has been intruded by diabase sills which provided mineralizing solutions that have serpentinized certain limestone beds. Chrysotile occurs as cross fiber veinlets parallel to bedding.

Among the amphibole asbestos deposits, only those in the northern Cape and northern Transvaal Provinces of South Africa constitute an important resource. The South African deposits occur with banded ironstone of the Transvaal Supergroup. Both the crocidolite deposits, located in the northern Cape, and amosite deposits (northern Transvaal) are situated within the banded ironstone, although separated by over 600 km. This lateral persistence is evident within the banded ironstone itself, in which individual bands, even those a fraction of a millimeter in thickness, can be traced for several kilometers without a perceptible change.

PROPERTY DESCRIPTION

Evaluation of the 42 properties was performed on resource values sufficiently defined to be considered demonstrated according to the definitions established by the Bureau of Mines and Geological Survey (*9*) and shown in figure 3. Resource estimates for some properties were available from published data, but several were obtained directly from company personnel or other confidential sources.

Table 4 contains resource and other pertinent information relating to properties evaluated for this study. Only five properties (Slate Creek, Abitibi, Penhale, Roberge Lake, and Pegaso) are undeveloped (i.e., have never produced). These properties contain 11.0 million t of demonstrated recoverable fiber. Six properties (El Dorado, Christie, Midlothian, Danielskuil, Riries, and Senekal) that had produced in the past but were inoperative at the time of this evaluation, are identified as past producers (PP) on table 4. Woodsreef, Australia, is currently producing at a reduced level, anticipating a possible return to full production in 1985. Because the operation has not been fully shut down, Woodsreef has been classified as a producer for this evaluation.

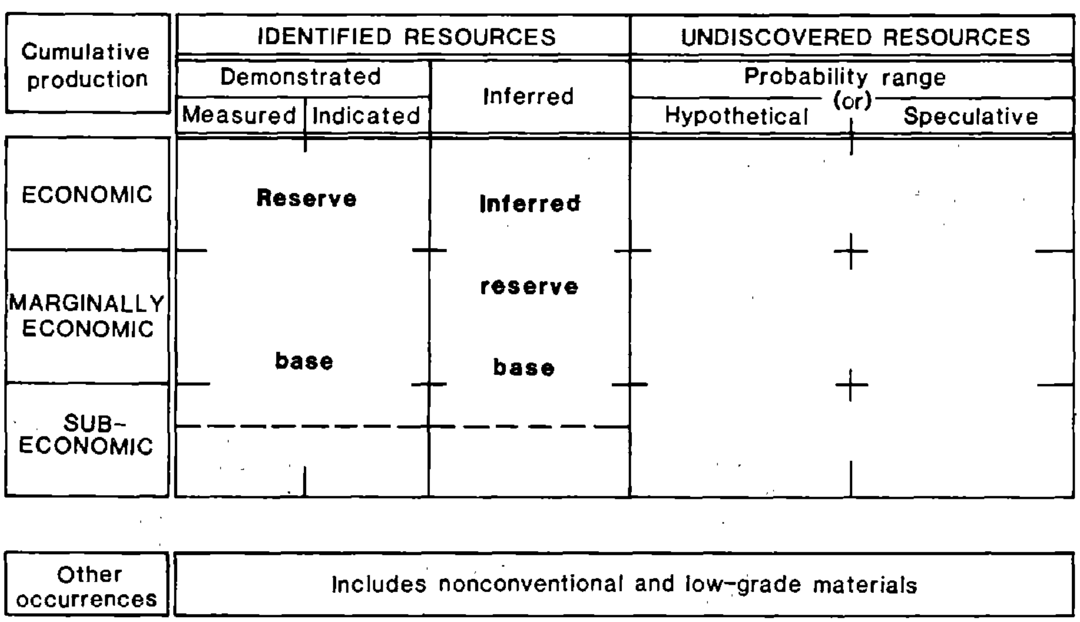

Figure 3.—Classification of mineral resources.

Table 4.—Property resource information, January 1982

Property name	Owner	Status[1]	Type[2]	Fiber grades	Fiber type[3]	Recoverable fiber[4]	Demonstrated recoverable fiber 10^3
United States:							
Alaska: Slate Creek	Tanana Asbestos Corp. and GCO Minerals	N	S	4	Ch	D	3,186.4
Arizona: El Dorado	Jaquays Mining Corp.	PP	U	3,4,7	Ch	D	3.7
California:							
Calaveras	Calaveras Asbestos Corp	P	S	4,5,6	Ch	B	278.3
Christie	Tenneco Oil Co.	PP	S	7	Ch	G	788.3
Santa Rita[5]	Union Carbide	P	S	7	Ch	G	2,926.4
Vermont: Lowell	Vermont Asbestos Company, Inc.	P	S	3,4,5,6,7	Ch	B	534.7
Total U.S.							7,717.8
Australia: Woodsreef	Woodsreef Mines Ltd.	P	S	4,5,6	Ch	D	482.5
Brazil: Cana Brava	S.A. Mineracao de Amianto	P	S	4,5,6	Ch	D	3,621.5
Canada:							
Abitibi	Abitibi Asbestos & Brinco Ltd	N	U	4,5,6,7	Ch	B	1,679.4
Asbestos Hill	La Soc. Nat. de l'Amiante	P	C	4,5,7	Ch	D	1,132.9
Baie Verte	Baie Verte Mines, Inc	P	S	4,5,6	Ch	B	1,046.3
Bell	La Soc. Nat. de l'Aminate	P	U	3,4,5,6,7	Ch	D	1,084.0
Black Lake	Lac d'Amiante du Quebec Lte. United Asbestos Corp. Ltd.	P	S	3,4,5,6,7	Ch	B	3,299.6
British Canadian	La Soc. Nat. de l'Amiante	P	S	3,4,5,6,7	Ch	B	1,834.2
Carey Canada	Jim Walters Corp	P	S	4,5,6,7	Ch	E	3,021.3
Cassiar	Brinco Mining Ltd	P	C	3,4,5,6	Ch	E	1,986.0
Jeffrey	Johns-Manville Canada Inc.	P	C	4,5,6,7	Ch	D	17,954.9
King-Beaver	La Soc. Nat. de l'Amiante	P	C	3,4,5,6,7	Ch	C	3,712.8
Midlothian	United Asbestos Inc.	PP	S	4,5,6,7	Ch	D	3,625.4
National	Lac d'Aminate Quebec Lte	P	S	3,4,5,6,7	Ch	C	983.3
Penhale	La Soc. Nat. de l'Amiante	N	U	3,4,5,6,7	Ch	C	1,173.4
Roberge Lake	McAdam Mining Corp. Ltd	N	S	5,6,7	Ch	B	2,818.8
Total Canada							45,352.3
Colombia: Las Brisas	Minera Las Brisas S.A	P	S	4,6	Ch	C	362.9
Cyprus: Amiandos	Cyprus Asbestos Mines Ltd	P	S	3,4	Ch	A	565.2
Greece: Zidani	Asbestos Mines of Northern Greece	P	S	4,5,6	Ch	B	3,706.6
Italy: Balangero	Amiantifera di Balangero SpA	P	S	4,5,6,7,8	Ch	C	5,198.4
Mexico: Pegaso	Cia. Minera Pegaso S.A	N	S	5,6,7	Ch	C	2,185.0
South Africa:							
Danielskuil	General Mining Union Corp.	PP	U	3,4	Cr	D	70.3
Elcor	...do	P	U	3,4	Cr	F	728.5
Emmarentia	Lonhro Ltd	P	U	3,4	Cr	E	50.2
Klipfontein	General Mining Union Corp.	P	U	3,4	Cr	E	224.1
Msauli	...do	P	U	4,5,6,7	Ch	D	532.2
Penge	...do	P	U	3,4	A	G	802.1
Pomfret	...do	P	U	3,4,6	Cr	D	391.5
Riries	...do	PP	U	3,4	Cr	D	40.0
Senekal	...do	PP	U	5,6,7	Ch	B	87.4
Wandrag	Lonhro Ltd	P	U	3,4	Cr	D	61.8
Whitebank	General Mining Union Corp.	P	U	3,4	Cr	E	123.8
Total South Africa							3,111.9
Swaziland: Havelock	Turner & Newall, Ltd and the Swazi nation	P	U	4,5	Ch	B	217.8
Zimbabwe:							
Gath's	Turner & Newall, Ltd	P	C	4,5	Ch	B	449.6
King	...do	P	U	4,5	Ch	D	2,282.0
Shabanie	...do	P	U	2,3,4,5,6	Ch	C	2,842.6
Total Zimbabwe							5,574.2
Grand total							78,096.1

[1]Status: P—producer; PP—past producer; N—nonproducer.
[2]Type: U—underground, S—surface; C—combined methods.
[3]a—amosite; ch—chrysotile; Cr—crocidolite.
[4]Recoverable fiber grouped into following ranges:

A	< 1.9%	E	8.0%–9.9%
B	2.0%–3.9%	F	10.0%–11.9%
C	4.0%–5.9%	G	> 11.9%
D	6.0%–7.9%		

[5]Includes 126 yr production at current annual rate of approximately 23,000 t/yr. Total resources in the New Idria intrusive are virtually unlimited.

AUSTRALIA

The Woodsreef property at Barraba merits special mention because Woodsreef Mines Ltd., in conjunction with ICI Australia Ltd., has developed and patented a method for wet processing of asbestos fiber. A special problem with the Woodsreef fiber is that it does not release as readily from the ore or fiberize (i.e., separate or open up) as easily as fiber from other producing areas, so that, with the dry milling process, a high percentage of fiber "dives" through the screen meshes and reports to the tails. Woodsreef is expected to be converted to the wet process in 1985, provided the necessary financing can be obtained. The prototype mill has been operational since January 1982 and is reportedly producing the forecast recoverable grade of 6% fiber, compared with 2.7% with the dry process (*10*).

Because costs relating to the wet process are uncertain and the process has not been developed on a commercial scale, the property was evaluated using the dry process. However, should the wet process become fully operational, the overall recovery will be substantially improved, and the total amount of recoverable fiber from the Woodsreef deposit will be higher than the total shown on table 4.

Woodsreef fiber is transported by truck and rail to

Newcastle, from where it is transported by ship to the following destinations in the accompanying approximate percentages as of 1981: Australia (6%), Japan and Korea (23%), Africa (5%), Southeast Asia (40%), Middle East (4%), Pakistan (18%), and North America (4%).

BRAZIL

Cana Brava produces approximately 140,000 t/yr of grades 4 through 6 fiber, 90% of which is used internally, with the remainder exported to Argentina and Venezuela. The operation supplies 95% of the total asbestos consumed in Brazil and can be expected to continue operating for more than 25 yr at the present production level.

CANADA

Canadian properties evaluated for this study contain more than 45 million t of recoverable demonstrated fiber. Except for fiber produced at Asbestos Hill, which is sent as ungraded concentrate to the Nordenham mill in West Germany for final treatment, all fiber from Canada is milled and graded within the country to the final stage for direct use in manufactured products.

Eight of the Canadian properties evaluated are in the important Thetford Mines asbestos region of eastern Quebec, an area which typically accounts for over 80% of annual Canadian production. Chrysotile exports from Canada account for 65% of total world exports of that fiber type, and shipments from Canada accounted for nearly half of estimated 1983 market economy country production (21% worldwide) of all fiber types; therefore, the importance of the Quebec producers cannot be understated.

The eight eastern Quebec properties evaluated are Bell, Black Lake, British Canadian, Carey Canada, Jeffrey, King-Beaver, National, and Penhale (fig. 4). All but Penhale are producers. All occur within the serpentine belt of Quebec, where serpentinized peridotite and pyroxenite occur as sheetlike stocks, dikes, and sills. Together, the eight eastern Quebec properties account for 75% of Canadian demonstrated recoverable fiber included in this study.

Most overseas shipments of fiber from Quebec are made in the form of 17.5-short-ton containers, which are trucked to Montreal and then shipped to their overseas destination. The majority of Quebec asbestos is delivered to the following major consuming centers: North America (38%), Europe (25%), Asia (20%), and Latin America (10%).

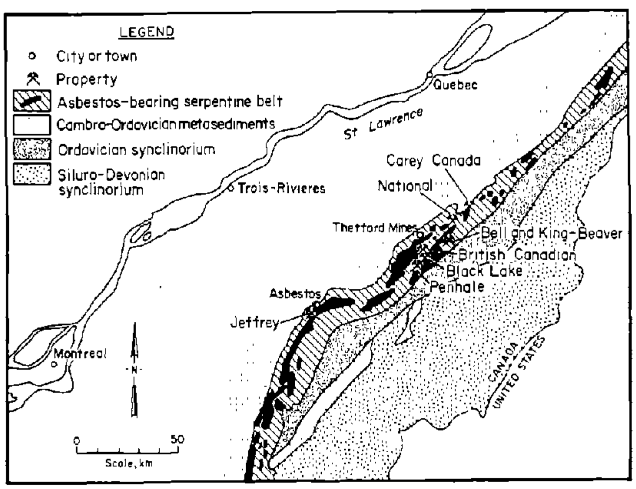

Figure 4.—Location map, Thetford Mines area properties.

Among producing Canadian properties, Jeffrey has been the most important historically and accounts for 40% of demonstrated resources in all Canadian properties evaluated. At full production, Jeffrey is the largest asbestos producer among market economy countries. The property produces fiber in grades 4 through 7. Present production is exclusively by open pit, but the operation might go underground when open pit reserves are exhausted, probably by the mid-1990's. The property was evaluated under this assumption. Jeffrey was recently acquired by J. M. Asbestos, Inc., from the Manville Corp. and has produced as much as 660,000 t/yr. Recently, however, production has been about 270,000 t annually, the figure used in this evaluation.

Baie Verte Mines, Inc., a wholly owned subsidiary of Transpacific Asbestos, Inc., has reactivated the Baie Verte, Newfoundland, mine after acquiring it from Advocate Mines in September 1982. The mine produced 40,000 t in 1983 and planned to increase production to 60,000 t in 1984. Transpacific is reportedly planning to implement the wet-milling process that is being developed for the Woodsreef, Australia, operation (*5*, p. 88). Transpacific is part owner in that operation.

The Cassiar operation of Brinco in British Columbia is currently an open pit mine, but there are tentative plans to go underground by the early 1990's when open pit reserves are expected to be exhausted. For this study the property has been evaluated based on this development plan. Cassiar asbestos is trucked to Stewart, British Columbia, then barged to North Vancouver from where it is sold and distributed to the following major destinations: Asia (24%), Europe (29%), North America (21%), and Australia (13%).

Asbestos Hill in northern Quebec is an open pit operation with only a few years of reserves remaining at the present pit designed capacity. The mine was closed in 1984 after operating at half capacity (25,000 to 35,000 t/yr) in 1983. The Asbestos Hill shutdown also resulted in closure of Asbestos Corp.'s Nordenham mill in the Federal Republic of Germany (*5*, p. 88). For purposes of this evaluation, full capacity production was assumed, continuing as an underground operation in 1986.

The present King-Beaver operation is an amalgamation of several mining operations dating from the early days (late 1800's) of asbestos mining in the Thetford Mines area of eastern Quebec. The operation exploits a series of ore bodies extending over an area of 2,130 m by 760 m to a depth of nearly 400 m from the surface. At a production peak of about 200,000 t/yr in the late 1970's, about a third of the total ore mined came from the underground (King) mine. At full capacity, about two-thirds of ore from the King-Beaver combined operation is sent to the Normandie mill and the remainder to the British Canadian #2 mill, both within 15 km of the King-Beaver operation. When the King (underground) mine is terminated by about 1986, the Normandie mill is expected to be used exclusively by the Penhale property (currently a nonproducer). All ore produced by the Beaver (open pit) mine would then be treated at the British Canadian mills. These plans have been included as part of this evaluation.

Among nonproducers, Abitibi and Roberge Lake, both in Quebec (although not in the Thetford Mines area), together account for 6% of Canadian demonstrated recoverable fiber. The Abitibi property would produce fiber in the intermediate range (grades 4 through 7), for which it would face competition from several current producers. A number of feasibility studies have been carried out, with early concepts favoring mining by open pit. However, owing to the high expense of glacial overburden removal (which varies from 18 to 27 m), the most likely mining method would be underground. This option was assumed for purposes of this evaluation. Roberge Lake (also known as Chibougamau) would be mined by open pit.

The Canadian properties, including nonproducers, have all been extensively drilled. The nonproducers are those that have been widely reported in the literature and have, for the most part, been examined in great detail, both geologically and from an economic standpoint. They are the properties most likely to begin production in the near future. However, given the widespread occurrence of favorable host rock (e.g., the Precambrian shield areas of Ontario, the ultramafic belt of the western provinces), and the lack of detailed exploration resulting from complex geology and extensive glacial cover (e.g., Abitibi), there is a high degree of likelihood that more asbestos deposits remain to be discovered in Canada.

COLOMBIA

Production began in 1981 from a small open pit mine at Las Brisas at a rate of 5,400 t/yr of fiber. Production reached 7,000 t/yr in 1983, with plans to produce 10,000 t in 1984. Expected capacity is 25,000 t/yr, but a target date to reach that level has not been set (*5*, p. 88). The operation ships its entire output of grades 4 and 6 fiber to Eternit's cement plant in Medellin, Colombia.

CYPRUS

Amiandos has an annual capacity of 35,000 t/yr of fiber, although production has been less in recent years (18,952 t in 1982). At full capacity (assumed for this evaluation), the property could produce until the late 1990's. Resources at lower levels of probability than demonstrated have not been determined, but it is known that there are other asbestos occurrences in the area. Apparently, though, only the Amiandos Mine area has fiber of sufficient continuity to justify exploitation at this time. Fiber is trucked to Limassol, from where it is transported to various consumers in Europe and Southeast Asia.

GREECE

The Zidani operation began production in 1981, with a design capacity of 100,000 t/yr of fiber. Depressed market conditions and technical problems, however, have kept production below that level. Production in 1983 was about 35,000 t. Plans were to increase output to 55,000 t in 1984, but it is not known when the operation will reach full capacity (*5*, p. 89).

At production capacity (assumed for this evaluation), the mine can produce for nearly 40 yr, supplying approximately 15% to 20% of its output to the domestic cement industry (*11*, p. 66). The mine produced 35,000 t in 1983, of which significant amounts were exported to Western Europe, Eastern Europe, the Middle East, and the Far East. Sales from Zidani are cutting into traditional Canadian markets in the Mediterranean and European regions, since transportation costs from Greece are lower than from Canada (*5*, p. 89).

ITALY

Balangero, also referred to as San Vittore, is the leading producer of asbestos fiber in Europe, with production reaching a maximum of 165,000 t in 1976. During the past few years, though, production has been about 130,000 t/yr. The mine is highly mechanized and has the highest productivity of any asbestos mine in the world. Demonstrated recoverable fiber has been calculated at over 5 million t to a depth of 180 m below the present pit bottom, with additional resources below that level. Most (60%) of the fiber produced at Balangero is consumed domestically; the remainder is shipped to Europe and western Asia.

MEXICO

The Pegaso property, also referred to as the Papalo deposits, had a 1-t/h pilot plant operating between March 1979 and August 1982. Apparently, there are no firm plans to bring the operation into production in the near future. If and when the property does come into production, it will be by open pit. For this evaluation, the property has been modeled to begin producing in 1987.

REPUBLIC OF SOUTH AFRICA

The asbestos deposits of South Africa occur in three separate geographic areas, each containing different types of fiber (fig. 5). Amosite and crocidolite (blue asbestos), the two amphiboles, are produced from the northern Transvaal and northern Cape Provinces, respectively. Chrysotile is produced from the Barberton district of the eastern Transvaal. The only amosite (northern Transvaal) property evaluated is Penge, which is the only operating mine in the amosite field in what was once an extensive mining area

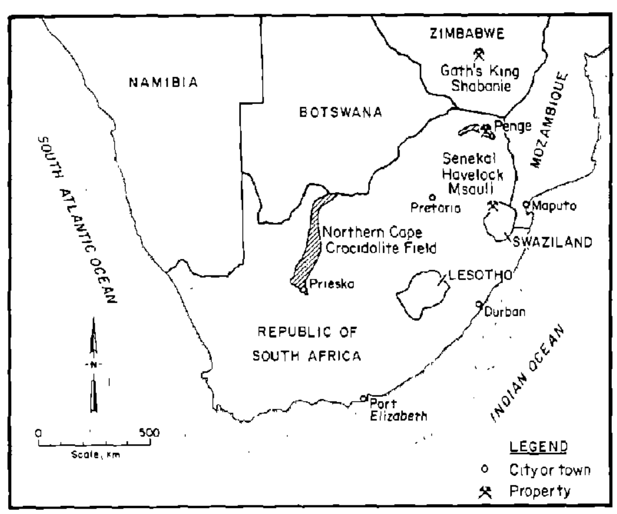

Figure 5.—Location map, southern African properties.

of many small operations. Msauli, a producer, and Senekal, a past producer, are the two chrysotile properties evaluated. The remaining eight properties produce crocidolite from the northern Cape field. Amianthus, although a crocidolite producer, had only a few years of life remaining as of the date of this study (January 1982), so it was deleted from the study. Bute, a recent past producer, has also been excluded because its reserves have been nearly exhausted.

Of the 11 South African deposits evaluated, all but Emmarentia and Wandrag are owned by the Griqualand Exploration and Finance Co. Ltd. (Gefco), whose parent company is General Mining Union Company Ltd. The two others are owned by Lonhro Ltd. through subsidiaries. Through a sequence of several acquisitions between January 1979 and December 1981, Gefco has become the major amphibole asbestos producer in South Africa, accounting for 90% of crocidolite production, which it blends with the remaining 10% from the Emmarentia and Wandrag properties into its products. Gefco is the sole selling agent.

The principal destinations of crocidolite fiber are Italy, the United States, the Middle East, and the Far East. Exact destinations by proportion are not known, but transportation costs for Gefco fiber were available and were used for this evaluation. Although Duiker Exploration (Lonhro's Emmarentia and Wandrag Mines) sells to Gefco at its Riries mill, fiber product distribution and Gefco costs were assumed for these properties.

The northern Cape field produces crocidolite from banded ironstones which are exposed in a north-south-trending syncline (the Dimoten Syncline) that is 470 km long and 40 km wide at its widest area in the south. Both limbs of the syncline have been folded into monoclines with dips generally at 6°. The deposits are located in the monoclinal or basinlike structures situated on either limb. Crocidolite development is related to the structures such as north-south folds, domes, and basins with subtle changes in dip. The greatest development of fiber occurs where two sets of folds intersect to form domes or basins. Deposits often show a sharp contact at the structure and fade out in values away from it.

Crocidolite reefs have a maximum width of 15 m, averaging 4 m. Most of the major operations are based on extraction from a number of small or medium-sized deposits (e.g, Pomfret, Whitebank, Riries), but some (e.g., Klipfontein) produce from a single continuous deposit. Where operations are based on multiple deposits, they are separated by 1 km or less.

The crocidolite deposits of the northern Cape are commonly divided into five geographical areas (fig. 6). The areas, with properties evaluated in this study (included in parentheses following the name of the area), are Danielskuil (Danielskuil, Emmarentia, Klipfontein), Kuruman (Elcor, Riries, Wandrag, and Whitebank), Pomfret (Pomfret), Koegas (none), and Postmasburg (none).

Kuruman is presently the most important district in the production of crocidolite. All mining to date has been carried out on the east limb of the Dimoten Syncline. The Pomfret Field is believed to have a large potential because known deposits are relatively large and of high grade, but thick sand cover and poor outcrop exposure render discovery of additional deposits a difficult task. Fiber deposits on the west limb of the Dimoten Syncline in the Postmasburg Field are largely undeveloped. Past production has been from a number of small, near-surface deposits and outcrop workings scattered throughout the district. A group of medium to large, high-grade (10% to 12%) deposits have been outlined near the center of the district but have not been developed. However, the district is thought to have considerable potential for development in the future.

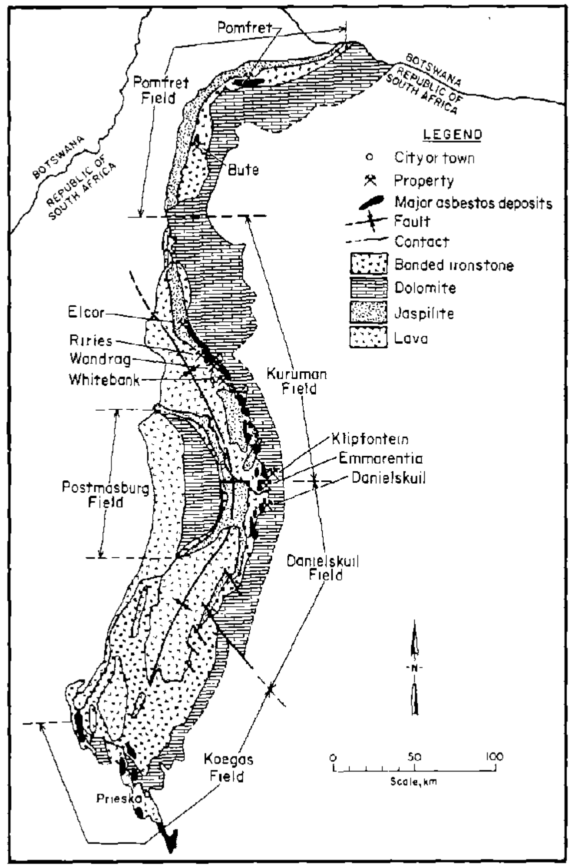

Figure 6.—Location map, northern Cape crocidolite properties.

In the Danielskuil District, only the area surrounding the town by that name has been prospected and mined to any significant extent. Klipfontein is the most prominent known deposit in the district. Very little is known about the development potential of the southern half of the district, although there is considered to be a good potential for deposits in structurally favorable sites.

Deposits in the Koegas area tend to be low grade, are generally deep seated (up to 500 m below the surface), and owing to narrow stoping widths (1 m), must be mined by labor-intensive hand methods. A major producer in the area was the Koegas Mine, which is now closed.

The northern Cape field accounted for 200,966 t of fiber in 1978; production has declined, owing primarily to market conditions, to about 112,00 t in 1982. Total annual production from crocidolite operations evaluated in this study is about 150,000 t/yr, averaged over the remaining lives of those properties. This includes the two past producers, Danielskuil and Riries, with combined annual production potential of 22,000 t.

SWAZILAND

The Havelock underground mine is in Swaziland near the Transvaal boundary, across which the Msauli deposit of South Africa is located (fig. 5). The ore body has been fully delineated, and all reserves are classified as measured. Turner & Newall owns 60% of the property and operates the mine under a lease from the Swazi nation which is due to expire in 1986. Msauli fiber is transported by truck to railhead, railed to port at Maputo, Durban, and Port Elizabeth, and shipped in the following percentages to Japan (65%), Europe (25%), and South America (10%).

UNITED STATES

The estimated 1983 production of 70,000 t of asbestos in the United States accounted for 2% of world production and 4% of output from market economy countries (*6*). Of the six properties evaluated, three are producers: Lowell, which is located along the Appalachian fold belt in Vermont and produces from a deposit that is similar geologically and mineralogically to those in the eastern townships of Quebec; and Santa Rita and Calaveras in California.

The Lowell operation produces chrysotile from an open pit mine on Belvidere Mountain in Vermont. The operation has a fiber capacity of about 38,000 t/yr, but annual output has been 25,000 t or less since 1977. For this evaluation, it was assumed that annual production would be approximately 28,000 t of fiber. Resource figures were based on the assumption that mine life will be 20 yr from the date of this analysis.

Calaveras was the first asbestos mine in California, with production as early as 1904. It has been operated continuously as an open pit since 1975 by the present owner, Calaveras Asbestos Corp., producing grades 4, 5, and 6.

Santa Rita and Christie (a nonproducer) are located in a 145-km² mass of serpentinized peridotite (the New Idria intrusive) near the southern end of the Diablo Range in Fresno and San Benito Counties. The intrusive is quite literally a mountain of slip-fiber chrysotile asbestos, averaging more than 50% fiber locally (*12*). Only grade 7 fiber is present, but the resource potential is, for all practical purposes, limitless. The demonstrated resource figures used in this evaluation apply only to the legal boundaries of the two properties evaluated, and only to the extent to which the fiber resource has been demonstrated (drilled). For this evaluation, 126 yr of production potential have been included for the Santa Rita deposit.

The El Dorado property, shut down since January 1982, is typical of the Arizona chrysotile deposits in that it is of small tonnage but contains relatively long fiber (grades 3 and 4, as well as 7) with low iron content. The property must be mined underground and employed hand sorting to avoid hauling waste the long distance (about 60 km) to the mill. The operation was economically viable for many years before its closure in 1982.

A potentially important undeveloped chrysotile deposit (Slate Creek) is located in a remote part of Alaska, containing approximately 3 million t of fiber. For this evaluation, the property was assumed to produce 100,000 t/yr of grade 4 fiber as an open pit operation. It has been reported (*13*) that the deposit also contains fiber in grades 5 through 7, although a percentage breakdown was not available at the time of this study.

The Slate Creek fiber would probably be transported by truck and rail to Seward, AK, and then shipped to Seattle, WA, where it would be sold.

ZIMBABWE

The Zimbabwean properties, Gath's, King, and Shabanie (fig. 5), are all underground producers owned and operated by Shabanie and Mashaba (Pvt) Ltd., a subsidiary of Turner and Newall, Ltd. Presently, the combined production capacity from the mines is 250,000 to 300,000 t/yr of fiber, based on capacity of the new mills at Mashaba and Shabanie. This production level is expected to be sustained through the end of the century. Production from Shabanie and Mashaba's operations is significant since they account for 50% of the world's textile fiber production (*4*, p. 33). Shabanie Mine, in fact, is the only deposit evaluated in this study that produces a significant amount of grade 2 (spinning grade) fiber.

All Zimbabwean fiber is transported by rail to Maputo, Port Elizabeth, or Durban for distribution to the following areas in the accompanying proportions: Japan (20%), United States (47%), Europe (20%), and South America (13%).

MINING, MILLING, AND TRANSPORTATION—METHODS AND COSTS

Following is a presentation of mining, milling, and transportation methods and costs associated with the various producing or proposed operations evaluated. Included in this discussion are several assumptions that were used to evaluate the properties.

Operating costs and capital investments for the appropriate mining, milling, and transportation methods were obtained or estimated for each deposit. In most cases, actual costs were available from published material, company personnel, other persons familiar with the operation, or a confidential, unpublished source (e.g., feasibility study).

The total operating cost is a combination of direct and indirect costs. Direct costs include direct and maintenance labor, materials, payroll overhead, and utilities. Indirect operating costs include administrative costs, facilities maintenance and supplies, research, and technical and clerical labor.

Capital expenditures were calculated for exploration, acquisition, development, and mine and mill plant and equipment. Capital expenditures for mining and milling facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital.

Mining method, annual capacity (average over the remaining life of each deposit), and ranges for mining and milling costs are shown in table 5. Weighted-average total operating cost (mine plus mill) for selected countries is shown on table 6. Operating costs are in terms of dollars per ton of recoverable fiber, averaged over the life of each property. Owing to the proprietary nature of cost data, only a general range can be shown for each property, but weighted average costs for countries with several properties were included in table 5.

MINING

Of the 42 properties evaluated, 19 do or could produce

Table 5.—Mining methods, production, and January 1982 operating costs

Property name	Mining method	Fiber grade	Av production, 10^3 t/yr	Recoverable fiber[1]	
				Mine	Mill
United States:					
Alaska: Slate Creek	Open pit	4	106.2	B	C
Arizona: El Dorado	Room and pillar	3,4,7	.7	H	F
California:					
Calaveras	Open pit	4,5,6	20.9	B	C
Christie	...do	7	21.9	A	B
Santa Rita	...do	7	23.2	A	A
Vermont: Lowell	...do	3,4,5,6,7	28.1	B	D
Australia: Woodsreef	...do	4,5,6,7	53.6	F	H
Brazil: Cana Brava	...do	4,5,6	139.3	A	A
Canada:					
Abitibi	Open stope	4,5,6,7	93.3	D	C
Asbestos Hill	Open pit; sublevel cave	4,5,7	87.1	D	C
Baie Verte	Open pit	4,5,6	61.5	D	B
Bell	Block cave	3,4,5,6,7	67.7	B	B
Black Lake	Open pit	3,4,5,6,7	150.0	B	B
British Canadian	...do	3,4,5,6,7	87.3	B	B
Carey Canada	...do	4,5,6,7	143.9	A	A
Cassiar	Open pit; sublevel stope	3,4,5,6	90.3	B	B
Jeffrey	Open pit; stope	4,5,6,7	272.0	B	B
King-Beaver	Open pit; block cave	3,4,5,6,7	142.8	B	B
Midlothian	Open pit	4,5,6,7	172.6	A	B
National	...do	3,4,5,6,7	89.4	A	B
Penhale	Block cave; modified cave	3,4,5,6,7	78.2	B	B
Roberge Lake	Open pit	5,6,7	97.2	B	B
Colombia: Las Brisas	Open pit	4,6	8.9	B	B
Cyprus: Amiandos	...do	3,4	35.3	B	B
Greece: Zidani	...do	4,5,6	97.5	A	B
Italy: Balangero	...do	4,5,6,7,8	130.0	A	B
Mexico: Pegaso	...do	5,6,7	75.3	A	B
South Africa:					
Danielskuil	Room and pillar; semishrinkage stope	3,4	11.7	D	D
Elcor	Room and pillar	3,4	33.1	B	B
Emmarentia	Room and pillar; semishrinkage stope	3,4	1.3	B	A
Klipfontein	Cut and fill	3,4	18.7	B	B
Msauli	Sublevel cave	4,5,6,7	66.5	B	B
Penge	Breast stope	3,4	42.2	B	B
Pomfret	Room and pillar	3,4,6	55.9	B	B
Riries	...do	3,4	10.0	C	C
Senekal	Sublevel stope	5,6,7	5.0	B	B
Wandrag	Room and pillar	3,4	7.7	B	A
Whitebank	...do	3,4	15.5	B	C
Swaziland: Havelock	Sublevel cave; shrinkage stope	4,5	31.1	C	B
Zimbabwe:					
Gath's	Open pit; cave; shrinkage stope	4,5	22.5	D	B
King	Panel retreat cave	4,5	99.2	B	A
Shabanie	Prebreak cave	2,3,4,5,6	135.4	C	B

[1]Cost ranges for mine and mill:

A	<$199	E	$400–$499
B	$100–$199	F	$500–$599
C	$200–$299	G	$600–$699
D	$300–$399	H	>$700

Table 6.—Average total operating cost for selected countries

Country	Weighted average cost of recoverable fiber, $/t	
	Mine	Mill
United States	107	226
Canada	157	141
South Africa	152	154
Zimbabwe	233	112

by typical open pit methods. The mines are highly mechanized. Eighteen produce exclusively by underground methods, and the remaining five either produce by combined open pit and underground simultaneously, or are currently operating by open pit and expected to convert to underground. This latter category includes Asbestos Hill, Cassiar, and Jeffrey, all in Canada. King-Beaver (Canada) and Gath's (Zimbabwe) currently produce about half by open pit and half by underground methods.

In terms of annual production averaged over the lives of all properties evaluated, open pit mining accounts for 1.8 million t/yr of fiber (61.6% of the total average annual production from all deposits). All but 0.5 million t is from operations that were producing at the time of this evaluation (January 1982). The combined (open pit and underground) operations with percentage of annual production (average over the remaining life) from open pit follow: Asbestos Hill (27%), Cassiar (45%), King-Beaver (94%), Jeffrey (19%), and Gath's (53%). The underground (King) portion of the King-Beaver operation is expected to be phased out by 1986, after which only the Beaver open pit will be in operation. For this evaluation, Asbestos Hill, Jeffrey, and Cassiar have been assumed to convert from their present open pit method to strictly underground operations in the future. Gath's is the only property evaluated that is expected to continue as a combined open pit and underground operation through the property's life.

The methods used in asbestos mining are largely dictated by the geological occurrence, type, strength, and other physical characteristics of the host rock. Selection of mining method must recognize ore body value and fiber length distribution, extent and value of dilution zone, rock mass classification, contaminants, and fiber degradation. Indiscriminate selection of mining method can result in high ore loss, high dilution, and expensive support maintenance costs.

Mining methods employed at the properties evaluated for this study are shown in table 5. With the exception of the El Dorado and northern Cape crocidolite operations, whose unique geological occurrences have resulted in unique mining methods for asbestos deposits, asbestos producers use mining methods that are similar to those used in operations exploiting other minerals.

Canadian asbestos occurs in irregular veins or veinlets in massive serpentinite deposits that are extensive both laterally and vertically, so that large-scale, highly mechanized open pit methods have been extensively employed. A relatively recent development in Canadian asbestos mining was block caving, which was found to be the most economical underground method. It was first introduced at the King Mine and is now the only mining method employed at Bell. Caving methods are also widely used in the Zimbabwean mines.

Crocidolite operations in the northern Cape of South Africa have typically consisted of a number of small underground mines using highly labor intensive methods to provide hand-sorted ore to feed centrally located mills. The present trend is toward less labor intensive operations. Three major mining methods have been used by the Cape operations: room and pillar, semishrinkage stoping, and post pillar with hydraulic fill (cut and fill). Among these methods, room and pillar is used by large producers as it lends itself to mechanization, and the wide stopes (4 to 6 m) allow the use of large, efficient underground machinery. The method results in nearly 94% recovery once the pillars are "skinned" to measure 1.5 by 1.5 m. Semishrinkage is used in conjunction with room and pillar at Danielskuil and Emmarentia. Cut and fill is used at Klipfontein, allowing for 90% extraction of ore at that operation.

All properties in the low mine-cost range (A range, table 5) are open pit operations. Additionally, most of the properties in this range have high grades (i.e., greater than 7% recoverable fiber). Properties in the low mine-cost range with high grades include Christie, Santa Rita, Cana Brava, Carey Canada, and Midlothian. Zidani has a low grade (less than 3%) but benefits from low labor costs. Pegaso, in Mexico, also benefits from low labor costs. Balangero is a highly mechanized, efficient operation with productivity among the highest of all asbestos producers.

The weighted average mining cost for U.S. properties is the lowest of those countries whose averages are shown. All but one U.S. property (El Dorado, a past producer) are open pit, and the average mining cost is influenced to a large degree by the Christie and Santa Rita (California) operations, which employ front-end loaders to mine high-grade asbestos-bearing material.

Among properties in cost range B ($100/t to $199/t fiber) are most of the Canadian and South African producers. The weighted average mine operating cost for South African crocidolite properties is $142/t recoverable fiber; cost for Canadian properties is $157/t. Although all of the South African crocidolite operations are underground, they have high grades, averaging 8.7%; the lowest grade among crocidolite properties is greater than 6%. In addition to their high grades, the South African operations are highly mechanized. Among Canadian properties in this cost range are those that currently produce or are projected to produce by the relatively inexpensive underground block caving method. These include Bell, which produces strictly by block caving; Cassiar, which currently produces by open pit but which is projected to utilize caving methods when it goes underground; and King-Beaver, which utilizes open pit (Beaver) and block caving (King). By 1986, only the Beaver open pit has been modeled to be in operation.

Among relatively high-cost operations, Abitibi, a non-producer, would be an underground operation (open stope) with low grade. Asbestos Hill, although presently an open pit operation, is projected to go underground in the near future. Baie Verte, although an open pit mine, is projected to have a high stripping ratio (4.6:1), which contributes to its relatively high mine cost. It also has a low grade (less than 4% recoverable fiber). Danielskuil is a past underground producer in South Africa with the lowest recoverable fiber grade of all crocidolite properties. Semishrinkage stoping is used in conjunction with room and pillar mining at Danielskuil, which contributes to its relatively high mine cost. Although the Gath's mine acquires half of its production by open pit, the grade is less than 4%. Woodsreef and El Dorado are the highest mine cost properties evaluated. Woodsreef's recoverable grade is very low (2.7%) but would improve (to 6%) if the wet process were installed (*10*), resulting in a lower cost than that shown. El Dorado's grade is more favorable, but it was a small, labor-intensive operation.

MILLING

The concentration process for asbestos is unique in that it involves separation of a fibrous mineral from a massive form of the same mineral. Thus, neither chemical composition nor specific gravity can be used as the basis for separation, which is done strictly by mechanical means.

A most important principle governing asbestos milling is separation of fiber from host rock with a minimum of fiber breakage. This is because the value depends largely on the fiber length. Modern mills are designed to remove the fiber by aspiration (air suction) after each crushing process so that destruction of fiber is minimized.

Essentially, all dry milling processes are very similar, relying exclusively on mechanical processes to separate and recover fiber. Asbestos milling consists essentially of coarse crushing, drying, and recrushing in stages, each step followed by screening and air separation of fiber from rock. Exceptions are the northern Cape crocidolite operations where, owing to the abrasive nature of the banded ironstone that hosts the fiber, all mines employ manual sorting of underground ore. Run-of-mine ore is passed over a 10-mm screen, with the coarse fraction reporting to a sorting plant where 30% to 40% of the total mine feed is hand-sorted to waste. Run-of-mine ore containing 8% to 11% fiber is upgraded to a mill feed averaging between 11% and 16%, depending on sorting efficiency.

In 1978, the design capacity of all crocidolite plants was approximately 200,000 t/yr. Presently, however, the policy is to operate only the most efficient plants, and their design capacity totals approximately 144,000 t/yr.

Woodsreef Mines Ltd. has operated a pilot plant wet-process mill since January 1982. Little is known about the process, except that it has improved the recovery of Woodsreef fiber from 2.7% with the dry process to about 6%. The Santa Rita operation in California also utilizes a wet process in part of its milling plant, but the particular details of that process are not widely available. Besides improving recovery of fiber from certain deposits, an especially promising aspect of wet mill processing is that it lowers fiber dust levels in the workplace. This is a particularly important concern in the mining and processing of asbestos.

Among properties in mill cost range A (less than $99), all have high grades, greater than 7% recoverable fiber. Because most milling processes are quite similar, cost is largely a function of recoverable fiber grade and labor costs. However, mill efficiency can be an important factor. At Woodsreef, for example, where the short fiber has a tendency to "dive" through the classifying screens in the dry mill, the effective mill recovery is only about 60%, compared with an estimated recovery of nearly 100% with the wet process (*5*, p. 89). Thus, the Woodsreef mill cost is high in relation to that of other properties evaluated. The mill operating costs for 26 of the 42 properties evaluated occur within the $100 to $199 (B) range, indicating that the milling process varies little among the properties.

The weighted average mill cost for Canadian properties is $141/t recovered fiber, compared with $155/t for South African properties, suggesting that the relatively high cost associated with hand sorting of ore at South African properties is largely offset by the corresponding mill feed grade increase resulting from that process.

TRANSPORTATION

For most properties, transportation of fiber from the mill is by truck, usually to the nearest railhead, from where the fiber is transported to the nearest port if it is meant for overseas consumption. In some cases, such as the Las Brisas operation in Colombia and Cana Brava in Brazil, where rail links are limited, transportation to point of use is solely by truck. The Cana Brava fiber is trucked to the major consuming center of Rio de Janeiro, a distance of nearly 1,500 km. The Cassiar property in extreme northern British Columbia, Canada, must transport its fiber by truck to Stewart, BC, then by barge to Vancouver, BC, from where it is distributed by rail (New York) or ship (Japan, Europe) to its destination.

The two most important asbestos-producing centers are the Thetford Mines area in eastern Quebec, Canada, and the northern Cape crocidolite field in South Africa. Thetford fiber is trucked to Montreal or Toronto, from where it is shipped by freighter to its various overseas destinations. Some fiber is railed directly to the United States. Specially designed 16-t containers are used to improve handling efficiency and minimize possible health hazards associated with exposure to fiber. Fiber transportation from the northern Cape crocidolite field in South Africa is by truck to railhead at either Vryburg or Lime Acres, and by rail 800 to 1,100 km to Port Elizabeth. The fiber is then transported by ocean freighter to foreign markets. Table 7 shows market distribution of fiber from general locations of producing properties evaluated that export a significant percentage of their production. The distribution pattern can vary substantially from year to year; however, the distribution pattern shown reflects the general export situation at the time of this evaluation.

Transportation costs play a major role in the marketing of asbestos. In many cases, the transportation cost determines the destination for fiber, especially in the case of higher grades (i.e., lower value fiber). Transportation costs to major importing regions for important exporting countries with properties included in this evaluation are shown in table 8. The figures include all costs to get the fiber from the mill to the customer's fabricating plant. Truck, rail, and ocean freight charges, as well as handling, insurance, warehousing, port fees, and marketing commissions, are included. The table includes costs of transportation from the amosite and crocidolite fields of southern Africa to the various regions. Although fiber is not presently transported in appreciable quantities to these areas, the deposits are the only commercially available source of these fiber types.

Table 7.—Market distribution of asbestos producers (*2*)

Source	1981 production, 10^3t	Portion to destination, %				
		North America[1]	Central and South America[2]	Europe[3]	Africa and Middle East[4]	Asia[5]
Australia	44.6	0	4	0	9	87
Brazil	138.4	0	100	0	0	0
Canada:						
Eastern	1,032.0	37	10	24	7	22
Western	90.0	21	8	29	5	37
Cyprus	34.3	0	0	65	0	35
Greece	100.0	0	0	40	40	20
Italy	137.1	0	0	100	0	0
South Africa:						
Northern Cape	102.3	10	0	30	0	60
Northern Transvaal	56.8	0	0	100	0	0
Eastern Transvaal[6]	76.8	0	7	16	5	72
Zimbabwe	247.6	47	13	20	0	20

[1]Major consuming centers for Canadian fiber are New York, Toronto, and Montreal; major consuming center for all other fiber is New York.
[2]Major consuming centers are Mexico, Colombia, and Brazil.
[3]Major consuming centers are France, the Federal Republic of Germany, and Belgium.
[4]Major consuming centers in the Mediterranean area are Egypt and Saudi Arabia.
[5]Major consuming centers are Japan and South Korea.
[6]Includes Swaziland.

Table 8.—Estimated mill to market fiber transportation costs

Source	Cost to destination (January 1982 $/t)				
	North America[1]	Central and South America[2]	Europe[3]	Africa and Middle East[4]	Asia[5]
Australia	0	90	0	120	80
Brazil	0	60	0	0	0
Canada:					
Eastern	50	80	120	130	210
Western	210	190	250	270	180
Cyprus	0	0	100	0	80
Greece	0	0	80	80	130
Italy	0	0	50	0	0
South Africa:					
Northern Cape	130	180	160	100	150
Northern Transvaal	80	130	110	40	100
Eastern Transvaal[6]	80	130	120	50	100
Zimbabwe	100	150	140	70	130

[1]Major consuming centers for Canadian asbestos are New York, Toronto, and Montreal; major consuming center for all other fiber is New York.
[2]Major consuming centers are Mexico, Colombia, and Brazil.
[3]Major consuming centers are France, the Federal Republic of Germany, and Belgium.
[4]Major consuming centers in the Mediterranean area are Egypt and Saudi Arabia; for South African deposits, figures presented reflect transportation to internal markets only.
[5]Major consuming centers are Japan and South Korea.
[6]Includes Swaziland.

The lowest cost shown is $40/t, the cost of internal transportation from the northern Transvaal to internal markets in southern Africa. The highest transportation costs are associated with transportation of fiber from the Cassiar deposit in northern British Columbia to the various regions. A substantial portion of these high costs is associated with transporting the fiber from the mine to port near Vancouver.

EVALUATION METHODOLOGY

An economic evaluation of each property provides an estimate of the average total cost of production for the operation over its estimated producing life. The evaluation uses discounted cash flow rate of return (DCFROR) techniques to establish the constant-dollar long-run price at which the asbestos fiber would need to be sold so that revenues are sufficient to cover all costs of production, including a prespecified rate of return on investment. In the price proportioning routine used in this evaluation, for each deposit, costs are burdened against total revenues required to meet the target rate of return. Then, revenues are assigned to the various products (i.e., fiber grades) according to the price proportions of those grades. In this manner, the burden of the cost of production for the deposit is not allocated to only one commodity, but is allocated among all commodities based on the price proportions of those commodities. This method is especially useful for operations producing commodities for which there is not a clearly defined primary product. It is the most appropriate method for determining costs for properties that produce commodities whose prices tend to vary in relation to one another.

The basis for establishing the price proportions for this evaluation was the January 1982 producer or posted prices quoted by Asbestos magazine (table 3); an analysis of producer prices during 1974–83 revealed that the relative prices of grades 3 through 8 remained very nearly constant, so that the January 1982 price ratios are representative of a reasonably long historical trend. Although actual and relative values of fiber grades may vary through time according to negotiated contracts, the price ratios based on January 1982 producer prices are representative of the long-term relative prices of the various fiber grades.

An implicit assumption in this evaluation is that each property represents a separate corporate entity, with negative cash flows in the developmental stage of a property carried forward in time as tax losses, rather than being applied against other corporate revenues in the year they occur.

All capital investments incurred 15 yr or more prior to the date of this analysis (January 1982) are considered to be totally depreciated. Investments incurred after 1968 have the undepreciated balances entered as an expenditure in January 1982. All subsequent investments, reinvestments, operating costs, and transportation costs are expressed in constant January 1982 dollars and entered in the year they have been projected to occur.

The life of each property was estimated by using the best available information to determine a likely future annual production rate, applied against the demonstrated resource of the property. The relatively depressed market conditions that have prevailed in the asbestos industry during the past few years have resulted in temporary closures or reduced capacities at several operations. For purposes of the availability discussion, operations that have produced in the past but were not operating at the time of this evaluation (January 1982) have been considered to be nonproducers; they have been identified as past producers on table 4. Given the current and likely near-term future market conditions, none of these properties is likely to come back into production in the near future.

Operations that have reduced capacity from past higher levels owing to recent depressed market conditions have been assumed to maintain production at the present (reduced) capacity if there was information available to support that assumption. Annual production averaged over the life of each property that has been assumed for this evaluation are shown in table 5.

Two separate analyses were performed for this evaluation with alternative target rates of return on investment specified. Average total cost of production for each fiber grade produced over the life of each property was estimated with a 0% and 15% DCFROR. The 0% is used to evaluate the "breakeven" cost where revenues are sufficient to recover total investment and production costs over the operation's life but provide no profit. For privately owned enterprises or those not strictly developmental in nature, a reasonable economic decisionmaking parameter is represented by the 15% DCFROR. This rate was considered the minimum return sufficient to maintain adequate long-term profitability and attract new capital to the industry.

AVAILABILITY

The amount of chrysotile asbestos fiber potentially available from evaluated properties for grades 3 through 7 fiber, by grade, is shown on the graphs in this section. Data for each fiber grade are presented on total availability curves for all properties evaluated and on annual availability curves for producers. Since only one property contains grade 2 and one property contains grade 8 fiber, no curves or discussions of costs are included for those grades. Crocidolite and amosite availability are discussed in a separate section.

On the total availability curves, properties that do or could produce fiber of the grade shown are ranked in order of increasing average total cost of production. Nearly all properties contain more than one fiber grade, so that most properties occur on more than one curve. The cost of producing each fiber grade at a given property has been determined according to the price proportioning routine described earlier in this report.

The costs on the total availability curves are presented in terms of 0% and 15% DCFROR at the mill. The at-mill cost is useful in comparing production costs among the properties and is the basis for the weighted average cost figures and cost discussion in this section of the report. The 0% ROR cost represents the breakeven cost of production, or the price of fiber necessary to cover operating and capital costs, but no profit.

The annual availability curves are not intended to present the Bureau of Mines prediction of how much fiber of each grade will be produced in the future; thus, they should not be interpreted as supply curves. The intent is to show how much fiber *could* be produced at a given cost from properties that were actually produced at the time of this evaluation (January 1982). To accomplish this, assumptions regarding most likely future annual production were necessary.

CHRYSOTILE, GRADE 3

Evaluated properties that do or could produce chrysotile fiber of grade 3 are listed below. Nonproducers are marked with an asterisk (*):

Canada.—Bell, Black Lake, British Canadian, Cassiar, King-Beaver, National, Penhale.*

Other.—Amiandos (Greece), El Dorado* (United States), Lowell (United States), Shabanie (Zimbabwe).

Of the 11 properties that contain grade 3 chrysotile fiber, 9 could produce at a cost (15% DCFROR, f.o.b. mill) equal to or lower than the January 1982 price of $1,478/t (fig. 7). The total amount of grade 3 chrysotile fiber potentially available from all properties is 1.59 million t, 97% (1.54 million t) of which is contained in the nine properties that have a cost equal to or lower than the January 1982 price.

The weighted average f.o.b. mill cost (15% DCFROR) for the six Canadian chrysotile producers is $976/t. Amiandos

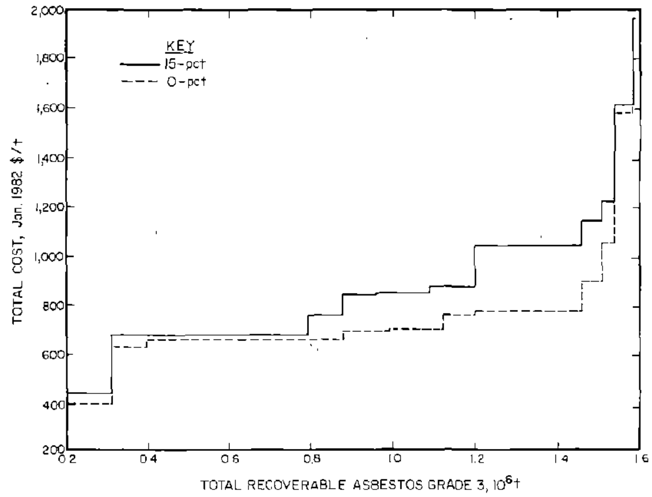

Figure 7.—Total availability, grade 3 chrysotile.

(Greece) and Shabanie (Zimbabwe) are among the lowest cost properties, and the two U.S. properties (Lowell and El Dorado) are among the highest.

In terms of annual availability (fig. 8), there is little difference in the amount of fiber potentially available at costs (15% DCFROR, f.o.b. mill) equal to or lower than the January 1982 price, or at costs 25% higher ($1,850/t) or lower ($1,100/t) than the January 1982 price. The amount of fiber potentially available at all costs annually ranges from 84,300 t in 1987–89 to less than 58,000 t in 2000. The total amount of grade 3 chrysotile fiber potentially available in 1987 at a cost equal to or less than the January 1982 price of $1,478/t from producing properties is 81,500 t, or approximately 97% of the total amount potentially available from all producers evaluated. At costs less than or equal to half of the January 1982 price ($740/t), the amount of

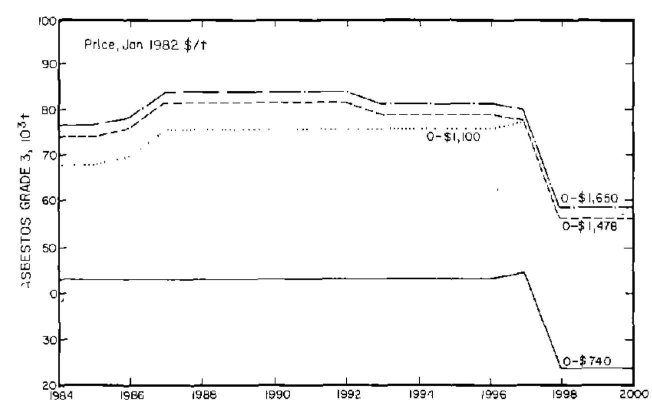

Figure 8.—Annual availability, grade 3 chrysotile.

fiber potentially available in 1987 from chrysotile producers is 43,000 t.

The two nonproducers could add only a small amount of grade 3 chrysotile fiber annually. Together, they could account for an additional 6,200 t in 1987, decreasing to 5,800 t in 2000 if they were brought into production by the mid-1980's.

CHRYSOTILE, GRADE 4

All but 6 of the 33 chrysotile properties evaluated contain grade 4 fiber. Only Santa Rita and Christie (United States), Msauli and Senekal (South Africa), Pegaso (Mexico), and Roberge Lake (Canada) do not. Those that do are listed below, with nonproducers identified by an asterisk (*):

Canada.—Abitibi,* Asbestos Hill, Baie Verte, Bell, Black Lake, British Canadian, Carey Canada, Cassiar, Jeffrey, King-Beaver, Midlothian,* National, Penhale.*

United States.—Calaveras, El Dorado,* Lowell, Slate Creek.*

Zimbabwe.—Gath's, King, Shabanie.

Other.—Amiandos (Greece), Balangero (Italy), Cana Brava (Brazil), Las Brisas (Colombia), Havelock (Swaziland), Woodsreef (Australia), Zidani (Greece).

At costs of production (15% DCFROR, f.o.b. mill) equal to or less than the January 1982 price ($974/t), there are 23 properties containing 20.40 million t of grade 4 fiber, or 97% of the total contained in all 33 chrysotile properties evaluated (fig. 9). Nonproducers account for 4.21 million t, or 21% of the group 4 fiber contained in all chrysotile properties evaluated. The weighted average f.o.b. mill cost (15% DCFROR) for Canadian producers, containing 11.42 million t, is $626/t.

In terms of potential annual availability (fig. 10), the peak year is 1990, when 674,000 t of grade 4 chrysotile fiber could be supplied by producers. Nonproducers could add 167,000 t to this total. Of the total of 841,000 t potentially available from producers and nonproducers in 1990, 805,000 t could be produced at an f.o.b. mill cost (15% DCFROR) equal to or less than the January 1982 price of $974/t.

In 1990, the two undeveloped deposits (Abitibi and Penhale) and one past producer (Midlothian), all in Canada, account for only 38,000 t.

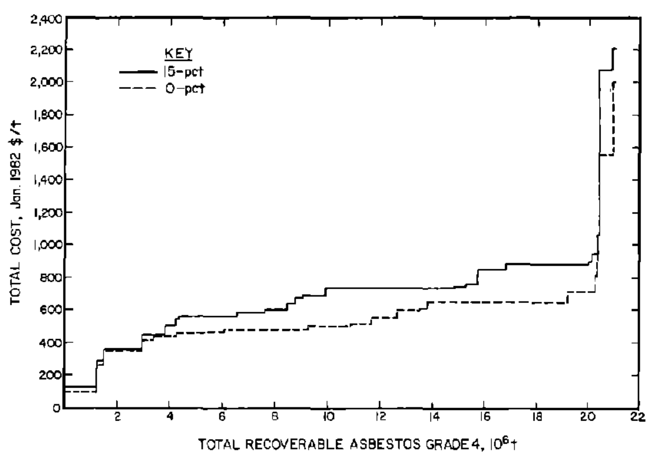

Figure 9.—Total availability, grade 4 chrysotile.

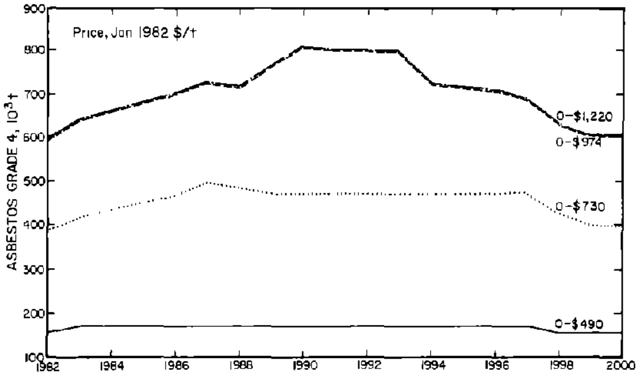

Figure 10.—Annual availability, grade 4 chrysotile.

CHRYSOTILE, GRADE 5

Twenty-seven (21 producers, 6 nonproducers) of the 42 properties evaluated do or could produce fiber of grade 5. The total amount of grade 5 fiber potentially available from all chrysotile properties is 16.74 million t (fig. 11). At an f.o.b. mill cost (15% DCFROR) equal to or less than the January 1982 price of $574/t, 13.61 million t is potentially available from 21 properties. Four of the six most costly properties are nonproducers. Properties that contain grade 5 fiber are listed below, with nonproducers identified by an asterisk (*):

Canada.—Abitibi*, Asbestos Hill, Baie Verte, Bell, Black Lake, British Canadian, Carey Canada, Cassiar, Jeffrey, King-Beaver, Midlothian,* National, Penhale,* Roberge Lake.*

Zimbabwe.—Gath's, King, Shabanie.

South Africa.—Msauli, Senekal.*

Other.—Balangero (Italy), Calaveras (United States), Cana Brava (Brazil), Havelock (Swaziland), Lowell (United States), Pegaso* (Mexico), Woodsreef (Australia), Zidani (Greece).

The weighted average cost of production (15% DCFROR, f.o.b. mill) for all Canadian properties, containing a total of 8.83 million t of grade 5 fiber, is $390/t. For the 10 Canadian producers, the weighted average cost is $365/t. These 10 properties account for 5.81 million t, or 35% of the total grade 5 chrysotile fiber contained in all properties evaluated. Including nonproducers, Canada accounts for 53% of the total. The three Zimbabwean properties contain 1.67 million t, or 10% of the total, and could be produced at a weighted average cost of $238/t.

The annual availability curve (fig. 12) shows a relatively stable potential production rate over the 1984–2000 period. The maximum annual production level from producers at an f.o.b. mill cost (15% DCFROR) equal to or lower than the January 1982 price of $547/t is 479,000 t in 1987. Of the total amount potentially available in 1987, 202,000 t is contained in producing Canadian properties. The minimum annual potential production over the 1984–2000 period is 393,000 t in 2000, reflecting the apparent exhaustion of demonstrated resources at several properties.

Canadian nonproducers could contribute an annual average of 97,000 t of chrysotile, but only 24,000 t would be available at a cost lower than $500/t. At $547, the January 1982 producer price for grade 5, less than 10,000 t of chrysotile could be produced from the Canadian nonproducers.

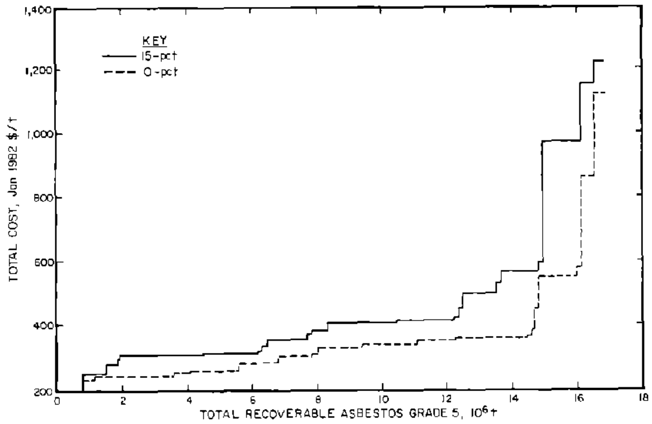

Figure 11.—Total availability, grade 5 chrysotile.

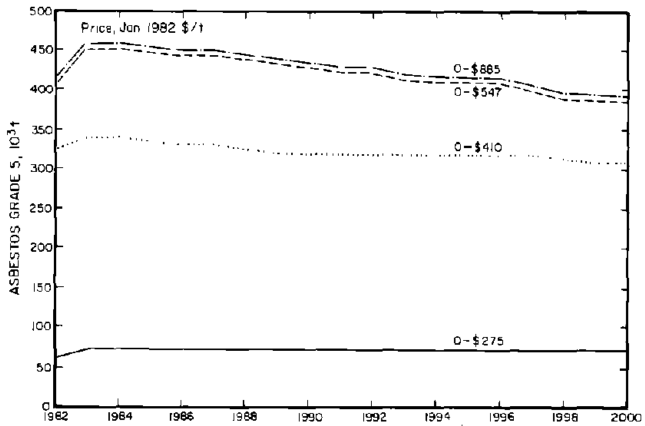

Figure 12.—Annual availability, grade 5 chrysotile.

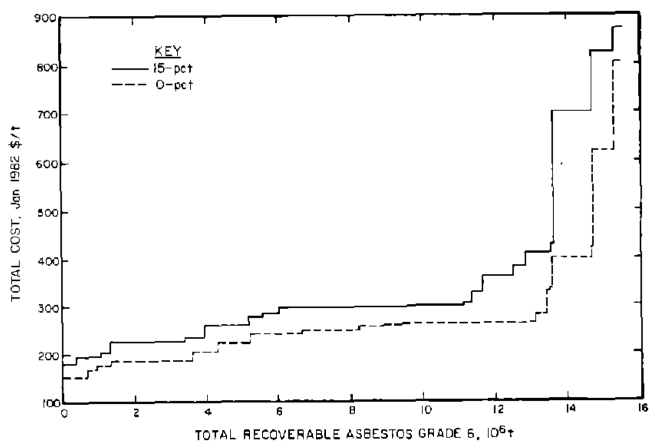

Figure 13.—Total availability, grade 6 chrysotile.

CHRYSOTILE, GRADE 6

All properties evaluated that contain chrysotile fiber of grade 6 are listed below, with nonproducers identified by an asterisk (*):

Canada.—Abitibi,* Baie Verte, Bell, Black Lake, British Canadian, Carey Canada, Cassiar, Jeffrey, King-Beaver, Midlothian,* National, Penhale,* Roberge Lake.*

South Africa.—Msauli, Pomfret, Senekal.*

Other.—Balangero (Italy), Calaveras (United States), Cana Brava (Brazil), Las Brisas (Colombia), Lowell (United States), Pegaso* (Mexico), Shabanie (Zimbabwe), Woodsreef (Australia), Zidani (Greece).

There are 12.84 million t of grade 6 chrysotile fiber potentially available from 19 properties with f.o.b. mill costs (15% DCFROR) equal to or lower than the January 1982 price of $386/t (fig. 13). Seventeen of the 19 properties are producers. The weighted average cost of production for Canadian producers is $270/t. These nine properties account for 7.06 million t, or 55% of total grade 6 fiber contained in all chrysotile properties evaluated. Including the four nonproducers, Canadian properties contain 9.91 million t. The weighted average cost for the four Canadian chrysotile nonproducers is $579/t.

At costs (15% DCFROR, f.o.b. mill) equal to or less than the January 1982 price, the amount of grade 6 fiber potentially available from producers between 1984 and 2000 is at a peak of 470,000 t in 1986–88 and gradually declines to 318,000 t in 2000 (fig. 14). The amount of grade 6 fiber potentially available in 1987 at costs lower than or equal to the January 1982 price (431,000 t) represents 92% of total production potential from producers in that year.

The six nonproducers could add a maximum of 22,000 t by 1987 at costs less than or equal to the January 1982

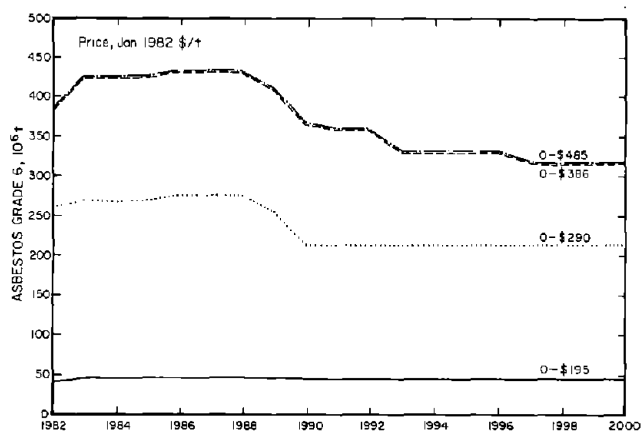

Figure 14.—Annual availability, grade 6 chrysotile.

price. The average annual availability from Canadian nonproducers is nearly 130,000 t, of which 60,000 t would have a cost lower than or equal to the January 1982 producer price of $386/t. The two other grade 6 nonproducers, Senekal and Pegaso, could account for an additional 26,000 t.

CHRYSOTILE, GRADE 7

The following 20 properties contain grade 7 chrysotile fiber. Nonproducers are identified with an asterisk (*):

Canada.—Abitibi,* Asbestos Hill, Bell, Black Lake, Carey Canada, Jeffrey, King-Beaver, Midlothian,* National, Penhale,* Roberge Lake.*

United States.—Christie,* El Dorado,* Lowell, Santa Rita.

Other.—Balangero (Italy), Msauli and Senekal* (South Africa), Pegaso* (Mexico), Woodsreef (Australia).

Of the properties listed above, 11 (7 producers, 4 nonproducers) are located in Canada. However, the grade 7 chrysotile resource from Canada is overshadowed by that contained in the New Idria intrusive in California, which for all practical purposes is unlimited. For this evaluation, only 126 yr of production potential at Santa Rita are included.

It is not possible to present a total availability curve for grade 7 chrysotile fiber since the costs associated with one or more properties would be disclosed. The total amount of grade 7 fiber contained in all chrysotile properties is 19.27 million t, 15.79 million t of which is contained in producing properties. At f.o.b. mill costs (15% DCFROR) equal to or lower than the January 1982 price of $175/t, there are 17.16 million t potentially available from 12 properties (9 in Canada, 7 of which are producers). The weighted average cost for the seven Canadian producers is $125/t, a figure that is heavily influenced by the Jeffrey operation, which accounts for approximately two-thirds of the total grade 7 chrysotile resource in all Canadian producers, and for 55% in all Canadian properties evaluated.

The amount of grade 7 fiber potentially available annually from producers (fig. 15) at f.o.b. mill costs equal to or lower than the January 1982 price of $175/t peaks at 403,000 t in 1985. The drop in production potential to 336,000 t in 1993 largely reflects the apparent exhaustion of demonstrated resources of the National property in Canada. Potential annual availability at costs less than or equal to $175/t decreases to 320,000 t in the late 1990's; total annual production potential (at all costs) is 321,000 t in 2000.

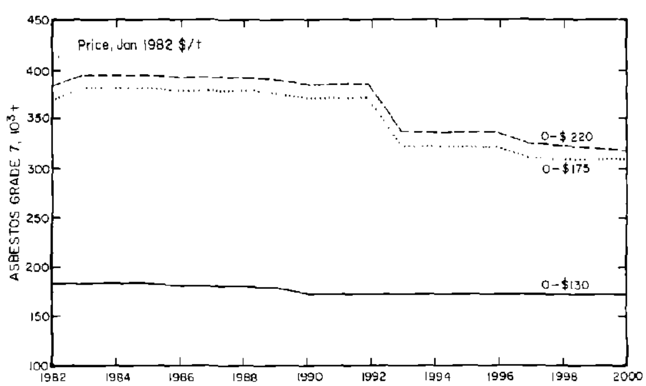

Figure 15.—Annual availability, grade 7 chrysotile.

Nonproducers could account for 60,000 to 70,000 t by the late 1980's, and as much as 147,000 t by 2000, resulting in no decrease in annual production from current levels.

AMOSITE AND CROCIDOLITE

Only one property, Penge, produces amosite, and only eight properties contain crocidolite. Six of the eight crocidolite properties are owned by one company, Gefco, and Gefco acts as the sole marketing agent for all crocidolite produced in the Republic of South Africa. For these reasons, availability curves for amosite and crocidolite could not be shown in this report. The following discussion, however, presents relevant general information concerning these fiber types in terms of total and annual availability.

The Penge Mine is virtually the only current source for amosite, producing over 40,000 t annually of relatively long fiber (equivalent to grades 3 and 4 in the Quebec grading system). Present demonstrated resources at Penge are approximately 800,000 t, sufficient to last through the end of this century at current rates of production. In addition, there is a resource of possibly more than 3 million t of potentially recoverable fiber that is currently inaccessible due to high water inflows.

Eight South African crocidolite properties were evaluated, six of which were producers at the time of this evaluation (January 1982). The total amount of crocidolite fiber (in terms of fiber length, roughly equivalent to grades 3 and 4 in the Quebec grading system) is 1.69 million t in all eight properties evaluated. The weighted average f.o.b. mill cost (15% DCFROR) of production has been estimated to be $422/t.

The eight crocidolite properties have a combined annual production potential (averaged over the life of each property) of approximately 132,000 t. Total world crocidolite production (all from the northern Cape, in the Republic of South Africa, including Bophuthatswana) in 1980 and 1981 was about 134,000 t, but declined to 112,000 t in 1982. Crocidolite production from mines in the Republic of South Africa was less than 100,000 t in that year. The two past producers, Danielskuil and Riries, have a combined average annual production potential of more than 21,000 t. Generally, the crocidolite deposits of the northern Cape are relatively small and thus do not have large demonstrated resources. The average size of the eight properties evaluated for this study is 211,000 t. Because of their relatively small size, each individual crocidolite occurrence cannot be expected to have a long production life; thus, potential annual availability analyses of this evaluation resulted in a steep decline by the early 1990's, when several of the properties will have exhausted their currently demonstrated resources. However, as noted earlier in this report, there is in general a favorable potential for discovery of additional deposits in the northern Cape, and it cannot be concluded that potential annual availability of crocidolite fiber will be severely reduced before the end of the century.

AVAILABILITY SUMMARY

Table 9 is a summary of asbestos availability for chrysotile fiber of grades 3 through 7. Total and annual potential availability are shown at 15% DCFROR costs equal to or lower than the January 1982 prices for each grade, and at costs equal to or lower than +25%, and −25% and −50% of January 1982 prices.

For all grades of chrysotile, nearly all fiber contained in all properties evaluated is potentially available at costs equal to or lower than +25% of the January 1982 prices. For all but grade 3, the amount of fiber potentially available at costs equal to or lower than −25% and −50% of the January 1982 prices is dramatically less than that available at costs equal to or lower than the January 1982 prices.

The situation is similar in terms of 1985 annual availability, although caution is advised since annual availability figures derived as a result of this evaluation are based on certain assumptions regarding likely future production levels. However, 1985 is sufficiently near term that the annual production figures from properties that were in operation in January 1982 should not differ substantially from present levels. A "typical" annual availability curve based on this evaluation shows declining annual availability over time owing to apparent depletion of demonstrated resources from producing properties. However, most of the properties evaluated have additional resources at lower levels of probability so that potential annual availability should not decline substantially within the foreseeable future.

Demonstrated resources of amosite fiber at the Penge property are sufficient to sustain annual production at the current level of 40,000 t/yr through 2000. An additional 3 million t of recoverable fiber is currently inaccessible because of water inflow but could become an important resource in the future. Currently demonstrated resources of crocidolite in the eight properties evaluated are generally small, and annual availability based on those resources is projected to decline precipitously by the early 1990's owing to exhaustion of resources at several of the properties. However, the potential for discovery of additional resources in the northern Cape crocidolite field is favorable, and the apparent decline in production potential probably is not an accurate representation of potential availability of this fiber type.

Table 9.—Chrysotile availability summary,[1] thousand metric tons

Grade	3	4	5	6	7
Number of properties:					
Producing	9	23	21	19	12
Nonproducing	2	4	6	6	8
Available fiber:					
Total	1,586	21,002	16,742	15,536	19,268
1985	76	685	483	462	403
Available fiber, based on costs = Jan. 1982 prices (P):					
Total:					
At 100% P	1,539	21,002	13,613	12,840	17,156
At 125% P	1,585	20,470	14,932	13,618	17,758
At 75% P	1,459	9,987	8,320	6,023	4,525
At 50% P	794	3,825	1,533	1,067	0
1985:					
At 100% P	74	677	446	424	381
At 125% P	76	680	453	426	395
At 75% P	68	450	334	268	183
At 50% P	43	171	71	46	0

[1]Based on total demonstrated resources, regardless of cost.

CONCLUSIONS

The results of this analysis suggest that, in terms of total availability, demonstrated recoverable chrysotile fiber in properties evaluated appears to be adequate to sustain current production levels well into the next century. It was not possible to compare the annual availability results with actual world or market economy country production and demand projections on an individual grade basis owing to the paucity of published data. However, the annual figures presented in this report for the early years of the analysis are a reasonable estimate of recent production levels from the major producing operations in market economy countries.

In general, the amounts of chrysotile fiber of grades 3 through 7 potentially available on an annual basis are projected to decline at a relatively slow rate by the end of the century owing to the apparent exhaustion of demonstrated resources at some properties. However, most of the properties evaluated have substantial additional resources at lower levels of probability, and long-term adequacy of chrysotile fiber of grades 3 through 7 is assured.

The potential availability of grade 2 chrysotile fiber could be a matter of some concern. At the time of this evaluation, only one property, Shabanie (Zimbabwe), was known to contain a significant amount of recoverable grade 2 fiber. Owing to its value for use as spinning-grade fiber, its limited geographical occurrence in relatively small amounts could be a matter of concern to present and potential users of the fiber. Only one property, Balangero (Italy), produces grade 8 fiber, but grade 8 has limited application and is of little value; consequently, its apparent low potential availability is not of major importance.

Although currently demonstrated resources of crocidolite in the eight evaluated properties are relatively small, the potential for discovery and development of other deposits in the northern Cape field appears good, and long-term availability of crocidolite fiber is probably not in jeopardy. The Penge property should be able to provide adequate amounts of amosite fiber from currently demonstrated resources at least through the end of the century, and for a long time beyond if recovery of presently inaccessible resources proves viable in the future.

In view of the generally depressed state of the asbestos industry during the past several years, in part resulting from the growing concern relating to potential health hazards associated with the exploitation and use of asbestos fiber, it appears likely that factors other than geologic availability of fiber will have the largest impact on the long-term viability of the industry.

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