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**Commodities,
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and Uses**

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Talc

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INTRODUCTION

The term *talc* refers both to the pure mineral and a wide variety of soft, talc-containing rocks that are mined and utilized for a variety of applications. Talc occurs fairly widely in a range of purities, and it is mined on every continent. The commercially exploited ores contain 20% to 99% of the pure mineral, and, although the trend is toward more upgrading and higher purity, many applications require the properties of the minerals that occur with talc.

The terms talc, *steatite*, and *soapstone* are widely used and misused in discussions of talc, its origin, and geology. Steatite was originally considered a relatively pure machinable talc, which was used in ceramic applications. Today there are two widely accepted uses of this term. In geology, steatite refers to a relatively pure, massive talc ore. In ceramics, steatite refers to a composition containing 80% talc and some fluxes, which is fired and used for electrical insulation—referred to in this chapter as *synthetic steatite*. Soapstone generally refers to a lower-purity talcose ore of mafic or ultramafic origin, which can be sawed or carved.

Talc has been used by humans for more than 3,000 years. The earliest uses were in sculpture and cosmetics. The ancient Chinese carved intricate sculptures from talc rock and made face powders using talc and rice flour. In the first century AD, the Roman philosopher Pliny referred to cosmetics made from *steatitis*. The Vikings used Scandinavian soapstone to carve pottery, many examples of which still survive. Similar artifacts from Native Americans have been found on Santa Catalina Island, west of Los Angeles.

Commercial production in North America dates from 1878 when Colonel Henry Palmer began mining talc for paper and ceramics near Talcville in western New York State. At about the same time, there are reports of small volumes of soapstone being mined in the Sierra Nevada in California for carving. Much of this early production was used for thermal insulating applications, including firebrick, stove insulation, burner tips, and wire insulators. Johnson's baby powder was introduced in the 1880s based on imported Italian powder. Commercial production began in 1904 near Johnson, Vermont; in Southern California in 1914; in Montana in 1935; and in Texas in 1952. U.S. production grew from 83,000 t in 1900 to 1.32 Mt in 1979 (Virta 2003); the major application was ceramic wall tile. A formulation based on tremolitic talc (~60%) and local clays was developed in the 1930s, and this consumed most California, Texas, and New York production well into the 1980s. That application has lessened with changing ceramic tech-

nology, and U.S. talc production has since declined to 817,000 t in 2003. Today, paper and paint are just as important as ceramics, and plastics are the most rapidly growing application.

The first true talc beneficiation plant, built in Johnson, Vermont, in 1937, used multistage froth flotation to upgrade talc ore from 55% to >95% purity. Today, this technology is used in the United States, Canada, Finland, Korea, and Brazil to produce high-grade talc from lower-grade ores.

In the early part of the 20th century, the United States imported talc from Italy and France for use in cosmetics. During World War II, these imports were replaced by domestic talc, and the United States became a net exporter to Europe, South America, and Asia. Over the last 20 years, Canada, and more recently China, have become significant exporters of talc to the United States for paper and plastics applications, respectively. In recent years, the United States again has become a net importer of talc.

In 2002, seven companies produced 817,000 t of talc from nine mines in Montana, New York, Texas, and Vermont, and 250,000 t were imported, mostly from China and Canada. Approximately 180,000 t were exported, mostly to Canada, with Mexico, Belgium, and Japan taking much smaller volumes (Virta 2004). Domestically, ceramics, paper, paint, and plastics are the major uses.

Worldwide, approximately 5 Mt were produced in 2002, with China being the major producer with 1.7 Mt. The United States, Finland, India, France, Brazil, Austria, Spain, Italy, and Australia are other countries producing more than 100,000 t each. Worldwide, paper is by far the major consumer (~40%) of talc, followed by ceramics (~20%), plastics, paint, and cosmetics. In general, world production is declining because of reserve depletion as well as replacement of talc by calcium carbonate in paper filling and by feldspar in ceramics.

The mining, beneficiation, processing, and application of talc is a sophisticated business involving geologists, mining engineers, mineral processing engineers, chemical engineers, surface chemists, and specialists in paper, plastics, ceramics, and cosmetics. In many instances, the processes and applications are unique to talc and even to specific talc deposits. The market for talc is heavily dependent on the scientific research and the technical skills of the producer. Without such applications development, the market declines. This is discussed in more detail in the Commercial Aspects and Future Trends sections later in this chapter.

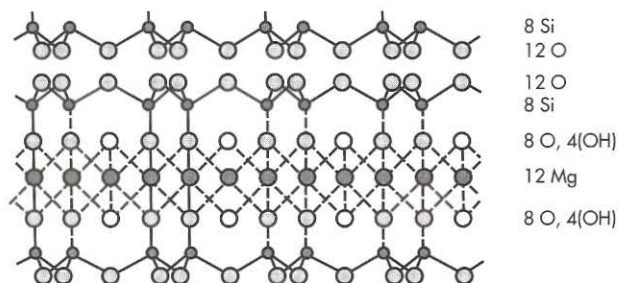


Figure 1. Talc crystal structure

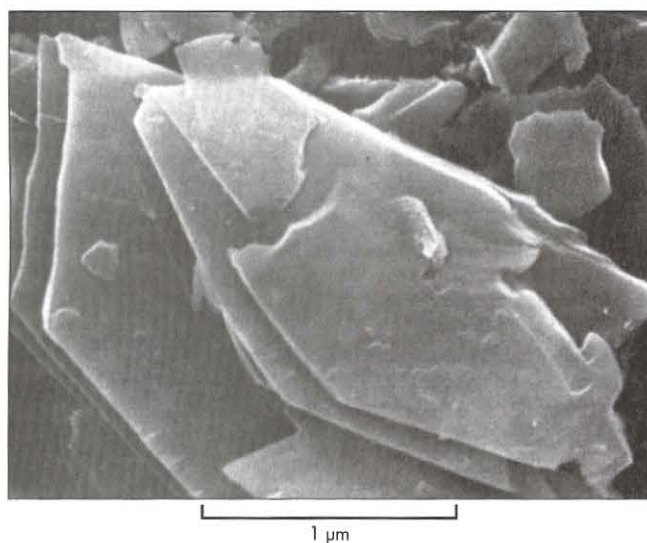


Figure 2. Scanning electron micrograph of talc

The Mineral Talc

Talc is crystalline hydrated magnesium silicate of the general formula $3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$ (see Figure 1). It is one of the layer silicates like kaolin and mica.

The adjacent layers of silica are very weakly bonded with only van der Waals forces, and this allows talc to be easily sheared along this plane. This gives it its natural slippery feel as well as its platy structure and softness (Figure 2). Talc is the softest mineral, with a hardness of 1 on a Mohs scale of 1 to 10.

When talc is split along the silica surface, the surface created is hydrophobic, or antagonistic to water. When it is fractured across the silica-brucite-silica layers, the surface created is ionic (electrically charged) and hydrophilic. Materials that have both a hydrophobic and hydrophilic component are surface active, and this gives talc its unique surface-active properties. Some types of talc are also known as soapstone, because these types are soft and have many soapylike (surface-active) properties.

Talc has a specific gravity of 2.78, a refractive index of 1.58, a specific heat of $0.208 \text{ cal/g}^\circ\text{C}$, and a thermal conductivity of $5 \text{ cal/g}^\circ\text{C}$. It is relatively inert and almost insoluble in conventional acids and bases but soluble in aqua regia and hydrofluoric acid. Talc has a pH in water of 9.0 to 9.5 and very little buffering capacity because of its insolubility. Regulatory authorities consider it a nuisance dust, but it has GRAS (generally recognized as safe) status as a cosmetics and food ingredient.

GEOLOGY

Deposits

The value of a talc deposit is a function of its purity, its color, and its location relative to the market. The purity issue is not related to the absolute percentage of talc present but more a function of specific mineral or metal impurities. Asbestiform minerals and metals such as arsenic and lead are particularly deleterious even at parts-per-million (ppm) levels, and quartz, serpentine, chromium, and pyrite are harmful at levels greater than 1,000 ppm. On the other hand, carbonates and chlorite (magnesium-aluminum silicate) can be beneficial even at levels up to 50%, especially when they are white and the composition is consistent.

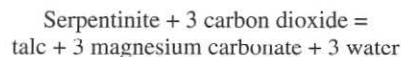
Origin of Talc

Although talc forms by a variety of geological processes, the origins of most talc deposits around the world are clearly defined by the host rock and the accessory minerals found with the talc. Talc deposits are divided into four types of origin: ultramafic, mafic, metasedimentary, and metamorphic. The processes associated with talc formation for each type are outlined in the list that follows.

- Type 1, ultramafic origin
 - Host rock—ultramafic rocks (e.g., peridotite)
 - Step 1—serpentinization of host; high temperature and pressure hydration with little loss of magnesium and silica to form serpentinite
 - Step 2—carbonization of serpentinite; influx of fluid containing 5% carbon dioxide to form talc and carbonate
 - Accessory minerals—magnesite, chlorite, serpentinite, mica, and sulfides
 - Localities—Vermont, United States; Ontario and Quebec, Canada; Norway; Finland; Russia
- Type 2, mafic origin
 - Host rock—mafic rocks (e.g., gabbro)
 - Step 1—serpentinization of host; hydration with little loss of silica and magnesium to form serpentinite
 - Step 2—carbonization of serpentinite; influx of fluid containing more than 5% carbon dioxide to form talc and carbonate
 - Accessory minerals—magnesite, chlorite, serpentinite, and mafic host rocks
 - Locations—Virginia, United States; Egypt
- Type 3, metasedimentary origin
 - Host rock—dolomite or magnesite
 - Process—hydrothermal alteration of host rock by influx of silica-containing fluid
 - Accessory minerals—dolomite, calcite, chlorite, quartz, and feldspar
 - Locations—Montana and Texas, United States; eastern Ontario, Canada; China; Brazil; Australia; India; France; Spain
- Type 4, metamorphic origin
 - Host rock—dolomitic or silica-containing dolomitic marbles
 - Step 1—metamorphism of host rock; subsurface temperature and pressure-driven conversions and recrystallization of the host rocks to form tremolite or actinolite within the host marble

- Step 2—steatization of the tremolite or actinolite; temperature- and pressure-driven alteration of the tremolite to talc and carbonate
- Accessory minerals—tremolite, carbonate, serpentine, actinolite, and quartz
- Locations—New York, California, and Georgia, United States; Italy (Val Chisone)

The formation of talc types 1 and 2 is almost identical. The basic reaction is

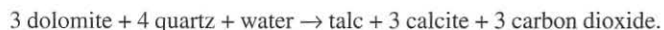


Mafic and ultramafic rocks are dark igneous rocks that are high in magnesium and iron and lower in silica. The products formed are high in iron (5% to 10%), and the magnesite is an iron isomorph. The mafic products are lower in talc content (15% to 35%) and generally useful only for carving or dimension stone. The ultramafic products have 30% to 70% talc and large crystal sizes (>100 µm) and are usually quite platy (high aspect ratio). The latter property results from the folding and fluid movement that takes place during the formation. The stoichiometry of the previous basic talc-forming reaction will give a talc content of 50% to 60%. A further enrichment of talc can take place if the talc-carbonate close to edge of the ore body reacts with silica-rich fluid in the host rock. This process is called "steatization" by geologists and can result in a narrow zone of up to 90% talc near the edge of the ore body. The whole process is called "steatization of serpentinite," and the ores are often called soapstone or lardstone. The higher talc content products are often used as is or upgraded to >95% talc purity by froth flotation.

The talc in ultramafic-type ores has high levels of iron and other heavy transition metals (nickel, chromium). Most of these metals substitute for magnesium in the talc lattice and cannot be removed. They are not available and are not toxic, but they do account for the green/blue cast of the pure talc and contribute to the strong brown color when the talc is weathered or fired.

Ultramafic is the most abundant deposit worldwide, but metasedimentary is by far the most widely exploited commercially and accounts for more than 70% of world production.

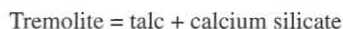
Metasedimentary deposits vary widely in purity and composition from <25% talc in some of the magnesite rocks in Brazil to >95% talc in some of the massive deposits in Montana and China. The basic reaction that forms most deposits is



This reaction would indicate that most talc of this type would be a minor ingredient in a calcite rock. In fact, few deposits have large amounts of calcite associated with them, as the hydrothermal fluids that introduced the silica are believed to have removed the calcite.

A second type of metasedimentary deposit is found in France, Sardinia, and Austria where magnesium-rich fluids altered mica schists to form chlorite, and the silica released during this reaction altered overlying dolomite to talc. These deposits have 25% to 75% chlorite along with the talc and are often referred to as chloritic talc.

Metamorphic deposits were at one time the most commercially important deposit type in North America. The basic reaction is



These deposits are quite variable in talc purity from ~30% in New York State to >70% in Madoc in Ontario. Associated minerals also vary in their levels, with carbonate being the major impurity in

the Madoc deposit in eastern Ontario and tremolite in New York. Tremolite, a calcium magnesium silicate, can occur in either blocky or prismatic forms. The deposits will typically contain tremolite of both forms. The prismatic structure results in a powder that has good dry pressing properties for ceramics. Because the ores are typically very low in iron content, they are white (good for paint) and they fire white (good for ceramics). Tremolite is also a much harder mineral than talc and will build a lower viscosity in suspensions. This property is valuable in paint.

Distribution of Major Deposits

In this section, the focus will be on commercial deposits that are presently being exploited, with lesser emphasis on either historically important or other known deposits.

North America

In the United States, talc is mined in Montana, New York, Texas, and Vermont. In Canada, talc is mined only in Ontario, with minor soapstone production for carving and stove liners in Quebec. Montana has overtaken Texas as the leading producer because of (1) the growth in paper and paint applications, for which Montana products are best suited; and (2) a decline in the older wall tile production technology, which is the biggest market for Texas talc.

Montana. Major massive talc deposits occur in the Gravelly and Ruby ranges of southwestern Montana. The talc is of metasedimentary origin in a carbonate host rock. Deposits range from thin (<1 m thick) veins to massive (100 m thick) pods of steatitic talc. The deposits were first mined underground in the late 1930s as a source of machinable steatite ore for defense purposes. Today three major open-pit mines produce approximately 400,000 tpy of mostly high-purity talc for paper, paint, ceramic, and plastic applications. Waste-to-ore ratios are quite high at greater than 6:1 in all cases.

The talc was formed by the hydrothermal replacement of magnesium-rich marble. Silica-rich fluids penetrated the marble, reacted with the dolomite, formed talc, and swept away most of the excess calcium carbonate. Cross-cutting fault zones and joints serve as ore-forming fluid conduits and often contain minor blooms as subsidiary veins of talc.

The talc in the Yellowstone mine in the Gravelly Range southwest of Ennis is very fine grained and white to light green in color with yellow staining in the weathered or oxidized zones. Dolomite and quartz are the major impurities, with minor amounts of chlorite, pyrite, iron oxides, and dendrites of manganese minerals.

The talc can occur in high-purity thin (<1 m) veins in dolomite or as thick (>200 m) pods of botryoidal form. The talc was formed during the Proterozoic era or approximately 1,700 million years ago. Economic reserves at the Yellowstone mine are in excess of 40 years at present rates of production.

The other major mines are the Regal and Treasure mines in the Ruby Range in Madison County near Dillon. This ore is not as fine-grained as the Yellowstone mine ore, is white to gray in color, and occurs in lenses of 1- to 5-m thickness in a dolomite host rock. Chlorite is a major impurity along with dolomite, quartz, and magnesite. Pyrite, graphite, mica, and titanium are minor components.

New York. Metamorphic talc ores are mined from the Precambrian Grenville Province in northwestern New York near the towns of Gouverneur and Balmar. In the early years of these mines, which have been exploited since 1878, underground mining was mainly used, but operations are now consolidated into two open-pit mines. The ores are highly tremolitic; typically 60% tremolite, 30% talc, and 10% serpentine. They are very white, low in iron, and occur in both thin veins (2 to 5 m) and thick seams (40 to 80 m) over a

13-km-long, 150-m-wide belt. The host rock is a marble with some gneiss. Zinc deposits also occur in the vicinity, and talc contamination was a major problem in the beneficiation of the zinc ores.

Product applications are focused on paint, with ceramic tile, once a major market, now declining in volume because of technology changes. That, along with health concerns about tremolite, accounts for the decline in production in this area over the last 20 years.

Texas. The major talc production in Texas is from the Allamore Formation near Van Horn in west Texas. The formation is approximately 32 km in length and 8 km wide with talc occurring very close to or at the surface, in thick (10 to 500 m) seams in a host marble and phyllite rock. The talc is of metasedimentary origin and quite unique in that most of it is very dark gray or black. The ore is typically 80% to 85% talc, 10% to 12% carbonates, 2% to 4% quartz, and 0.1% to 0.7% graphite, which accounts for the black color. It is very low in iron content (<0.3%) and thus fires white. Smaller zones of pink to white talc occur and are mined for color-sensitive applications.

The major market for west Texas talc has always been ceramic tile. Because low-cost natural gas is available for firing, the tile industry has become concentrated in the southwestern United States and across the Mexican border in Monterrey. Although tremolitic talcs—well suited for pressing into tile—had been available from California and New York, the low cost and proximity of the Texas talc made these deposits more attractive. It was found that if some of the talc was calcined in lump form and then milled with the raw ore, a much more pressable mixture was produced. This became the standard for west Texas talc.

In recent years, production has steadily declined as ceramic tile technology changed, and talc is used now more as an additive than as a major component of tile body raw materials.

Vermont. Vermont has produced talc for more than 100 years. In the late 1800s, soapstone was mined in Vermont and New Hampshire and cut into blocks for stoves and heating utensils. Production of talc powders began in Johnson, Vermont, in 1904. At one time, seven mines were active in the state, but production is now limited to one, the Argonaut, near the town of Ludlow in central Vermont. The Vermont deposits are part of the Appalachian Orogenic belt, which extends north into Quebec and the Superior Province of eastern Ontario. Similar deposits are found in Norway, Finland, and the province of Karelya in Russia.

Talc was formed from the alteration of peridotite (ultramafic) rocks of Precambrian age, first into serpentine and then to talc and magnesium carbonate by reaction with carbon dioxide. Talc-carbonate mineralization generally is found as an alteration zone rimming a serpentinite core. The deposits vary in size from 1 m wide by 200 m length to 150 m wide by 1.5 km length. The margins of the deposits usually have a thin blackwall containing a biotite-chlorite schist in contact with the surrounding host peridotite. Subsequent shearing has complicated the structures and created zones of high-grade platy talc. Grades typically run 45% to 70% talc, with magnesite, chlorite, serpentine, quartz, and mica being the major impurities. Minor amounts of magnetite, chromite, nickel sulfides, and manganese minerals are scattered in the deposits.

Along with the Ludlow deposit, talc has been mined near Johnson, North Troy, and Waterbury in northern Vermont and in Windsor and Chester in southern Vermont. Vermont talc is crushed and milled as a whole ore for use in rubber, roofing, flooring, and other construction products. Some talc ore was also purified by froth floatation for use in cosmetics and reinforcing plastics, but that is now uneconomic. Environmental activism, directed at both the mining and transport of talc, is strong in Vermont and has hurt the industry in the past 20 years.

Other U.S. Production

Over the years, California and Georgia have also been major talc producers, and Arkansas, Alabama, Maryland, Nevada, North Carolina, Oregon, Virginia, and Washington have had limited production, but other than some intermittent campaigns on old mines and tailings piles, production in these states has ceased today. Only limited discussion of these deposits will be given here, but the reader is referred to a report by Greene (1995) for a more complete description.

In southeastern California, the Inyo or Talc City district was a major producer of high-purity steatite talc from underground mines from 1914 until 1978. This metasedimentary-type deposit produced a very white and very machinable grade of talc. Further east, the Southern Death Valley–Kingston District produced, from the late 1920s to the late 1980s, a very white tremolitic talc, valued for its properties in ceramic tile and industrial coatings, especially marine paints. In the northern Sierra Nevada foothills, small, altered ultramafic deposits were mined until 1997 for roofing and construction products. Similar small deposits have been mined in Oregon and Washington states for soapstone blocks.

In Georgia, deposits of the metamorphic type were mined underground in the Chatsworth Area until 1990. Roofing and construction were the major uses, and a froth floatation plant was built in 1987 to make products for paper and plastics. The project failed because of the inability to produce a high-brightness product and the failure to effectively remove tremolite from the talc. In Talladega County, Alabama, a small metasedimentary-type deposit was mined from 1954 until 1998, and a flotation plant upgraded the product for cosmetics markets. Near Murphy, North Carolina, small metamorphic-type deposits, which produced high-brightness talc for cosmetics and paints, were mined until the early 1980s. In Maryland and Arkansas, altered ultramafic deposits were mined for roofing and ceramics markets.

The mineralogy and chemistry of the commercial North American deposits produced today are summarized in Tables 1 and 2. Tables 3 and 4 present the mineralogy and chemistry of the major international talc ores.

Canada

Canada has deposits of talc in almost every province, but today production is limited to Ontario, with minor soapstone production in Quebec. Canadian production in 2000 was approximately 80,000 t. Major altered ultramafic deposits occur in Quebec, Ontario, Newfoundland, and British Columbia similar in nature to the Vermont deposits. Mining of soapstone, which was sawed for use in lining paper digesters, was a major business in the Broughton Area, dating back to World War I. Powder production began in the 1960s with a dry mill in Broughton and a flotation plant near St. Hyacinthe near the Vermont border. These operations have since shut down because of environmental and health (asbestiform contamination) concerns, and now only minor soapstone cutting for stove liners and sculpture carving continues.

Mining of the metamorphic deposits near Madoc in eastern Ontario, which dates from 1896, is now the only North American underground talc mine. The ore ranges from 30% to 80% talc, with dolomite, calcite, tremolite, and mica as the major impurities. It is white to gray in color and milled without beneficiation for applications in plastics and paints.

An altered, ultramafic deposit in Penhorwood Township in northeastern Ontario near Timmins was developed by open-pit mining in 1975, and a froth floatation plant was built adjacent to the mine. The ore is about 45% talc, with magnesite, magnetite, chlorite, and serpentine the impurities. It is now the major talc producer

in Canada and makes products for the paper, plastics, paint, and ceramic industries.

Central and South America

There is minor talc production in Mexico, Argentina, Peru, Colombia, and Uruguay. The major South American producer is Brazil, which mines about 300,000 tpy from deposits in Parana, Bahia, Sao Paulo, and Minas Gerais states. Parana is the major producing state with 200,000 tpy of talc from metasedimentary deposits used primarily in the ceramic tile industry. The ore is 60% to 90% talc, with carbonate, chlorite, and quartz as the major impurities. It is gray to black in color but fires white because of a low iron content. In Bahia Province, a higher-purity white talc is produced by floating talc from a magnesite ore that is mined for steel refractories. Also in Bahia, some highly platy, mica-type talc ores are selectively mined in small quantities for the cosmetics market.

Europe

The major talc producer in Europe is Finland, with almost 500,000 t, followed by France (350,000 t), Italy (140,000 t), Austria (135,000 t), and Spain (100,000 t). There are major modified ultramafic deposits in northern Europe across northwestern Russia, Finland, Sweden, and Norway. The Finnish paper industry resorted to using these ores as fillers during World War II, when Cornish kaolin could not be obtained. A large paper company, United Paper Mills, developed the Lahnaslampi deposit in central Finland in 1969. A huge flotation facility was built nearby at Sotkamo, and production began to supply filler for papermaking. Two more major deposits at Horsmanaho and Lipasvaara, each with nearby flotation plants, were opened in 1977 and 1985, respectively. These are now consolidated under Mondo Minerals and produce talc primarily for paper coating, filling, and pitch control.

The deposits are all 55% to 65% talc with magnesite as the main impurity. Nickel sulfides occur in the Lahnaslampi ore and are recovered separately in the float circuit and sold as a by-product. The float plant upgrades the talc to ~95% purity with the balance being chlorite and magnesite.

In France, Talc de Luzenac has mined a talc-chlorite deposit of metasedimentary origin at the Trimouns mine in the Pyrenees in southern France for 100 years. The ore vein is 10 to 80 m thick, more than 1,500 km long, and dips at 20 to 60 degrees. The talc was formed when magnesium-rich fluids altered footwall silica and alumina-rich mica schists and gneisses. Chlorite, which makes up 30% to 60% of the ore, was formed in the micaceous and feldspathic footwall during magnesium enrichment, and the silica that was released during chloritization transformed the overlying dolomites into talc. Unmineralized dolomite forms the hanging wall of the deposit. Although the average ore is about 60% chlorite and 35% talc, through selective mining and hand sorting, grades with up to 90% talc are produced. Carbonates (0% to 3%), quartz (0% to 3%), and iron (0% to 2%) are the other impurities. Because of the elevation (2,500 m), mining is campaigned from May through October. After the ore is graded in lump form, it is transported by an overhead cableway down the side of the mountain to the mill located in the village of Luzenac. Paper and plastics are the major markets.

A very similar type of deposit comes from Austria's main producing mine in Rabenwald in the province of Styria. The talc-chlorite ore is mined in an open pit on the top of a mountain, and, after sorting, lump and screened ores are transported down the mountain to the mill in Oberfeistritz by an overhead cableway. In the nearby village of Lassing, 10 underground talc miners in 1998 were killed when the mine was inundated with mud after a heavy rainfall. That mine is now closed.

Table 1. Typical mineralogy of North American talc ores

Mineral	Montana	Texas	Vermont	New York
Talc	95	80	60	30
Carbonates	2	15	35	<2
Tremolite		trace		60
Serpentine			trace	10
Chlorite	1	1	3	
Quartz	0.5	3	trace	1

Table 2. Typical chemistry of North American talc ores, wt %

Oxide	Montana	Texas	Vermont	New York
SiO ₂	61.0	56.8	37.0	60.0
MgO	31.0	31.3	34.0	27.0
CaO	0.3	2.3	1.0	8.0
Al ₂ O ₃	<1	<1	2.5	<1
Fe ₂ O ₃	1.5	0.3	6.0	0.3
LOI*	5.3	8.1	20.0	4.0

* LOI = loss on ignition.

Table 3. Typical mineralogy of international talc ores, wt %

Mineral	Finland	France	China	Australia
Talc	55	55	93	95
Carbonates	40	2	3	2
Chlorite	5	40	3	1
Quartz	trace	1	0.5	0.5

Table 4. Typical chemistry of international talc ores

Oxide	Finland	France	China	Australia
SiO ₂	37.5	45.1	61.0	61.1
MgO	34.0	31.0	32.2	31.1
Al ₂ O ₃	3.5	11.0	2.0	1.0
Fe ₂ O ₃	6.5	2.1	0.7	1.0
LOI	22.0	9.0	5.9	5.5

In Italy, IMI Fabi operates two large underground mines in the Sondria region of northern Italy. The ore, a metasedimentary type with high levels of dolomite and poor color, is used mainly in roofing and noncolor-sensitive plastics applications. Luzenac Val Chisone operates another underground mine at Fontane, near Pinerolo in northwestern Italy. The ore, of metamorphic origin, is particularly platy and white and is prized in cosmetics and plastics. Luzenac also operates a small open-pit talc-chlorite deposit in Sardinia.

Spain

High-purity steatite talc is mined in Leon, and a low-grade ultramafic deposit is mined in Malaga. The Leon ore is from a high-grade metasedimentary deposit with good brightness and low iron content and is especially useful to the large Spanish ceramic tile industry. The Malaga deposit is used mainly in roofing and agricultural applications.

Other European Production

The other major producer in Europe is Norway. Mondo Minerals operates two talc-magnesite deposits (ultramafic origin) in

Altemark and Framfjord. Because of reserve issues, production has fallen significantly in recent years. The ore is milled at plants in Norway, England, and the Netherlands and sold primarily for industrial paint applications. Other small ultramafic deposits are mined in Sweden, the Shetland Islands, and Karelya in western Russia. A quite famous but small, high-purity steatite-grade talc deposit was mined at Gopfersgrun in Bavaria until 2002. The first machinable steatite used by industry was from this deposit, and the first synthetic steatite composition was produced by Thurneaur in 1932 with talc powder from this ore.

Africa

Relatively little talc is produced in Africa, with Egypt, Morocco, and South Africa having the only meaningful amounts of production. Egypt has deposits of both ultramafic and metamorphic origin in the southeastern deserts in the Precambrian metamorphic rocks of the Nubian-Arabian shield. Production has tended to be intermittent because of logistical, economic, and ownership issues. Some high-quality, cosmetics-grade talcs are mined near Agidir in Morocco. South African production is from mainly lower-grade mafic deposits that are milled for low-value uses in rubber dusting, fertilizers, and putties.

Australia

In Australia, three relatively high-grade metasedimentary deposits are mined. In Western Australia, the large Three Springs mine is in a massive, finely crystalline, white, high-purity talc deposit that has been mined by open-pit methods since 1961. The ore body is approximately 500 m long by 350 m wide by 20 m thick and is cut by a series of diabase dikes. Most of the ore is exported in lump form to Japan and Europe for paper and ceramic applications. Luzenac purchased the Three Springs deposit from Western Mining in 2001.

Also in Western Australia, the Mt. Seabrook deposit is a smaller, macrocrystalline, high-purity talc deposit that was opened in 1971. Although operation has been intermittent because of ownership changes and its remote location, the ore is valued in cosmetics markets for its platiness. In southern Australia, the Mt. Fitton deposit is the main source of talc for the Australian domestic market. The talc occurs in narrow (1 to 5 m thick) veins in a dolomitic rock, and both high- and low-purity grades are produced and shipped to a mill in Adelaide.

Asia

Asia is both a major talc-producing and -consuming region. China is the world's largest producer and exporter with 1.7 Mt, while Japan (450,000 t) and South Korea (200,000 t) are major importers. India (450,000 t) is the other major producer with most talc consumed domestically (Roskill Information Services 1997; Harris 2001; Virta 2004).

China

China has approximately 120 working talc mines located in three provinces: Liaoning and Shandong in the north and Guangxi in the south. Almost all the talc is of metasedimentary origin, and much of it, especially in Liaoning and Guangxi, is of high purity and has high brightness. Ownership is distributed among a range of provincial, district, and local village governmental bodies with limited private ownership.

The Liaoning deposits formed as metasomatic replacements of magnesitic and dolomitic carbonates of the Late Proterozoic Liaohe-Dashiqiao Group. The carbonates are dominantly magnesite with some tremolitic deposits within dolomite and calc-silicate rocks. The rock orientation is east-northeast. High-purity veins are gener-

ally podiform and sheared. Mined widths range from 2 to 15 m with strike lengths from 10 to 500 m. Deposits are mined both underground and in open pit. The ore is sorted in lump form at the mine or in nearby villages, and about 50% is exported to Japan, Taiwan, and Korea.

In Shangdong, the deposits belong to the Late Proterozoic Jueten-Zhanggezhuang Group. The talc is formed by metasomatic replacement of magnesium carbonates. Most ore is mined underground in veins of 7 to 30 m in width, often extending for hundreds of meters. The ore is of lower grade (<85%) talc, with the balance being magnesium carbonate and dolomite. Most ore is milled and used locally in the paper and ceramic industries.

In Guangxi, the talc deposits belong to the Middle Proterozoic Banxi-Heong Group and are the largest, highest-purity veins of talc in China. The principal mines are located along a N30°E fracture zone within a belt 2 km wide by 8 km long. The host rock is an off-white dolomitic marble that is contorted into high-amplitude isoclinal folds.

The talc veins are concordant, lenticular bodies that average 5 m in thickness and are 200 m long. The veins widen to 80 m and have sharp but irregular contacts with the host marble. The ore is typically light green to gray and locally very white. Chlorite, dolomite, magnesite, and quartz are the main contaminants.

Almost all mining in Guangxi is in open pits. Most high-brightness ore is exported to Europe and the United States in lump form. Reserves of high-brightness talc and production have been reported as diminishing in recent years.

India

The major Indian reserves and production are in the state of Rajasthan where the Golcha Group is the dominant producer. Most deposits are of the metasedimentary type, mined by open-pit methods, and sorted and processed locally for the domestic market. Approximately 5% of production is exported to Europe, Southeast Asia, and western Africa.

Production of talc is limited elsewhere in Asia, with Korea, Japan, and Iran having significant deposits and some production. At one time, Korea was a major producer, but output has fallen because high-quality, low-cost ore is available from China.

TECHNOLOGY

Exploration

Despite the availability of many modern geophysical techniques, the most effective talc exploration techniques are traditional field diagnostic, sampling, and mapping methods. Although talc is physically weak, it is chemically very stable, and the presence of talc in outcrops and in the overlying soils is the best diagnostic tool. After the deposits are sampled and mapped, if the quality is acceptable, the deposit is drilled, the quality confirmed, and the reserve estimated.

The value of any talc deposit is a function of its color, purity, and location, along with the availability of appropriate markets. Nowhere is this more true than in Finland, where relatively low-purity and low-color ultramafic deposits were developed successfully to serve the local paper market and replace expensive imported kaolin.

Mining

Most talc is mined today by conventional open-pit, drill-and-blast, shovel-and-truck techniques. The major difference from conventional technology is that blasting is minimized to reduce breakage of soft talc ore, and all shovel work is accompanied by a high level of selectivity to minimize cross contamination of high- and low-grade material. Many producers analyze blast-hole cuttings

to delineate ore grades and select blast patterns accordingly. Shovel operators can select ore or waste by color or texture for different grades. Equipment such as 10-m³ shovels and 150-t trucks are common in North America and Europe, while 1-m³ shovels, 20-t trucks, and even hand-carried baskets are used in Asia and Brazil.

A typical western talc deposit is drilled on 30- to 50-m spacing, and the ore body is characterized by mineralogy, color, and chemistry. From this, the ore body is defined and a computer-aided mine plan is generated. Overburden is removed and stored elsewhere for eventual use in mine reclamation. Mining is typically done on 5- to 10-m benches. Before each blast, drill holes are analyzed and, if necessary, the shot is reconfigured to remove potential waste or segregate a better quality of ore. After the blast, the shovel operator will selectively scoop the rock into haul trucks and designate it as waste or as a low or high grade of ore.

Waste-to-ore ratios are often quite high, especially for massive steatite deposits. Typical values range from 5:15 for massive ores and 1:3 for the lower-purity ultramafic grades. Underground mining is now less common and is declining rapidly in importance. Pure talc is a very soft, noncompetent rock, which is often highly fractured, of varying thickness, and in steeply dipping bodies. Where veins are thin and the surrounding rock is competent, overhand mining is acceptable with limited timbering. In thicker veins, underhand mining is necessary; where the veins dip steeply, shrinkage stoping is used. Some low-grade deposits can be mined by room-and-pillar methods, for which equipment is much smaller, blasting and mucking much more selective, and waste-to-ore ratios much lower than in open-pit mining. Continuous miners can be used on softer high-grade veins.

Reclamation

In contrast to past practice, reclamation is now an integral part of all talc mining in developed countries. Waste piles are graded, covered with topsoil, seeded, and monitored for a return to natural vegetation. For both surface and underground mining, both surface and subsurface water flow is measured, monitored, analyzed, and if necessary treated to meet local and national discharge standards. Some pits are backfilled or converted to a beneficial long-term use, such as recreation.

Beneficiation

Two major types of ore beneficiation are used for talc: sorting for massive talc ores and froth flotation for ultramafic and lower-grade ores. The sorting technology includes hand sorting of lump ore, mechanized optical sorting of pebble-sized ore, and slide sorting of lump ore to separate talc from dolomite and other impurities. Hand sorting usually takes place in sheds at process plants. Screened ore (5 to 25 cm in size) is run across belts, and, if low grade, talc is picked from the ore; if high grade, waste is picked from the talc. A slide-sorting process to replace this function was patented by Cyprus Industrial Minerals (now Luzenac America) in 1988. Talc has a much lower coefficient of friction than dolomite or quartz, so when dropped on a rotating plate, talc will quickly slide off while the other ore will be carried around and removed by a scraper. This type of sorting is particularly useful for high-grade talc that occurs in narrow (<1 m) veins in a carbonate host rock.

Optical sorting processes usually require talc to be washed and screened into narrow pebble size (1–2 cm) range. A camera scans each particle as it falls through a testing zone, and then jets of air either remove ore (for low grade) or waste (for high grade). This type of sorting is suitable for higher-value products such as required for cosmetics or plastics applications.

An important factor in the sorting and color beneficiation technology is that blending of low- and high-color ore is not linear. If equal parts of an 80 and a 60 brightness ore are mixed, the color is not 70 but much closer to 60. Conversely, if a small fraction of high-brightness ore is sorted out of a low-brightness ore, the effect on the color of the remaining low-brightness ore is minimal.

Ore beneficiation by froth flotation is usable for almost any ore, but it is particularly useful for ores where the talc is intercalated with the waste, such as talc ores of ultramafic origin. Ore is crushed and then milled to liberation size, typically about 50% passing 325 mesh. It is slurried in water at about 25% solids, and a frother, such as methyl isobutyl carbinol, is added. It is then passed through two to five stages of flotation where the talc content is upgraded to >95% purity. Carbonates, quartz, chlorite, and tremolite are selectively removed by this process. If a problematic level of dark magnetic minerals is present, high-energy magnetic separation is used to remove them from the floated product. The concentrate is thickened, filtered, and flash dried. Some producers mill in conjunction with the drying process.

Analytical Techniques and Measurements

A tiny fraction of talc is sold in lump form for carving, machining, or decorative applications. A significant volume of Chinese, Australian, and U.S. production is exported in lump form to the consuming countries. The vast majority of the ore must be reduced to a powder for end use. The size needed ranges all the way from –10 mesh (top size 2.5 mm or 2,500 μ m) to 1,250 mesh (top size 10 μ m). The distribution of the particles, sometimes called the granulometry, is also important. Some applications require a narrow particle-size distribution and some a broad distribution. Finally, the shape of the particles is critical in some applications and is affected by the grinding method.

In describing milled products, a number of measurements are used, most notably median particle size and top size. Median particle size is most often measured by sedimentation techniques using an instrument called a sedigraph. The sedimentation technique assumes that all particles are spherical, which talc particles are not. A sedimenting talc platelet will behave like a much smaller sphere, skewing the reported distribution toward the fine end. The technique is generally used only for subsieve-size particles (100% finer than 100 mesh [150 μ m]). The technique will give a full particle-size distribution and is accurate down to ~0.3 μ m. The other major subsieve technique is laser particle size analysis with instruments made by a number of companies including Coulter, Alcatel, and Horiba. Unlike the sedimentation technique, the laser analyzer measures the long dimension of the talc platelet, and thus the distribution reported by the laser will be quite a bit larger than that by sedigraph.

For top-size measurement, sieving and Hegman drawdowns are used. Sieves of 40 to 325 mesh are common. The Hegman bar, also called the fineness-of-grind gauge, is a technique borrowed from the paint industry. A small quantity of talc powder is dispersed under high shear in a vegetable oil. A small portion of the talc in oil dispersion is placed on the Hegman bar, which has a very accurately machined groove with a depth of 100 μ m at the top end and zero at the bottom. When the talc in oil dispersion is drawn down through the groove, the coarsest particles will show up somewhere in between, and the material is given a Hegman rating based on the largest particles in the sample. For instance, particles of 70 μ m give a 3 Hegman, and particles of 25 μ m would give a 6 Hegman.

Other critical properties that are measured include surface area, bulk density, and color. Surface area is measured by the Brunauer, Emmet, and Teller (BET) method. It consists of adsorbing

The most common milling machine in the talc industry is the ring roller mill, with the Raymond roller mill being the most popular type (Figure 4). In this mill, ore up to 50 mm in size is swept into a grinding zone between a set of rotating rolls that mill the talc between them and a horizontal ring. The fine product is swept out of the milling zone up to an air separation zone. Here a set of horizontal blades, called a whizzer, creates an airflow in a horizontal direction to the sweep air and forces the coarse particles out to the side and back down the circumference of the cylinder into the grinding zone. The fine product continues with the sweep air and is removed by centrifugal action in a cyclone. The air is recirculated with a large fan back into the grinding zone. A slipstream of air is pulled off after the fan into a dust collector. This keeps the whole system at a slight negative pressure and removes fines that are too fine for the cyclone to remove.

Roller mills are effective devices for milling softer (up to 3.5 Mohs hardness) materials down to 325 mesh top size (44 μm). They appear to preserve the aspect ratio and, if heat is applied, have the capability to do limited drying of wet feed. The primary control mechanism on the mill is the whizzer speed, with a higher speed giving a finer top size and a finer median particle size.

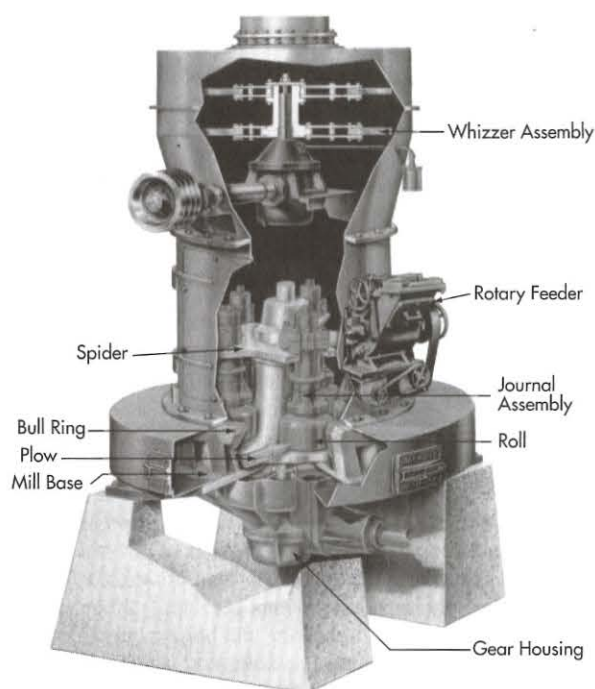
Newer mills use the more-sophisticated cage classifiers in place of the whizzer, which is not an efficient separation device. Cage classifiers require a higher pressure drop and usually a bigger fan but will enhance both throughput and top-size control. Products as fine as 5 Hegman can be made with enhanced classifier systems. Some producers use ball mills in closed circuit with air classifiers, especially for harder tremolitic talc or ore with high carbonate content.

To mill from a 325 mesh to a 6 Hegman, the most efficient machines are hammer mills with built-in classifiers, such as the Raymond vertical mill or the Hosokawa Micron air classifying mill, or ACM. The ACM is a compact hammer mill with an integral highly efficient cage classifier. The hammers are mounted on a plate in a cylindrical housing, and the rotation forces the particles to impact a serrated liner. They are then air-swept into the cage classifier zone where the coarse are knocked back and the fines are sent on to collection in a baghouse. The ACM can accept feed up to approximately 6 mm. The primary control mechanism in the ACM is classifier speed, with a higher speed giving a finer top size and a smaller median particle size.

For ultrafine grinding, often called *micronizing*, fluid energy mills are used. In this process, high-pressure (>10 bar) air or steam is expanded through nozzles into a grinding chamber. In some of these, the grinding chamber is a doughnut-shaped system, and the high-speed air flowing around the chamber in a centrifugal motion causes the powder to grind against itself. In the Aljet type, the fine product is taken off on a slipstream on the inside of the doughnut. In the Alpine type, the grinding is done by streams of opposing nozzles that inject pressurized air and powder into the base of a cylinder (Figure 5). The fines are taken by the milling air into the classification zone on the top of the cylinder where multiple cage classifiers reject coarse particles back into the mill. Product from all these systems are collected in baghouse filters, with care being taken to ensure that any cooling does not approach the dew point of the steam effluent.

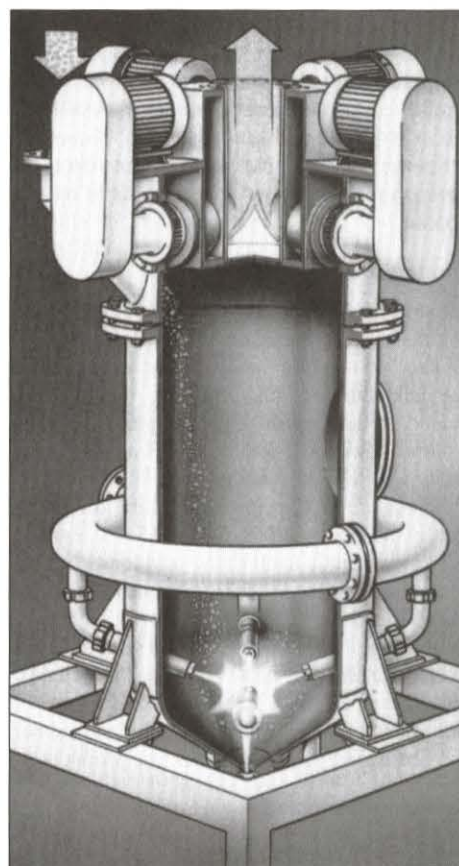
Fluid energy mills are effective for milling from approximately 4 down to 7 Hegman top-size products. At the same top size, they will give a much finer median particle size than the ACM, and the centrifugal-type mills are believed to be better delaminating devices than the ACM.

The primary control mechanism in fluid mills is the integral or external classifier speed, with a higher speed giving a finer product. For mills without a classifier, the product can be made finer with a higher fluid-to-talc ratio or a higher fluid pressure.



Adapted from Combustion Engineering sales brochure.

Figure 4. Raymond roller mill construction features



Adapted from Hosokawa Alpine sales brochure.

Figure 5. Alpine fluid energy mill

Size Classification

The separation of products by particle size is just as critical a part of process technology as milling and, in most cases, is integrated into the milling circuit.

Screens are excellent absolute size separation devices, but their capacity and efficiency decline rapidly with finer meshes, and they are subject to rapid blinding and high maintenance with fine powders, platy materials, and agglomerates. In general, conventional screens are effective for separation of talc powders down to about 60 mesh. Below this, the powders agglomerate and blind the screens. For scalping-type applications (<0.5% oversize), air-swept screens can be used for powders down to 100 μm .

Air classifiers are devices in which a stream of air that contains fine particles (usually <100 mesh) is subjected to a velocity perpendicular to the direction of flow. This will cause the coarse particle to be deflected, allowing the fine particles to pass through. Two types of devices are used to create the perpendicular flow—blades (sometimes called whizzers) and cages that have a fanlike design. The latter are much more efficient, especially at fine particle sizes, but have higher pressure drop, lower capacity, and more potential problems. Typically the flow is upward, and the cage or whizzer is mounted vertically. When the separation points get finer (<20 μm), however, it is often advantageous to mount the unit horizontally.

Classifiers do not make a clean cut, and a platy particle behaves like a much smaller sphere. In addition, there are problems with bypassing, dispersion, and airflow control. In the most sophisticated units, all the accepted (fine) particles are forced through the vanes of the cage and exit through a hollow shaft on which the cage rotates.

The primary control parameter is the speed of the whizzer or cage, but other variables like airflow, air-to-solids ratio, and particle surface energy have significant effects. For any classifier, the higher the air-to-solids ratio, the better the classifier will work. But the operating cost is higher and the capacity is proportionally lower. Higher surface energy will have a detrimental effect in encouraging agglomeration, and this energy is an inevitable by-product of the milling process.

Densification and Compaction

The fluffy nature and low bulk density of fine talc products makes packaging and shipping difficult and expensive. To overcome this, producers use de-aeration and agglomeration technology to increase the bulk density of fine products.

The standard de-aeration technology uses a Carman densifier to pull air out of powders. The powder is transferred through a horizontal screw, which is surrounded by a filter cloth. A vacuum is pulled on the outside of the cloth, increasing the bulk density of a fine product by more than 100%, from 0.15 to 0.3 g/cc. The process has little effect on the talc itself as the powder reflows with minimal agitation. It does allow the product to be packaged in smaller sacks or to get 100% more talc in a regular sack.

In compaction the fine talc is wetted with about 20% water in a continuous mixer, and this paste is forced through a circular die to form pellets. These pellets are then dried to ~2% moisture for paper applications and <0.5% moisture for plastic and rubber. Bulk density is increased from 0.15 to 1 g/cc for fine products.

Other Processing Technology

A limited amount of talc is surface treated to improve its performance in specific applications such as plastics, rubber, and cosmetics. Amino-silane, polyethylene glycol, and stearates are some of the materials used. In general, the level of coating on talc products is rel-

atively low, in many cases less than 1%. This is in contrast to carbonates, where stearate coatings reach 3 wt % for ultrafine products.

A major development, especially in northern Europe, is the delivery of fine talc to paper mills in slurry form for use in paper coating. Fine talc, which has high surface energy and hydrophobicity and a platy structure, is difficult to wet in water and extremely difficult to make into a stable, high-solids slurry. Nevertheless, close to 350,000 tpy are now produced in this form in Europe. The talc is dry milled and then made down into slurry using high-energy mixers and a proprietary package of dispersants and stabilizers. The slurries have solids content of 61% to 65% and a viscosity of ~200 centipoise. A limited amount of talc is also shipped for pitch-control applications in slurry form, but the solids content is much lower and no chemicals are used.

Packaging and Shipping

Talc products are shipped in supersacks (400 to 1,200 kg) and in paper bags (usually 25 kg), stacked on wooden pallets. Transportation to the customer is a significant portion of the total cost of talc products, averaging 25% to 30% of the cost and, in some cases, more than 50%.

Most talc products are now shipped by truck. The combination of faster, more-reliable delivery and lower costs for most customers continues to favor this mode. Rail is used for larger-volume bulk customers when the haul distance is more than 500 km. Most trucks will deliver coast to coast in 4 or 5 days while rail delivery will typically take 2 to 3 weeks.

Bulk trucks are very popular with customers, because the truck driver unloads the material with a compressor on the truck, in contrast to bulk railcars where the customer has to supply the compressor and unload the material. Most product is shipped directly to customers. Smaller customers typically purchase through chemical distributors, who buy the product from the talc mills and store it locally.

PRODUCT APPLICATIONS

The section that follows is not intended to be scientifically complete or to cover all the applications and potential applications in different industries, but is more heavily weighted to major applications, major developments, and technological changes that affect talc consumption. This section also attempts to evaluate talc's position in the market compared to competitive minerals and chemicals.

Almost all of the talc markets are mature and thus are characterized by limited growth (at or below gross domestic product [GDP] rates), customer consolidation, competitive substitution from other minerals, and downward pressure on prices. This is certainly true of the pulp and paper, paint, rubber, joint compound, putty, flooring, roofing, cosmetics, and agricultural markets. The exceptions are plastics and ceramics. Although plastics is a mature business, it is enjoying a growth spurt as talc-reinforced polypropylene replaces more expensive engineering polymers in automotive applications. New applications in ceramic pollution-control devices are also showing significant growth.

In most markets, talc competes with other minerals, such as calcium carbonate, kaolin, and silica. In some markets, however, most notably pitch control, talc competes with alternative pitch-control technologies, including dispersant and detackifying chemicals, periodic solvent washes, or improved processing procedures.

Another critical piece of the application picture is the usability of the talc product. In paper, for instance, although customers prefer slurry, producers find it more convenient to supply a dry product. In plastics, customers prefer a dense, dustless, easy-to-disperse pellet. Plastic compounders are now supplying concentrates of 70% to 80% talc in plastic resin.

Paper

Pitch Control

Beginning as an accidental development of Sierra Talc Company in the northwestern United States in the late 1950s, the pitch-control market has grown steadily to become the largest market for talc in North America today, consuming close to 160,000 t in 2000 (Table 5). The pitch-control market has consistently been dominated by Montana-based products, and although the talc has become coarser over the years, the market continues to accept microcrystalline products from Montana as the industry standard.

Wood is made up of three components—fiber, cellulose, and resins—that are liberated from each other in the pulping process. In thermomechanical pulping, the wood is broken apart by a combination of heat and energy, and all the components are left in the final pulp. In chemical pulping, a combination of mechanical, physical, and chemical separation processes are used to produce essentially pure fiber. It is in chemical pulping that talc works best, helping to produce a cleaner and more valuable fiber. Talc has also had good success in recycle mills, where previously used paper is repulped, and contaminants, such as ink and adhesives, are removed by physical means. In both cases, talc is used more or less as a scavenger for the residual oil droplets or resin particles that are left in the pulp. It prevents them from adsorbing on machine surfaces, screens, and felts, and the talc/contaminant mixture is retained in the pulp as an inert filler.

The mechanism by which talc works is not totally clear, except that it effectively sorbs on to the pitch, detackifies it, and limits its ability to deposit. Some of the mechanisms that appear viable are migration of the talc into the oil phase, the peptizing of pitch particles by the surfactant-like talc, the adsorbing of pitch onto the larger planar surfaces of talc, and the steric stabilization of the pitch dispersion by the talc. One or more of these mechanisms is likely to be effective in different situations.

Where talc is ineffective, as in thermomechanical pulp, the mechanism is clear. The anionic trash (lignin products) left in the pulp preferentially adsorb on the surface of talc and render it ineffective. Even 1,000 ppm of anionic surfactant will completely negate the ability of talc to work in this environment.

In earlier years, talc was added to the process in repulpable 50-lb bags. Talc producers, such as Cyprus, developed talc dispersion units (TDUs) that can take talc from a supersack or bin and produce a dilute (~5%) suspension of talc in water. Typical addition rates are 5 to 10 kg of talc per ton of pulp. The standard product for the application is a microcrystalline Montana talc product milled to a 3.5- μ m median particle size and a surface area of 13 m²/g.

The main competition for talc is from specialty chemical companies. Traditionally, these companies sold dispersants for this application, but dispersants sent the pitch to the waste treatment plant where it added to chemical oxygen demand (COD), whereas talc kept the pitch in the pulp. The specialty chemical companies have now revised their products and sell materials with trade names such as Surround and Detac, a competitive recognition of the peptizing and detackification properties of the talc product.

Paper Coating

The concept of talc as a paper-coating pigment was developed by the Finnish United Paper Mills and its subsidiary FinnMinerals in the early 1980s. Partially driven by a need to control the costs of imported English coating kaolin, the company found that talc significantly improves print quality and cuts down on core burst problems when used as a component of rotogravure grades of lightweight coated paper. Today, more than 300,000 t of talc are

Table 5. Talc usage by major market area, ktpy

Market Area	North America	Europe	Asia
Paper	195	605	1350
Plastics	160	280	170
Paint	150	155	105
Ceramics	130	150	90
Putties	120	90	50
Cosmetics	35	25	25

used for this purpose in Europe. North American coating talc use is minuscule because of the relative economics of talc and kaolin. In Europe, most kaolin is imported from the United States or Brazil and is more expensive than talc. In North America, high-quality delaminated kaolin is available from Georgia at half the price of talc.

The coating product used in Europe has a 2.5- μ m median particle size and 85 GEB and is sold in a highly stable 63% to 64% solids slurry. Most is produced in Finland from a macrocrystalline ore made by froth flotation and dry micronizing.

Paper Filling

Talc has been used in paper filling for more than 80 years, especially where it was inexpensive and where kaolin was not available locally, such as in southern Europe, China, Japan, and Finland. At one time, more than 1 Mtpy was probably consumed worldwide for this application. With the increase in alkaline pulping throughout the world, usage has declined, but the market still exists for certain grades in Europe, China, and Japan. The typical product is 99.9% -325 mesh, and 80 to 85 GEB. Because of its surface and larger particle size, talc has better retention in paper than kaolin, improves drainage and print properties, and generally makes a stronger and smoother sheet.

Little talc has been consumed in North America for this application since Georgia kaolin became plentiful and inexpensive in the 1930s. In the rest of the world, the application is declining because of the availability of less-expensive ground and precipitated calcium carbonate fillers.

Paints

Talc and other mineral pigments such as calcium carbonate have been used in coatings for more than 100 years. Initial use was based on local availability, acid insolubility, and whiteness. Over time, talc has been recognized for its good anticorrosion and moisture barrier properties, weathering and antisetling properties in oil, hiding and color extension, and flattening properties. Today approximately 150,000 tpy are used in paint in both North America and Europe.

Basically, two grades are sold. The coarser 3 Hegman grades are used for general purpose extension in architectural (household) coatings and as a functional additive in alkyd primers and industrial coatings. Finer 5.5 to 6.5 Hegman grades are sold for flattening in alkyd coatings, barrier applications, and corrosion prevention in maintenance coatings; for pigment extension in color concentrates; and for viscosity build in gel coats. The coarser products represent 60% of the overall volume. Other than top size, the most important properties of a talc in coatings are color or brightness and its contribution toward the paint viscosity. The viscosity build property is loosely related to oil adsorption (ASTM D281), and a high or low value can be beneficial depending on the system employed.

Although most of the products sold are made from high-purity, platy ores, the tremolitic New York State talc and the natural

talc-carbonate ores are favored for certain applications because they have lower viscosity and better scrub resistance than pure talc. The 3 Hegman grades are made on roller mills or ball mills in closed circuit with air classifiers. The 6 Hegman grades are made on fluid energy mills and air classifying mills.

In water-based coatings, talc is a good spacer for prime pigments such as titanium dioxide; it reinforces the film, contributes to low shear rheology (antisetling), and helps to roughen the surface, which reduces gloss and promotes interlayer adhesion. In oil-based coatings, talc wets out easily, reinforces the film, reduces permeability, and has inherent corrosion-resistant properties. The gray epoxy paint on U.S. naval vessels is pigmented with mostly Montana talc and a little lampblack.

Talc competes with calcium carbonate, kaolin, and mica in the paint market. Although it is more expensive and generally not as bright as calcium carbonate or kaolin, it has better weathering and anticorrosion properties and a lower "b" value or yellowness than kaolin. Because of its higher cost, however, it is rarely used (only when its functional properties justify the extra expense) as an inert "filler." As the production of oil-based coatings continues to decrease, the paint market is relatively static for talc because the limited overall market growth just about compensates for the loss of talc share.

Plastics

Plastics is the fastest-growing market for talc in North America, with growth rates of more than 6% per year with close to 140,000 t consumed in 2000. The main application is reinforcing and nucleating polypropylene, especially for automotive uses. Lesser amounts are used as film antiblock additives and in engineering and thermoset polymers.

The polypropylene (PP) application is driven by a basic technology shift in automotive production. Talc-reinforced polypropylene replaces a number of more expensive and exotic engineering polymers, especially acrylonitrile butadiene styrene (ABS) and polyurethane in the interior panels and exterior bumpers of cars. The engineering polymers sell for \$2 to \$4/kg; polypropylene sells for \$0.7 to \$0.9/kg. But PP itself does not match the strength, heat resistance, dimensional stability, or molding properties of the more-expensive polymers. PP is a semicrystalline polymer, and talc surface has the ability to improve the crystallization rates to the point that dimensional stability is improved, mold shrinkage is reduced, and stiffness is improved. Fine talc is used at 2% to 10% concentration in large parts like bumpers for this purpose. Talc is also capable of reinforcing PP, increasing stiffness 150% at 30% to 40% loading. This property is used in interior panels and dashboards. Molded color is extremely critical in this application because the parts are color matched. Under the hood, black parts such as ducts and covers are also made from talc-reinforced PP. Here, heat resistance and long-term heat stability are critical. In the PP resin, 325-mesh talc products are used at 30% to 40% concentration.

The shift to PP has been driven by Japanese manufacturers, who have reduced the number of parts and the total cost of their cars by using this and other technologies over the last 10 years. As more Japanese auto companies have begun manufacturing in North America, they have been followed by Japanese compounders for talc-reinforced polymers. These compounders tend to use the finest and whitest talc products, and their technology is now being transferred to U.S.-based companies.

Talc-reinforced products are also used in appliances such as washing machines and refrigerators, in plastic trays for fast-food restaurants, and in fire-retardant applications where talc will increase low shear viscosity and prevent the hot plastic from dripping.

In polyethylene film, talc at about 0.5% will act as an antiblock. It detackifies the resin so that adjacent layers of film will not stick together, but it will not negatively affect film clarity or strength. Talc is also used to nucleate and reinforce nylon and polyester for electrical and packaging applications.

A major handicap to talc use in polymers is the difficulty of mixing it into resin. Most of this is done by specialty compounders, who use high-energy extruders or rubber mixers. These compounders now generally sell their products as 40% to 80% talc in resin concentrates to the manufacturers who actually mold the parts. These master batches are mixed with virgin plastic pellets and extruded or molded at the proper talc loading, usually less than 30%.

Even though talc has a major position in plastics and its use will continue to grow as domestic auto producers switch to PP, it is losing market share to calcium carbonate, especially stearate-coated fine 1- to 3- μ m products, elsewhere in the plastics market. Carbonates provide impact resistance but little stiffness. They work well in applications where the finished product is low in price and disposable, such as plastic grocery bags. Carbonates have always dominated the thermoset portion of the market but now are growing dramatically in film, polyvinyl chloride (PVC), and general construction products. With the exception of nylon, kaolin finds little use because of its surface properties. It does not mix well with polymers and will degrade the polymer during compounding.

Talc is also widely used in a related industry: rubber. Micronized talc is used as a reinforcing agent in mechanical rubber goods such as hoses and belts and as an insulating agent in wire and cable coatings. It will also function as a process aid in extruded rubber profiles such as the seals on automobile doors and windows.

Coarser 325-mesh talc is used as a dusting agent on molded products such as tires and elastomeric thread. These markets, however, are declining.

Ceramics

Ceramics remains a major use for talc in the Americas, especially in the floor and wall tile industries of the United States, Mexico, and Brazil. At one time, tile consumed 50% of U.S. talc production, at more than 600,000 tpy. The tremolitic and white firing talcs from Death Valley in California and from New York, and later the white-firing ore from west Texas, were particularly preferred. The typical body was 60% talc and 40% ball clay, pressed and slow fired to form a porous bisque, which was then glazed and refired to make the final tile. Until the 1970s, when new glazes were developed, this was the only way to make a tile on which the glaze did not crack.

This technology is no longer economically viable. Most tile products today are either single-body porcelain tiles or pressed, glazed, and fired only once. Feldspar, silica, and ball clay are the major body components, with talc reduced to the role of a fluxing additive to reduce porosity and increase strength. As such, it is used at levels of 3% to 7% in the body. This is still substantial, as the ceramic tile industry is very large and growing at more than 5% per year.

In tile applications, talc purity is not critical, but low iron content (<0.5%) is. Most of the product used in the United States and Mexico still comes from west Texas, with minor amounts from New York. Many producers purchase lump ore and co-mill the talc with feldspar and other ingredients. Where powder is used, coarse products with 99% passing 100 mesh are typical.

A major growth market for talc is the honeycomb cordierite substrates used in automotive catalytic converters and diesel particulate filters. As clean air regulations become more stringent and extend to include light- and heavy-duty trucks, this market is

expected to grow dramatically. Cordierite is a magnesium aluminum silicate, which is formed at 1,350°C by firing a mixture of talc (35%), kaolin (40%), and alumina (15%). Cordierite has an extremely low coefficient of thermal expansion, which allows it to go through thousands of heating and cooling cycles and maintain its mechanical strength. This market is dominated by two suppliers: Corning of the United States and NGK of Japan. High-quality talc from North America is used worldwide in this application.

The traditional electrical porcelain markets in synthetic steatite and cordierite are declining rapidly. Synthetic steatite can be made by pressing or extruding a mixture of 80% talc, 10% plastic kaolin, and 10% feldspar and firing to 1,250°C. Although synthetic steatite was used in high-temperature and high-frequency insulators in the automotive industry and in appliances, today better plastic products are replacing the synthetic steatite in lower-voltage applications. Other markets in whitewares and kiln furniture are declining because of technological changes.

Talc does not compete with any other mineral in ceramics.

Construction Products

This area, which includes roofing shingles, vinyl flooring, joint compounds, caulking compounds, and automotive body patching, is a huge market for minerals, most of which are low in price. More than 100,000 tpy of talc are sold into this market, most of it low brightness and low purity. The major mineral used in this market is limestone, with close to 10 Mt utilized each year.

In the manufacture of asphalt roofing shingles, coarse platy talc is applied to the back of the shingle to prevent sticking during the manufacturing process, storage, and shipping. A platy talc with 100% passing a 30-mesh sieve and <40% passing a 200-mesh sieve is preferred. Talc competes with sand and coal slag in this application. In the manufacture of rubberized asphalt sheet roofing, 200-mesh roller-milled talc can be used as a filler to reduce the loss of lighter hydrocarbons in the asphalt and improve weathering. Talc also competes with limestone in this market.

In vinyl flooring, talc is used in the felt backing to prevent cracking when the felt is bent during installation. In sheetrock joint compounds, 200-mesh talc is added to build body, prevent cracking, and promote sanding properties. Such compounds are typically 85% carbonate, 10% talc, and 5% resin and other additives.

In caulking compounds, talc and synthetic silica are used together to obtain the right combination of flow (low high-shear viscosity) and sag resistance (high low-shear viscosity). Both coarse and fine products are used at 5% to 25% levels in the formula. In automotive body patch, talc makes up about 45% of the formula, with polyester resin as the balance. Talc builds viscosity and creaminess and allows for good sanding after the polyester cures. The mixed talc-carbonate Vermont ores milled to 200 mesh are preferred.

Cosmetics and Pharmaceuticals

Baby and body powders are one of the more traditional and best-known uses for talc, but it is a market in continuing decline. In developing countries, talc is used extensively in bar soaps and detergent powders, but elsewhere body powders are being replaced by stick and spray deodorants, and many powders are now starch or starch-talc blends. About 35,000 tpy are used in this area, and, although the average selling price is one of the highest in all industry segments, both pricing and volume continue to decline.

The major products are pure 200-mesh roller-milled talc made to tight chemical, microbiological, and loose bulk-density specifications. The market has now gone primarily to high (>0.5 g/cc) loose bulk-density products that flow and fill better and are sold pri-

marily as superstore brands. Only a few brand name marketers such as Johnson & Johnson participate now, and their share continues to decline. Elsewhere, 200-mesh talc is also used as a minor ingredient in "speed-stick" type underarm deodorants, whereas finer talc is used in pressed powders, creams and lotions, and chewing gum.

The market for talc in cosmetics and personal care is still very much under a cloud because of potential action from the National Toxicology Program (NTP) on the health aspects of talc.

Other Applications

Agricultural Products

Talc has traditionally been used as a carrier for all kinds of pesticides, herbicides, fungicides, and crop dusts, although these uses have declined except for seed potato dusts. It is also used as a parting agent for granular fertilizers and ammonium nitrate, but this application has been replaced largely by oil-based soaps. Talc is used as a flow improver for hygroscopic feeds like soy meal, as a process aid in certain types of olive oil production, and as a lubricant in many seeder machines, where it competes with graphite.

Friction Products

Coarse talc is used in the manufacture of brake pads, primarily to adjust the coefficient of friction in conjunction with graphite. Talc is also used as a lubricant in some dry lube and grease formulations.

Wastewater Treatment

Talc can act as a flocculant for the mixed bacteria in biological oxidation systems that are widely used to remove soluble organics from both municipal and industrial wastewater or as an absorber of oil and grease in primary treatment. The application has been patented by Luzenac and commercialized in Europe.

HEALTH AND SAFETY

In the last 30 years, health and safety concerns have become a major issue in the talc industry. The initial problems, dating to the 1970s, were related to asbestiform fibers, but in the last decade, they have extended to crystalline silica and even the talc mineral itself.

Talc powder is considered a nuisance dust and has a threshold limit value (TLV) for an 8-hr exposure of 2 mg/m³. All manufacturers now require workers handling talc powders to wear dust masks if the exposure is close to this level.

The geology of talc makes it apparent that certain types of talc deposits will be associated with asbestiform fibers (metamorphic and ultramafic types). The major commercial type, metasedimentary, is associated with silica. When asbestos carcinogenicity became an issue in the 1970s, much of the talc-producing industry was affected. Fibrous tremolite was recognized as being a carcinogen and tremolite was a component of talc produced in California, Georgia, New York, and North Carolina. All these deposits, with the exception of New York, were shut down. Tremolite occurs in two forms—blocky and fibrous—and R.T. Vanderbilt, the major New York producer, challenged the regulations that treated all tremolite as a carcinogen. In 1994, the federal government agreed and subsequently regulates only the fibrous form.

Although the legal labeling requirement is 1,000 ppm of asbestiform mineral, the analytical techniques for analyzing asbestos have now improved, allowing for its detection by electron microscopy at 10 ppm. Luzenac shut down a mine in Quebec in April 2001 when asbestos fibers were detected at well below the legal limit.

In 1985, respirable crystalline silica was named a probable human carcinogen by the International Agency for Research on

Table 6. World talc production and trade statistics, ktpy

Country	Production	Exports	Imports
China	1,700	950	~2
United States	817	180	250
Finland	475	125	<10
India	465	25	<10
France	330	150	30
Brazil	300	6	10
Australia	180	145	10
Italy	140	75	65
Austria	135	110	40
Spain	114	63	64
Canada	80	45	50
Japan	45	5	550
South Korea	45	2	280
Mexico	12	2	68
Germany	10	3	210
The Netherlands	0	78	160
Belgium	0	74	92

Source: USGS, Industrial Minerals, Roskill and Finnish, Spanish and Brazilian government statistics.

Cancer, triggering labeling requirements required by U.S. government regulations. *Respirable* is basically defined as the 0.5- to 10- μ m particle size range. These regulations require all products containing more than 1,000 ppm (0.1%) of a known carcinogen to be labeled. Although almost all talc products exceed this 1,000 ppm of total crystalline silica, most of the silica is not in the respirable range.

Many producers also maintain that there is a long history of safe talc use, and that because these mixtures of talc and silica have been found safe in extensive use tests, there is no need to label. The Occupational Safety and Health Administration of the U.S. government has now accepted this logic.

More recently, a number of epidemiological studies have shown a weak association between perineal talc use and ovarian cancer. There is a strong difference of opinion within the scientific and medical communities as to the validity of these studies, both because the association is weak and because no fundamental scientific basis exists for the association. In 1998, the NTP placed talc on a review list for possible listing as a cause of ovarian cancer. After peer review and public comment, the NTP panel of experts voted 7 to 3 in late 2000 not to list talc in this category. Nevertheless, the debate continues, and much fundamental and applied science, as well as political pressure, is now being applied by both sides. In 2004, NTP announced that it will reexamine the issue and that review is under way.

COMMERCIAL ASPECTS

Worldwide, talc is approximately an \$800 million per year business at the finished product level. Some 5.0 Mt of product are sold at an average of \$160/t. Virta (2004) estimates the value of U.S. production (0.857 Mt) at \$23.3 million at the ore level, at an average of \$27.18/t. On a worldwide basis, this appears to be low, and where ore is traded, statistics suggest a value of ~\$65/t f.o.b. mine.

Table 6 summarizes world production. The major producer, China, has a very diverse ownership, mostly state and local governments. Most exported ore is handled by traders such as Dailen Haicheng Talc Trading, Gongrong International, Minmet, and South

China Trading Company. Well-known producers are Liaoning Ahai Talc with an output of 180,000 tpy, Haicheng Beihai Minerals (100,000 tpy), and Pingdu talc mine (100,000 tpy).

Worldwide, the major private producer is the Luzenac group of Rio Tinto plc, which produces approximately 450,000 tpy in the United States and Canada; 600,000 tpy in France, Austria, Spain, Italy, and Belgium; and 150,000 tpy in Australia. Other major producers and their production totals are

- Mondo Minerals: 550,000 tpy in Finland, the Netherlands, and Norway
- Golcha Group: 250,000 tpy in India
- Costalco: 200,000 tpy in Brazil
- Barretts Minerals of the United States (subsidiary of Minerals Technology): 150,000 tpy in Indiana, New York, and Ohio
- Gouverneur Talc (subsidiary of R.T. Vanderbilt): ~120,000 tpy in New York
- IMI Fabi: ~120,000 tpy in Italy and the United States
- Wold Resources; ~120,000 tpy in west Texas.

Over the past 20 years, there has been a major consolidation of production both in the United States and worldwide. In 1982, the United States had 14 producers with 26 active mines, and at least 5 were underground. Today, there are only seven producers and 9 mines, all open pit. Production in formerly major producing states such as California and Georgia has almost ceased because of environmental and economic factors. There is less production of lower grades such as the higher tremolite and carbonate products and much higher production of the higher-purity Montana, Chinese, and floated grades.

International trade in talc is very large, with some producers such as China, Australia, and Austria exporting most of their talc and some consumers such as Japan, South Korea, and Germany importing to meet their needs. In the Far East, China and Australia are the major exporters, and Japan, South Korea, and Taiwan are the major importers. Most imports are ore, which is then milled domestically for paper and plastics markets.

In Europe, the major exporters are France, Finland, Austria, Italy, the Netherlands, and Belgium. The major importers are Germany, the Netherlands, the United Kingdom, and Belgium. In contrast to Asia, most trade is in finished goods, except for Belgium and the Netherlands, which import mostly ore.

In the Americas, there is significant cross-border trade between the United States and Canada in finished talc products, and a significant export of ore and finished products from the United States to Mexico, primarily from west Texas to Monterrey, Mexico, for ceramics. The United States is a major importer of ore, especially from China, which is milled in the United States for plastics and cosmetics markets.

This trade is now manifested in an increasing reliance in Europe and the United States on talc ore imports from Asia and Australia—both now net importers of talc. Along with this trend is the growth of mineral processors, which mill and market purchased and mostly imported ore. This growth has been facilitated by two factors. First, significant quantities of high-quality ore are available at reasonable prices, mainly from China and to a lesser degree from Australia and India. Second, the sale of talc requires a high degree of product application expertise and marketing acumen, skills that are not always present in mining companies.

The pricing environment for talc has been extremely poor over the last 10 years. There has been an excess of both ore production and milling capacity, and pricing of equivalent products has either not kept pace with inflation or declined in real terms. Although the

average price for talc product has increased, this is somewhat deceiving, as lower-cost materials such as silica sand and calcium carbonate have displaced talc in lower-value applications and left talc with a smaller number of higher-value-added markets. The poor state of the major consuming markets, especially paper and construction products, has not helped. Industries such as paper, ceramics, roofing, and paint have suffered from excess capacity, poor pricing, consolidations, and shutdowns in the same time frame.

Overall production of talc worldwide appears to be falling significantly. Production was estimated to be 7 Mt in 1990, 6 Mt in 1995, and 5 Mt in 2000. This appears to be driven by less demand for lower-grade tremolitic and carbonate ores in construction markets along with a conversion of European and Asian paper-filling markets from talc to calcium carbonate.

The industry has also struggled with environmental and health issues, and the legal problems experienced by asbestos producers and users cast a heavy shadow over investment and business prospects.

FUTURE TRENDS

These trends—increases in demand for higher-purity products in plastics and paper coating, decline in demand for construction and paper filling, and consolidation and continued environmental concerns—are likely to continue. Future talc applications will be concentrated in the high end of the value chain, where the price is more elastic. Volumes are unlikely to grow and may continue to decline. Revenue growth, however, may be more positive because of the growth in higher-value applications.

The prospects on the pricing front appear better. Chinese production is declining, especially in the higher-purity bright ores. Ocean freight rates from China to Europe and North America have increased significantly in recent years. The quality of the available lower-priced carbonate and tremolitic ores in Europe and the United States is not sufficient for the paper coating and plastics market.

Unless a major new low-cost source of high-quality ore is developed, then, pricing should remain firm and at least keep pace with inflation. Of course, technology changes can always have an impact on demand. The construction market for talc has largely been lost to lower-priced carbonates, kaolin, and silica sand. If more economic alternatives to talc are found in paper coating and plastics, demand will continue to decline. The challenge remains for talc producers to develop new applications for their product, but this effort has declined significantly in the past decade with consolidation and lower profitability.

The environmental climate for talc mining is also challenging. Permitting, even for dry milling and smaller mining operations typical of talc, is very difficult. With some operations located in environmentally sensitive locations, existing facilities are subject to a high degree of scrutiny. The health concerns with talc and its associated minerals are likely to become more acute. Although existing producers are committed to ensuring that sound science is applied to the issue, health issues are an emotional subject and difficult to deal with in a public forum.

Generally, then, the future for talc is at best cloudy, with significant challenges to be addressed for the remaining producers. The key competitors will not be from within the community of talc producers and marketers but from the minerals or technologies competing for a position in the portfolio of available applications.

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