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Talc

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Talc, when it can be isolated as a pure mineral, has a composition of 63.36% SiO_2, 31.89% MgO, and 4.75% H_2O. However, as an industrial commodity, talc rarely approaches theoretical purity. Nevertheless, the impure talc products of commerce find a multitude of uses and few substitutes in many industrial applications.

Minerals commonly associated with and sold together in talcose mixtures are tremolite, chlorite, dolomite, mica, and magnesite. *Steatite* was originally a mineralogical name applied to pure talc. In today's commerce *steatite* generally refers to the massive variety of talc suitable for electrical insulator manufacture. Block steatite ore can be machined into various shapes. Impure varieties of massive or block talc are still commonly referred to as soapstone. Soft massive talc, suitable for crayon manufacture, has been referred to as French chalk.

It has been common practice to discuss talc, soapstone, and pyrophyllite under the same general heading. In the case of soapstone and talc, this is a natural thing since many different types of platy, soft minerals exhibiting a high degree of lubricity (commonly referred to as "slip") have been grouped together and called soapstone or talc. Further, there is a mineralogical relationship of pyrophyllite to montmorillonite and talc to hectorite. Thus, talc and pyrophyllite are sometimes referred to as clay minerals. When finely divided talc or pyrophyllite are combined with water in proportions to make a slurry, the end product does have the appearance of a clay-water mixture.

Soapstone for utensils and ornaments was mined by prehistoric Indians on Santa Catalina Island, CA. In the mid-1800s, soapstone from deposits along the western foothills of the Sierra Nevada mountains was used by white settlers for building and ornamental stone and in the linings and foundations of furnaces (Anon. 1956). Previous to 1916, the annual recorded production in California did not exceed 2000 tons. In the period 1912 to 1918, output rose sharply when the Talc City, Western, and Silver Lake mines were put into operation. From 1916 to 1935, the state's annual output of talc was in the range of 9,000 to 20,000 tons. In the mid-1930s, the use of talc in wall tile grew rapidly. In California, the production of talc grew to 63,000 stpy in 1943. The post-war building boom helped California production to grow to 120,000 tons in 1951. In 1968, production was 165,000 tons, 1969 was 145,000 tons, 1970 was 185,000 tons, and 1972 was 155,000 tons.

Talc mining in New York state dates to about 1878 when a Colonel Palmer and associates opened the first commercial talc mine on the Nelson Freeman farm near Talcville, New York. In 1893, this operation was sold to the International Pulp Co. which changed its name to the International Talc Co. in 1944. The company was acquired by R.T. Vanderbilt Co., Inc. in 1974.

A new talc operation, the Gouverneur Talc Co. owned by the R.T. Vanderbilt Co., began operations near Balmat, NY, in 1948. The initial capacity of the processing plant was 200 stpd (Gillingham, 1950). Subsequent expansions have increased capacity to over 600 stpd.

The Vermont talc industry began just after the start of the 20th century. Talc was discovered in the area of the present Johnson, VT, talc mine in 1902. The American Minerals Co. initiated plant operations at Johnson in 1904. The Magnesia Talc Co. opened a plant at Waterbury, VT, in 1913 (Burmeister, 1963; Trauffer, 1964) and acquired American Minerals Co. in 1923. The Waterbury mine has a long history as a producer of talc crayons.

The Eastern Magnesia Talc Co. was formed in 1924 by a merger of the Eastern Talc Co.

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The Geology section of this chapter was written by Richard H. Olson.

and Magnesia Talc Co. In 1956, the Vermont Mineral Co., with a talc mine at Hammondsville was also acquired. A new plant was then built at Gassetts to produce roofing products.

In order to produce high-grade products for several markets, the Eastern Magnesia Talc Co. began operating a modern froth flotation plant at West Windsor, VT, in 1964. The ore is provided by the Hammondsville mine. As of 1972, this operation is known as Windsor Minerals, Inc., a totally owned subsidiary of the Johnson and Johnson Co.

The Texas talc deposits were first mined commercially in 1952 and by 1970 ranked fourth in US production behind New York, California, and Vermont. Principal use of this talc is in the ceramics industry. Lundquist (1970) reports on a process for acid treatment, calcination, and grinding Texas talc and talc-kaolin mixtures. By his process, Lundquist increased the brightness value from 65 to over 94.

End Uses

Talc is an extremely versatile mineral. In spite of the relatively low purity of most ores mined, talc has found a steadily increasing number of uses. With the exception of pure steatite grades, hand-picked platy cosmetic talcs, and a few products from wet processing plants, the industrial products are really mixtures of many minerals. For example, much of the talc used by the ceramic industry is a mixture of platy talc and tremolite; most of the filler-grade talc sold to the paper, plastics, and rubber industry is, at best, about 90% talc mineral with the balance being dolomite, calcite, chert, clays, serpentine, chlorite, actinolite, iron and manganese-containing minerals, and carbonaceous material.

Table 1 lists chemical analyses of typical talc ores and products.

Talc, along with many of the filler-type industrial minerals, is subject to steadily increasing demands for higher purity and better quality control. A good example is the talc sold to the cosmetic and toilet goods industry. Prior to the end of 1960, a wide variety of talc and talcose products were accepted for cosmetic use if they met rather loose and uncomplicated specifications. A good cosmetic talc had to be reasonably light-colored, have good "slip," be free of gritty or hard mineral particles, and measure up to a certain fragrance-retention standard. Now, the cosmetic talc market is a demanding one. Not only has the industry itself set higher and new standards, but new rulings from federal

TABLE 1–Typical Chemical Analyses of Talc Ores and Products, %

	Pure Talc (Theoretical)	1	2	3	4	5	6
SiO_2	63.36	35.98	59.15	47.92	62.65	59.80	54.92
MgO	31.89	32.95	31.34	26.00	30.23	27.45	27.20
Fe_2O_3	–	0.65	3.36	6.82	1.51	0.05	0.46
TiO_2	–	0.02	–	0.15	–	–	–
Al_2O_3	–	0.43	0.26	7.35	0.31	0.57	–
CaO	–	0.00	0.15	4.14	trace	6.80	5.76
K_2O	–	0.00	–	0.00	0.05	–	–
Na_2O	–	0.00	–	0.00	0.15	–	–
CO_2	–	20.45	1.76	–	0.27	1.18	–
H_2O	4.75	2.73	4.30	0.05	4.87	–	–
MnO	–	0.41	–	0.00	–	0.39	–
S	–	0.06	–	0.09	–	(SO_3) 0.07	–
NiO	–	0.21	–	–	–	–	–
Cr_2O_3	–	0.18	–	–	–	–	–
CoO	–	0.01	–	–	–	–	–
FeO	–	5.96	–	–	–	0.15	–
Less O for S	–	0.05	–	–	–	–	–
P_2O_5	–	0.01	–	0.00	–	–	–
LOI	–	–	–	7.51	–	4.75	10.76
	100.00	100.10	100.32	100.03	100.04	101.21	99.10

Source: 1-5, Chidester, 1964; 6, Pence, 1955.

1. Average Vermont carbonate ore.
2. Flotation talc, Johnson Mine, Vermont.
3. Roofing granules, Cohutta Talc Co., Georgia.
4. Steatite, Yellowstone mine, Montana.
5. Average talc ore, Talcville, Gouverneur District, New York.
6. Texas Talc.

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agencies have made heavy demands on talc product quality.

Table 2 lists the various properties of talc which are important in specific markets or industries.

Talc in Paint

In 1979, an estimated 237,000 tons of talc were used as extender and filler pigments in the paint industry. This is 24.7% of the total US talc production of about 960,000 tons for that year. This paint pigment extender tonnage was exceeded only by calcium carbonate.

Some of the important properties of talc used in paint are color, fineness, oil absorption, chemical inertness, and optimum viscosity. The measurement of oil absorption is important. This property is measured by ASTM Method D 281-31 which measures the number of parts of acid-refined linseed oil required to produce a coherent paste with 100 parts of talc pigment.

Talc helps reinforce paint films and also prevents sagging of paint films. It prevents settling of solids to the bottom of the paint container. Talc is very soft and thus contributes minimal abrasion to process and application equipment. It disperses easily in both aqueous and solvent-based paints. Talc is used for gloss control in paints where an exact degree of sheen or luster is required. Gloss is usually determined with a reflectance meter at 60° inclination. Sheen values are determined with the same meter and with the film at 85° inclination.

A very useful, uncomplicated method used for testing the fineness and degree of dispersion of paint and other wet ground products involves use of the Hegman gage. This gage can also be called a "fineness of grind" gage (Anon., 1970). It is a precision-machined, smooth, flat, hardened steel block with one or two grooves or "paths" about 5¼ in. long and ½ in. wide. The groove depth ranges from 100μ (about 4 mils) at one end to zero depth at the other end. A scraper blade is the second component of the gage. In use (on talc products), an aliquot of a mixture of talc and linseed oil (about 1 part talc to 4 parts of oil) is placed in the tapered part of the groove. Then the mixture is wiped down toward the "zero" depth end of the gage with the stainless steel wiper blade. The fineness is determined by holding the gage to a familiar light source and observing the area where the coarse particles begin to appear. The angle between the face of the gage and the line of vision should be not more than 30° nor less than 20°. The fineness readings can be given

TABLE 2—Talc Properties Important to Specific Industries

- Paint Industry
  - Color (whiteness)
  - Particle shape
  - Packing quality
  - Oil absorption
  - Fine particle size (Hegman gage rating)
  - Opacity
- Paper Industry
  - Free of grit (low Valley Abrasion value)
  - Color (with MgO as 100, prefer 90 or higher)
  - Opacity
  - Particle size (less than 5μ)
  - Low alkali content
  - Effective in controlling pitch, oil, or other oleoresinous substances
  - Talc pigment gives lower wax pick values than clay pigments
  - Talc gives lower ink receptivity than clay
- Ceramic Industry
  - Uniform chemical composition
  - Constant amount of shrinkage on firing
  - Fired color
  - Particle size distribution
- Cosmetic Industry
  - Contain only traces of dolomite, tremolite, quartz, or any harsh minerals
  - Some chlorite may be acceptable
  - No color change after heating
  - Odorless; have good fragrance retention when compounded
  - 100% through 100 mesh and 98% minimum through 200 mesh; finer grades as specified by buyer
  - Neutral to litmus paper
  - Water-soluble substances, 0.1% maximum
  - Acid-soluble substances, 2.0% maximum
  - Loss on ignition, 5.0% maximum
  - Arsenic (as As); 3 ppm maximum
  - Lead (as Pb), 20 ppm maximum
  - Total aerobic plate count including yeast and mold, 100 per g maximum
  - Gram negative bacterial plate count, less than 10 per g
  - Good "slip" and "unctuosity" when applied to human body, also the white color should disappear as the talc is rubbed into the skin
  - Good deodorizing ability
- Plastics Industry
  - Low iron content
  - Particle shape
  - Reinforcing ability
  - Compatibility with resins and other components (talc is inert)
  - Superfine particles
  - Resistivity
- Roofing Industry—Asphalt Backing and Surfacing
  - Minimum oil absorption
  - Color
  - Particle size consist
  - Brightness
  - Particle shape
- Petroleum and Automotive Industries—Lubricants, Body Putty, Asphalt Undercoating
  - Free from grit (pure platy talc for lubricants)
  - Chemically inert
  - Nonwicking (undercoating)
- Rubber Industry
  - Good lubricity
  - Free of grit
  - Color (only in white rubber and latex)
  - Resistivity
  - Must be chemically compatible when used as latex filler

in microns or mils. A reading of 6 on the gage is about equal to 25μ.

Talc in Paper

One of the fastest growing uses for talc has been in the coating and filling of paper. As a filler it is effective as an inexpensive titanium dioxide extender and is outstanding as a pitch control additive. Talc also assists in improvement of gloss, opacity, and brightness. Its retention in the paper fibrils usually approaches 100%. In 1970 (Cooper and Hartwell, 1970), a forecast of a 3.75% annual increase in demand for talc paper filler was made. Present indications are that this is a conservative estimate and the annual increase may reach as much as 5%.

The main reason for the rapid growth of talc consumption in paper is the availability of high-quality micronized talc manufactured to exacting specifications. Talc filler should not contain more than 2 to 5% calcium carbonate, or similar minerals which react with the alum used in paper formulations. Particle size ranges from 5μ to less than $\frac{1}{2}\mu$ with surface areas from 4 to 25 m^2/g. Generally, the Valley Abrasion * number will be very low, from 2 to 6; thus, abrasion of paper making equipment and printing equipment is minimized.

When talc is used as a titanium dioxide extender in paper, it has a distinct weight advantage (talc specific gravity 2.8 vs. 4.2 for TiO_2). This feature grows in importance as postal rates increase.

High-purity talc products are finding a good market in competition with titanium dioxide fillers. Considerable history has already been made in the paper industry where talc fillers have found an excellent market for use as titanium dioxide extender agents. In 1979, titanium dioxide (anatase) sold for about 53¢ per pound in slurry shipments and 57¢ per pound in bags.

The best grades of talc sold, in 1979, for only 5 to 10¢ per lb. This indicates that talc, when it can be substituted, even partially, will continue to be a formidable competitor for substantial titanium dioxide markets.

The unique property of preferentially wetting oily materials in the presence of water makes talc extremely effective in "pitch control." Pitch and other oleoresinous components of paper pulps cause serious manufacturing problems if they are not controlled. Talc absorbs the pitch and helps prevent accumulations which would otherwise deposit on the rolls, wire, and other parts of the paper machine. Competitive materials such as diatomaceous earth and clay usually are either too abrasive or much less effective in the presence of water.

The ultrafine particle size talc products (maximum particle size of 5μ) now finding use in paper coating colors have similar ranges of particle size distribution as coating clays and precipitated calcium carbonate. The talc products can be used to pigment latex, starch, or alpha protein coating colors. The ultrafine talc products can be used along with clay, calcium carbonate, and titanium dioxide pigments to control rheological properties, calendering, gloss, ink holdout, opacity, and brightness.

Talc in Ceramics

Talc finds use in many ceramic products. It is a versatile component having beneficial effects relating to the control of thermal expansion of ceramic bodies. Talcs low in accessory carbonate minerals exhibit low ignition losses. A typical New York talc will have an ignition loss, at 2100°F, of 5 to 6%. In comparison, many Texas and California talcs lose 8 to 13% of their weight when fired.

Talc is used in cordierite (talc-clay mixture fired to Cone 12) bodies such as developed for use in electrical insulators. Cordierite has a very low thermal expansion. New York and Texas talcs are used in the semivitreous whiteware field, especially wall tile and in dinnerware bodies. These have been found to be ideal raw materials for the following reasons:

1) The formation of enstatite produces high thermal expansion bodies resulting in glazes being put in compression which in turn tends to prevent crazing (hairlike cracking in a glaze).

2) Low moisture expansion bodies are produced, resulting in good resistance to delayed crazing.

3) The hard, massive nature of the ores aids in either dry-pressing or in the making of good casting slips.

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* The Valley Abrasion tester measures wear (in milligrams), of a wire cloth specimen, caused by a circulating suspension of the talc and the rubbing action of an oscillating Micarta block. After 6000 cycles, the wire cloth is washed, dried, and weighed. The loss in milligrams is the Valley Abrasion number.

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4) Low firing temperatures are possible.

5) Fast firing schedules are possible—as fast as 1 hr cold to cold.

6) Shrinkage and absorption of bodies are fairly constant over a long temperature range.

7) Good white-fired bodies are possible.

8) Glazes of unusual brilliance and attractiveness can be fitted readily to high talc bodies.

As far back as 1930 reports began to appear praising the improved craze resistance of semivitreous bodies when New York talc was used.

A minor use of talc is as an addition to the clay-flint-feldspar type of dinnerware bodies. Talc is added up to 6% of the body and results in greatly improved craze resistance.

Talc is used as a glaze ingredient as it provides a low-cost source of MgO.

Talc is used as a mold dusting compound to help the release of large castware pieces.

Synthetic lava talc is made from ground steatite-grade talcs. In these applications, as much as 80% talc is used in the mixtures. When steatite-grade talcs are used for the manufacture of high-frequency insulators, limits of 1.5% CaO, 4% Al_2O_3, and 1.5% iron oxides are usually imposed. This extrapolates to a maximum of about 5 to 10% nontalc minerals. Preferably, this should be only 1 to 2% nontalc components.

Talc can be used to replace clay in many ceramic bodies. It promotes translucency of the finished ware and makes it more durable.

Specifications for talc used in the ceramic industry are increasingly more demanding. The uniformity of most ceramic talcs supplied by producers using hand-sorting or other primitive beneficiation methods is only fair at best. As more sophisticated ore processing methods are applied to talc ores, the ceramic industry is beginning to receive higher quality talcs with very uniform chemical and physical properties.

The use of talc in ceramic tile has not even approached the increases in residential and commercial construction. For example, a 50% increase in housing starts in 1970 to 1971 gave only a 10% increase in tile consumption (Perry, 1972). New grades, sizes, and colors of tile are being developed to help increase the market. The Tile Council of America forecasts replacement of portland cement as a setting material in the future (Bennett, 1972). Also, increased use of edge-bonded panels and colored grouts is predicted.

Pence (1955) gave an early report on white-firing talc for ceramic use from west Texas. The talc described was from claims located in Hudspeth County about 23 miles west of Van Horn, Texas. The ore analysis was 54.92% SiO_2, 27.20% MgO, 5.76% CaO, 1.36% Al_2O_3, 0.46% Fe_2O_3, and 10.76% ignition loss. By firing standard 4¼ x 4¼ x ⅜-in. hand-pressed tile, Pence obtained satisfactory results in color, density, glaze fit, and other properties required in ceramic wall tile.

At 750° to 900°C talc loses its one molecule of combined water; at 900° to 1000°C it dissociates into the metasilicate $3\ MgO \cdot SiO_2$ and silica. At 1200° to 1300°C it converts to clinoenstatite, $MgO \cdot SiO_2$. The final products of the thermal decomposition of talc are clinoenstatite and cristobalite.

In pottery, talc may constitute 40% of the body composition. The thickness of the object being made, the texture, porosity required, and the firing conditions all influence the amount of talc used. Tableware often contains 15% talc.

Talc in Plastics

Talc is an important filler material for plastics. It improves chemical and heat resistance, impact strength, dimensional stability, stiffness, hardness, thermal conductivity, tensile strength, creep resistance, and electrical insulation properties. In some cases, the processability, especially faster molding cycles, of the plastic is also improved. Talc can be used in both thermoplastics and thermosets.

Talc is used as a reinforcing extender filler in many thermoplastics. It controls melt flow, reduces creep in molded parts, increases molding cycles, increases heat deflection temperature, and dimensional stability. When platy varieties of talc are used, a beneficial lubricating effect is noted on molding machine parts. And perhaps most important of all, the use of talc decreases the overall cost of the plastic product. Talc can be used as a filler in quantities from 1 up to 50% by weight when polyolefin compositions are involved (Poppe et al., 1972). In a rare case, up to 70% talc has been used in a cellulose ether that is both thermoplastic and water soluble.

In all filler applications, where talc is added to an organic component, a new dimension is rapidly developing. This is the chemical bonding of the talc filler to the resin matrix (in the case of plastic composites). The technology involved is old since initial successes in bonding glass fibers to various plastics were reported in the early 1950s.

The development of processes for the chemical coating of talc fillers is now reaching a considerable degree of sophistication. Silane coupling agents are used to improve performance of talc fillers in plastic materials. Ranney, et al. (1972) report that the tensile strength of a 50% (by weight) loaded polyethylene plastic can be increased 25 to 30% over the non-silane-containing standard.

In both rubber and plastics, the use of filler minerals was originally for the sole purpose of reducing cost. Thus such minerals were called extenders or extender pigments. With the advent of products such as silane-coated clays in the rubber industry, it became evident that filler minerals could be functional as well as reduce overall cost.

Silane coupling agents are used with clays, talc, and other mineral fillers. These agents are a chemical family of organosilicon monomers which characteristically possess two different kinds of chemical functionality. The general formula for the molecule is: $R{-}Si(OX)_3$ where R is the organofunctional group attached to the silicon atom in a thermally and hydrolytically stable manner. In this formula, OX designates hydrolyzable groups upon silicon. These groups are generally believed to be the means whereby the silane coupling agents interact with the siliceous inorganic surfaces (e.g., talc) to form a more durable bond with the filler mineral. With the increased bonding, it is often possible to increase the filler loading without sacrificing the properties required in the polymer system.

Talc in Roofing Products

Talc is used both as a filler and as a surfacing material in the manufacture of roofing. When used as a filler, the talc acts as a stabilizer for the melted asphalt constituents. It helps increase stability and weather resistance. When talc is sprinkled on the surface of either asphalt shingles or roll roofing, it prevents the roofing from sticking during manufacture and storage before use.

Typical size specifications for talc used for stabilizing roofing products are:

Tyler Mesh	Range, % Wt.
+ 35 mesh	none
+ 65 mesh	10-20
− 65, + 100 mesh	15-30
− 100, + 200 mesh	25-35
− 200 mesh	20-25

The market for low-grade talc used for surfacing, filler, and backing for smooth surface roofings and for filler and backing of asphalt roofing shingles is growing rapidly. When used for surface coatings, the color and staining properties of the product are important. When talc is used as backing, the primary qualifications are particle size range, particle shape, absorbency, and above all, low cost.

Miscellaneous Uses of Talc

Talc is used in a wide variety of textile materials. Textile sizing compositions include binders and mineral fillers. Some textiles use sizings for temporary stiffeners and appearance for sales appeal. The degree of whiteness is often very important and thus favors talc or other extremely white minerals. Where extreme whiteness of color is important, talc often competes with titanium dioxide at a considerable cost advantage.

A relatively new market for talc and pyrophyllite fillers is in the integral foamed latex rubber backing for carpets, rugs, and parquet hardwood floor panels. When used with fabric, the main purpose of the latex is to provide a flexible backing for the fabric and, at the same time, lock the pile material to its own backing. Impurities in the filler such as calcium, magnesium, iron, and manganese which can chelate with the latex are undesirable. Specially coated fillers with additional latex reinforcement properties are under development.

Upholstery fabric backing also uses substantial tonnages of mineral fillers. The filler loadings run about 75 to 100 parts per 100 parts of latex. Major fillers are clay, talc, pyrophyllite, and calcium carbonate. Similar back coatings are used in drapery materials, but the filler loadings are lower than for upholstery. Talc is a favored material because of its ability to meet the demand for whiteness of color.

The lubrication properties of talc are unique and found in very few minerals. The history of talc as a component in extreme temperature range greases is extensive and significant. The dispersion characteristics so important to lubricants which operate over a wide temperature range without freezing or running off the bearing surface are assisted by use of talc. A representative grease capable of use over an extreme temperature range might include a silicone oil, colloidal silica thickener, molybdenum disulfide, talc, and several chemical additives to prevent corrosion of the bearing surface or decomposition of the lubricant (Elstron, 1961).

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Both platy and nodular talc powders are covered by US Patents for use in corrosion proofing compositions such as those used in automotive undercoating (Miller and Holtzapfel, 1970). The talc is about 50% by weight finer than 10μ and no more than 3% coarser than 325 mesh. Talc plays an important part in the prevention of "wicking" action in the composition. Undercoating products containing fillers such as asbestos are often subject to failure resulting from a wicking action which causes moisture to travel through the corrosion proofing coatings.

The use of talc in dry fire-extinguishing powders has been patented (Cawood, 1962). Talc is used in quantities ranging from 10 to 15 parts per 100 parts of product. The talc is used primarily to maintain the desired free-flowing condition so essential in dry powders used in fire extinguishers.

Talc is used in the textile industry both for loading and "bleaching" materials such as cotton sacks, cordage, rope, and string. For such purposes, a good grade of low-abrasive white talc is required. Talc used for backfilling textiles can be of lower quality.

Other uses for talc include:

Cereal polishing (rice, corn, barley)
Bleaching agents
Odor absorption from foods
Floor wax
Water filtration
Leather treatment (oil absorption)
Joint fillers and grouts
Insecticides
Textiles
Shoe polishes
Welding rod coatings
Printing inks
Encapsulant for acceleration testing artillery shells up to 50,000 g
Coating for iron ore pellets in direct reduction processes
Source of magnesium in plant foods

Mineralogy

Talc is a hydrated magnesium silicate with the theoretical formula $Mg_6[Si_8O_{20}](OH)_4$. The chemical composition of talc found in nature, however, is quite variable. It is an extremely soft mineral and is rated No. 1 in Mohs' scale of hardness. It varies in color from snow-white to greenish gray and various shades of green. Its specific gravity ranges from 2.58 to 2.83. Talc usually derives as a secondary mineral by alteration of other magnesium silicates such as serpentine, pyroxene, or siliceous dolomite.

In industry the word talc covers a broad variety of rocks and rock products.

Talc deposits can be classified into four major categories:

1) Steatite—compact, massive, cryptocrystalline, can be sawed, drilled, or machined to required shapes. Steatite converts on firing at 1800°F for 6 hr to interlocking crystals of clinoenstatite—then called "lava." This has good electrical insulating properties.

2) Soft platy talc—is an alteration product of sedimentary magnesium carbonate rocks. Chlorite is a common accessory mineral. This is the most important type of talc. It possibly has more uses and more potential than any other talcose material.

3) Tremolite talc—sometimes called "hard" talc. It is massive or laminated rock composed of varying percentages of tremolite, anthophyllite, calcite, dolomite, serpentine, and true soft talc. It is characterized by calcium oxide contents of 6 to 10%.

4) Mixed talc ores—includes the so-called "soft talc," a friable, white schistose rock composed of platy talc, dolomite, calcite, serpentine, and many other trace minerals. In some low-grade deposits, mixtures of talc, chlorite, and dolomite are common.

Talc is a mineral that meets the criteria of a "sheet silicate" mineral. Its structure is like that of pyrophyllite except that the octahedral sites in the layers or "sheets" are occupied by magnesium instead of aluminum. Also, none of the octahedral sites are vacant (which is not the case with pyrophyllite). Chemically pure talc is rarely found in nature in commercial quantities. Practically all of the talc produced is an impure product. Even the hand-sorted, selectively mined cosmetic talcs contain many extraneous mineral components.

When the major talc products in world trade are examined, it becomes obvious that only a miniscule percentage of world reserves are "pure" talc. When impure talc products are reprocessed by froth flotation, or similar selective separatory methods, very high purity talc mineral can be produced. It would seem objective to call a talc "pure" if it contains upward of 95% $Mg_6[Si_8O_{20}](OH)_4$.

Table 3 lists the approximate composition of the minerals present in talc ores.

The main isomorphous components of the tremolite group are ferric iron, manganese, and aluminum. Tremolite can contain 2 to 3% sodium. Tremolite includes three varieties

TABLE 3—Approximate Composition of Minerals Present in Talc Ores, %

	SiO_2	MgO	CaO	CO_2	Fe	Al_2O_3	K_2O	Na_2O	H_2O	TiO_2
Talc	63	32							3-7	
Serpentine (antigorite)	44	43							8-13	
Chlorite	33	36				18			5-14	
Anthophyllite	58	30	2						15-2.2	
Tremolite	57	28	13						15-2.3	
Actinolite	52	5	9		34				3	
Diopside	56	18	26							
Feldspar	65					18	17			
Magnesite		48		52						
Dolomite		22	30	48						
Calcite			56	44						
Quartz	100									
Muscovite	46	0.1				39	10	0.6	4.3	
Magnetite (Fe_3O_4)					72					48.0
Ilmenite ($FeTiO_4$)					33					
Pyrite (FeS_2)					47					
Tourmaline*	36	11	0.5			33	0.6	2.3	3.8	0.2
Graphite (100% C)										

* 10% B_2O_3

—iron tremolite, manganese tremolite (hexagonite), and fluorine tremolite. Tremolite, which has the theoretical composition $2CaO \cdot 5MgO \cdot 8SiO_2H_2O$, is commonly the major component in talc ores, at the expense of the mineral talc itself. This relationship may hold throughout large talc-mining districts, e.g., the New York and California-Nevada districts. Other talclike minerals which may constitute various proportions of talc ores are anthophyllite, antigorite, chlorite, pyrophyllite, and serpentine.

Povarennykh (1972) includes pyrophyllite, talc, minnesotaite, and willemseite in the pyrophyllite group of minerals. In his description of the group varieties, he includes Mg-pyrophyllite, Fe-pyrophyllite, Fe^{2+}-talc, $Fe^{2+}Fe^{3+}$-talc, Ni-talc, and Mg-willemseite. Talc can contain up to 1% nickel and pyrophyllite can contain up to 9% magnesium. These chemical variations of the pyrophyllite group show the wide variety and possibilities of the occurrence of "talclike" pyrophyllite.

Barnes (1958) reported weak to medium infrared luminescence of talc minerals from various parts of the world. Steatitic talc from Manhattan, NV, showed medium luminescence. Tremolite from Kragero, Norway, and Outokumpu, Finland, also exhibited medium reaction.

At the Jatoba talc mine near Ponta Grossa, Brazil, a claylike antigorite has found commercial acceptance as a diluent for insecticides and as "talc" for pharmaceutical uses (Brindley and Santos, 1971). This is another example of a talclike mineral finding commercial acceptance as "talc."

Faust and Fahey (1962) provide a good review of extensive studies by others relating to the distribution of minor elements in magnesium-rich minerals and rocks. There is good agreement by the scientists that "the rocks of the ultrabasic suite and their hydrothermally altered forms rich in serpentine contain an unusually high concentration of nickel, chromium, cobalt, and scandium. Moreover, some of the investigators have observed that the carbonate-rich rocks, in contrast, contain very small to practically negligible concentrations of these elements." This is in agreement with the high nickel content of some Vermont talcs and its complete absence in some western carbonate-talc ore bodies.

Differential thermal analysis (DTA) and X-ray diffraction both provide good analytical methods for identification of talc and also many of the impurities associated with talc ores. A large endothermic peak at 965°C is typical of relatively pure talc mineral analyzed by DTA methods.

It is of considerable geological significance that tremolite from some metamorphosed carbonate rocks contains fluorine. On the basis of fluorine analyses of 22 talcs from worldwide deposits, it was noted talc from metamorphosed sedimentary rocks contained from 0.11 to 0.48% fluorine. Talcs derived from ultramafic rocks contained less fluorine (Ross and Smith, 1968).

Later work by Troll and Gilbert (1972) on fluorine-bearing tremolites points out that the theoretical value for pure fluoro-tremolite is 4.65% fluorine. One sample of tremolite used in this work from Richville, NY, contained

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1.51% fluorine. Analysis of a sample of lavender-colored tremolite showed 0.30% fluorine. The US Bureau of Mines (USBM) and the National Institute of Environmental Health Sciences (NIEHS) have reported on the characterization data of fine mineral test samples, including nonfibrous tremolite (Campbell, et al., 1980).

Occurrence and Reserves

Talc deposits are found in many countries. Good quality talc ores are found in Africa, the Americas, Australia, Republic of China, Finland, France, Greece, India, Italy, North and South Korea, Manchuria, Norway, Romania, Sardinia, and the USSR.

Table 4 is a summary of geologic and commercial data for the principal talc districts of the United States (Chidester, et al., 1964).

As governmental regulations concerning exposure to mineral dusts increase in frequency and severity, those talc deposits containing asbestiform minerals may decrease in importance. The filler industry shows preference for very high-purity platy talc which has minimal health hazards upon exposure to its dust.

Geology

Talc deposits occur on every continent and the geology of these deposits is roughly similar to those of the United States. The most common host rocks for the formation of talc are dolomite and ultramafic rocks. Chidester et al. (1964) consider that there are three major types of talc deposits in the United States: deposits associated with sedimentary rocks; deposits associated with ultramafic igneous rocks; and deposits associated with mafic igneous rocks.

Good examples of talc deposits associated with sedimentary rocks are those of the California-Nevada, Montana, New York, and Texas districts.

Good examples of talc deposits associated with ultramafic igneous rocks are those of the Vermont district.

Talc deposits associated with mafic igneous rocks occur in the central Appalachian Mountains and are the source of most of the soapstone quarried in the United States. These rocks, which contain relatively minor amounts of the mineral talc, were probably formed by the hydrothermal alteration of gabbroic rocks. As they are not a source of talc products, they will not be discussed here. The first two types of talc deposits, however, are important as a source of talc products.

The easiest method of forming pure or relatively pure talc deposits is shown in the following reaction as presented by Winkler (1974):

$$\begin{aligned} &3\ \text{dolomite} + 4\ \text{quartz} + H_2O \\ &\qquad = \text{talc} + 3\ \text{calcite} + 3\ CO_2. \end{aligned}$$

The geological settings of US talc deposits are as varied and diverse as would be expected for any naturally occurring mineral commodity of secondary origin, but there are nevertheless some broad similarities. First, talc is invariably a secondary mineral formed in preexisting rocks either directly from those rocks, or through the introduction of new material. Second, all economically important deposits have been formed under conditions of low-grade regional metamorphism. Third, commercial bodies are generally tabular and concordant, being molded after the shape of the parent material, which is most commonly a sedimentary or metasedimentary rock unit. Fourth, most of these talc ore bodies occur within Precambrian rock units; the few which do not are found within rock units whose age is no younger than Early Paleozoic. Finally, in almost every instance where the conditions of genesis can be either firmly established or confidently inferred, the time of the talc formation is Precambrian as well.

The reasons for this almost total restriction of talc to the Precambrian in both space and time are presently unclear. It may be easier to comprehend in the case of ultramafic rocks, for these may indeed be much more abundant in the Precambrian than in younger geological systems. It is, however, somewhat more difficult to understand with regard to dolomitic rocks, for these are certainly much more common in the Cambrian and younger geological systems than they are in the Precambrian. It may be that deep burial and the consequent conditions of dynamic metamorphism could have attained sufficient intensities only during Precambrian time; such a theory would perhaps explain the formation of talc in Montana and New York, for instance, but would probably not be applicable to some of the other districts, which admittedly have undergone deep burial but do not show conditions of extreme dynamic metamorphism and isoclinal structure, such as California-Nevada. It seems safe to say, how-

TABLE 4—Summary of Geologic and Commercial Data for the Principal

State and District	Form and Size of Talc Body	Country Rock and Parent Rock	Paragenetic-Sequence in Alteration of Parent Rock to Talc	Mineral Comp and Impur
California: Silver Lake—Yucca Grove	Lenses, mainly of massive tremolite rocks, as much as 800 ft long, 20 ft thick, and 200–300 ft deep; schistose/talc rock forms layers and lenses 1 ft or more thick, mostly along the footwall.	Feldspar-quartz-diopside-carbonate hornfels, commonly separated from the talc body by phlogopite-feldspar-tremolite schist a few inches to several feet thick. Tremolite and talc apparently derived from beds of sedimentary dolomite 5–20 ft thick that form parts of pendants in bodies of granitic rock.	Dolomite → tremolite → talc.	Chiefly tremolite a minor forsterite, and carbonate. I clude phlogopit quartz, carbonat dike rocks.
Southern Death Valley, Kingston Range.	Tabular to lenticular bodies as much as 5000 ft long, 80 ft thick, and 400 ft downdip; most are of schistose to massive talc rock, but some contain interlayered tremolite rock in various proportions, and some are entirely of tremolite rock.	Cherty and noncherty dolomite, diabase, and argillite, commonly silicated at the contact. In most deposits, one kind of rock forms the hanging wall, another the footwall. Talc and tremolite derived from generally massive and commonly cherty or siliceous beds of dolomite.	Carbonate+chert → tremolite → serpentine → talc. Intermediate steps in the process did not take place in many deposits.	Principally talc; mostly-subordina places predom purities chiefly iron oxide stain rock inclusions.
Inyo Range—Northern Panamint Range.	Small pods to lenses and tabular bodies as much as 500 ft long, 50 ft wide, and 400 ft downdip. Some bodies show large-scale variations related to differences in parent rock, permitting selective mining.	Principally dolomite and quartzite, in a few places granitic rock and limestone. Talc derived principally from massive beds of dolomite and quartzite, locally from granite or diorite.	Dolomite and quartzite → talc; also granite and diorite → talc.	Chiefly talc; tremo purities generally chiefly chlorite, quartz, pyrite, an
Georgia: Chatsworth	Lenticular bodies as much as 5000 ft long, 150 ft thick, and 300 ft downdip. Lenticular and spindle-shaped bodies of massive talc rock (crayon talc) are dispersed through talc-carbonate rock that shows large-scale variations in color, texture, and mineral composition.	Schist, slate, granite, and granite gneiss. Mode of origin doubtful; parent rock either sedimentary carbonate rock, mafic igneous or volcanic rock, or ultramafic igneous rock.	Probably: dolomite → serpentine → (chlorite) → talc. Possibly: ultramafic or mafic igneous rock → serpentine → (Chlorite) → talc+carbonate.	Talc rock princ minor magnetite ate rock chiefly bonate with min pyrite, chlorite, spar, actinolite,
Maryland	Irregular tabular masses adjacent to pegmatite dikes in serpentinite; irregular envelopes surrounding a serpentinite core; and lenticular masses.	Schist, gneiss, pegmatite, and serpentinite. Talc derived by replacement of parts or the whole of serpentinite bodies that vary widely in size.	Dunite and peridotite → serpentine → talc+carbonate.	Talc rock chiefly ties, chiefly chlo Talc-carbonate tially talc and car chlorite, magne tine, and other in
Montana: Dillon-Ennis	Small veins and pods to lenses as much as 700 ft long, 100 ft thick, and more than 200 ft in vertical extent.	Dolomite and quartz-mica schist. Talc derived from beds of dolomitic marble that range widely in size.	Dolomite →talc; also dolomite → tremolite → talc.	Essentially talc amounts of impu chlorite, graphit manganese and and inclusions rock.
Nevada: Palmetto-Oasis	Elongate zones of discontinuous pods and lenses to tabular masses more than 5–500 ft long; generally 1–15 ft, but as much as 50 ft thick; and 140 ft downdip.	Chiefly dolomitic marble, hornfels, and diabase; locally granitic rock, phyllite, and schist, commonly one kind of rock forms the hanging wall, another kind the footwall. Talc derived chiefly from extensive beds of dolomitic marble and hornfels, but locally from phyllite, schist, and granitic rock; commonly occurs at fault contacts.	Chiefly: dolomite → talc. Locally: hornfels, granite, schist, and phyllite →talc.	Chiefly talc with and carbonate, tremolite. Much terial is nearly p
New Mexico: Hembrillo Canyon—San Andres Mountains.	Lenses as much as 300 ft long, 25 ft thick, and of undetermined depth.	Chiefly argillite; locally carbonate rock and silica-carbonate rock. Talc probably derived from extensive sedimentary units of argillite.	Not determined	Chiefly talc with ite; locally stai oxide.
New York	Sheetlike to lenticular zones as much as several miles long and 300 ft wide.	Dolomitic and calcitic marble, diopsidic marble, and thin quartz-diopside layers. Talc derived chiefly from beds of dolomite and siliceous dolomite that form units as much as 5000 ft thick and several miles long; some talc derived from granite, syenite, quartzite, and amphibolite.	Dolomite + quartz → diopside → tremolite → anthophyllite → serpentine → talc. One or more minerals may be omitted in the sequence.	The proportion anthophyllite, pentine varies may predomina lite rock is Quartz, carbon manganese and and gypsum a purities.
North Carolina: Murphy	Small pods to lenses as much as 700 ft long, 50 ft thick, and 200 ft downdip. Many deposits exhibit large-scale variations in color, texture, and distribution of impurities, permitting selective mining.	Calcite marble, locally highly siliceous and commonly tremolitic at the borders of the talc deposits.	Dolomite+quartz →silicated rock →talc.	Essentially talc. chiefly minor quartz, carbona stain, and rarely

TABLE 4—Continued

State and District	Form and Size of Talc Body	Country Rock and Parent Rock	Paragenetic-Sequence in Alteration of Parent Rock to Talc
Texas: Allamoore	Largely unknown, but some tabular masses are several thousand feet long and several hundred feet wide, with tabular and irregular inclusions of carbonate rock, phyllite, and masses of chert that range widely in size.	Cherty dolomite; some conglomerate, phyllite, and diabase. Talc probably derived from extensive beds of sedimentary or pyroclastic rock such as dolomitic marl or magnesium-rich tuff.	Not determined
Llano	Mostly small lenses and pods in schist or along margins of serpentinite masses as much as 4 miles long and 1 mile wide.	Schist, gneiss, and serpentinite. Talc derived from lenticular bodies of serpentinite and from tabular and lenticular units of schist, gneiss, mafic volcanic rock, and carbonate rock.	Details unknown. Serpentinite and metamorphosed sedimentary and volcanic rock altered variously to one or more of talc, carbonate, tremolite, and anthophyllite.
Vermont	Shell of talc rock 1–3 ft thick surrounds a zone of talc-carbonate rock that ranges in size from a shell 1–20 ft thick around a serpentinite core to the entire mass of the original serpentinite body.	Schist, greenstone, and serpentinite. Talc rock and talc-carbonate rock derived almost wholly from serpentinite bodies that range in size from small pods to lenses several miles long and a mile wide; a small proportion of the talc rock is derived from schist.	Dunite and peridotite → serpentinite. Serpentinite+CO_2 → talc+ carbonate. Serpentinite+SiO_2 → talc. Schist or greenstone → talc+ chlorite.
Virginia: Schuyler	Lenticular bodies of the same extent as the original igneous rock body.	Gneiss, schist, and amphibolite. The talc (soapstone) was derived from lenticular bodies, probably originally hypersthene gabbro, as much as 180 ft thick and 1500 ft long.	Hypersthene gabbro → amphibole+chlorite → talc+ carbonate.

Source: Chidester et al., 1964.

ever, that even though conditions of extreme dynamic metamorphism have not necessarily been attained in all six talc-mining districts of the United States, conditions of burial beneath miles of rock cover have been attained in every one of them.

The six major talc-mining districts in the United States are New York, Vermont, the southern Appalachians, Texas, California-Nevada, and Montana.

New York

All of the known commercial talc here occurs within the Balmat-Edwards or Gouverneur mining district. A comprehensive study of talc in the United States by the US Geological Survey (Chidester, et al., 1964) indicates that New York had at that time almost 75% of the United States' "measured and indicated" talc ore and about 40% of its "inferred" talc ore. With only relatively minor exceptions, all known talc in this district lies within a narrow belt, which probably averages only 500 ft or so wide and is only about eight miles long.

The New York talc district was long the most important in the United States in terms of total annual production, being rivaled or surpassed only by Vermont. Over the past couple of decades, however, both Montana and Texas have also pulled ahead of New York. It is most peculiar, therefore, that the New York district, although dominant in production for so much of the past century, and even more dominant in terms of proven and potential ore reserves, is geographically the smallest in area of all six talc-mining districts in the United States.

The bedrock complex of the Gouverneur mining district consists exclusively of metamorphic rocks of Precambrian age (the Grenville Series), but two specific lithologic types, gneiss and marble, dominate. The gneiss is thought to be the older unit and is about 3,000 ft thick; the marble, thought to be the younger unit, has a maximum known thickness of about 2,000 ft. Thin sheets and lenses of amphibolite occur within both the marble and the gneiss, but are relatively minor in total volume. Brown and Engel (1956) subdivided the marble sequence into 15 units, of which only Unit 13, the "talc unit," is known to contain commercial deposits of talc, tremolite, or zinc minerals. Unpublished geological investigations indicate that the composition of most of the marble within this mining district is relatively simple and probably does not and did not originally differ greatly along strike. The talc unit, a dolomitic marble, shows evidence of being only 250 ft or so thick in its least contorted areas: greater thicknesses are probably due to structural flowage.

Bodies of ultramafic rock have been intruded into a sequence of phyllite, schist, gneiss, greenstone, and amphibolite rocks. These ultramafic bodies subsequently have been locally serpentinized and partly converted into talc. The talc deposits are commonly associated with dunite, peridotite, and serpentinite, which were probably their parent rock.

These ultramafic rocks form part of a belt more than 2,000 miles long, which extends from Alabama to Newfoundland (Chidester, et al., 1951). The talc ore itself is more of a talc-carbonate complex, which locally grades into a carbonate complex commonly rich in magnesite. The talc ore is relatively dark-colored, has schistose structure, and is relatively high in iron content, particularly at the surface where the iron has been enriched by weathering processes. Although the mineral talc itself is a relatively major constituent, the grade of Vermont talc ores generally is considerably lower than those of the other districts in the United States.

The ultramafic bodies are as much as 1 mile wide and as much as 3.5 miles long (Chidester, et al., 1951). The commercial talc bodies, which occur in those ultramafic bodies known as the *verde antique* type, are zoned around cores of serpentinite. The talc-containing zone (steatite zone) forms the outer shell or zone of the body; between it and the serpentinite core is the *grit zone*, which is commonly several feet to several tens of feet thick. *Grit* is the miners' term for rock which is composed of talc and carbonate minerals only.

There are few masses of high-purity talc in the Vermont district large enough to mine as such. Tremolite is not known and talc itself is the only talclike mineral contained within the ultramafic bodies.

In northern Vermont, entire ultramafic bodies have been converted into grit and have widths on the order of 100 ft or so. In southern Vermont one similar body has a width of about 175 ft. At least 145 talc occurrences are known in Vermont within an area having a strike length of about 150 miles and a width ranging from five to 25 miles. Homoclinal folding is the regional structure; isoclinal folding is thought to be uncommon, for little repetition due to folding has been noted.

Few workers have attempted to date either the host rocks of the Vermont talc-mining district or the time of steatization, but studies by Christman (1959) and Christman and Secor (1961) suggest that the age of the parent rocks is Early Paleozoic, probably Ordovician.

Open-pit mining is relatively minor, with most of the production coming from underground workings, some of which extend to vertical depths of more than 1,000 ft.

The ore reserve situation in the Vermont district has never been seriously investigated by anyone who would be at liberty to disclose the results of such a study. Judging from the geographical distribution of the known talc bodies, however, the total ore reserves must be extremely large.

Producers historically have had the choice of grinding the talc ore as mined and simply size-classifying it for relatively low-priced dusting compounds and fillers or of beneficiating it by flotation or other means in order to derive high-value products containing major amounts of the mineral talc. To manufacture the most profitable product line in this district, an operator must employ wet-processing beneficiation techniques. The Eastern Magnesia Talc Co., Inc. (now Engelhard Minerals and Chemical Corp.) has been using wet-beneficiation methods on ores near Johnson, VT since 1937. The ore is subjected to froth flotation, then dewatered in a rotary vacuum drum filter. The filter cake is then dried, pulverized, and air-classified (Harrah, 1956). Eastern Magnesia Talc Co., Inc. established another, more modern froth flotation plant at West Windsor, VT in 1964; since 1972 this operation has been known as Windsor Minerals, Inc., a wholly owned subsidiary of Johnson & Johnson Co. (Trauffer, 1964).

Vermont's talc production in 1979, according to the US Bureau of Mines, was 346,000 tons with a value of $2,755,000.

Southern Appalachians

Although numerous deposits of talc and soapstone are known in the Appalachian Mountain province between Vermont and western North Carolina, none of them have such a history of past or present production, nor in the writer's opinion the future potential, to even suggest the possibility of their becoming major talc-mining districts. These occurrences in Massachusetts, Connecticut, Rhode Island, New Jersey, Pennsylvania, Maryland, and Virginia are described by Chidester, et al. (1964).

Several more attractive talc occurrences and ore deposits, however, are known between Murphy in western North Carolina and Dadeville in eastern Alabama. Compared with those of the other five major talc-mining districts in the US, these are relatively small deposits, but some of them are quite important in that they

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noted in 1873, are present in Tallapoosa and Chambers Counties, Alabama, where they are associated with ultramafic bodies (Neathery, 1968). The talc content ranges from 3 to 26%, probably averaging 20% for the better deposits; annual production has been about 5,000 tons (Neathery, 1970). Neathery, et al. (1967) describe flotation-concentration feasibility studies, which show that good-grade talc concentrates can be made from these ores, but the economics of such an operation have yet to be proven.

Texas

Texas has two talc districts—the Llano district in the central part of the state and the Allamoore district to the northwest of Van Horn in the western part of the state. The latter district is the one most recently put into production and is now the only one of any importance.

The Allamoore district extends about 20 miles east-west and is as much as 5 miles wide. Its ore deposits are in the Allamoore Formation, of Precambrian age, which consists of thousands of feet of carbonate rocks, volcanic rocks, and phyllite (King and Flawn, 1953). The talc appears to the writer to be associated with dolomite, but it also appears to interfinger with phyllite in certain parts of the district. Edwards (1980) feels that phyllite is invariably the host rock, but Bourbon (1981) believes that the talc formed in Precambrian time by the replacement of primary sedimentary magnesite. Field relationships indicate that carbonate rock other than calcite is the host rock for these talc deposits.

The ore-bearing strata, which are in the lower plate below a large overthrust fault (the upper plate having been almost entirely eroded), dip either vertically or steeply to the south. No ore body of which the writer is aware has ever been bottomed-out by either drilling or mining. Large iron-oxide-stained "horses" of either carbonate or volcanic rock are common within the talc zones, but generally are easily eliminated by the use of selective mining methods. Talc is commonly found from the grass roots down and the soil cover is generally less than 1 ft thick. Caliche is abundant in the uppermost 5 ft or so of these dark-colored ore bodies, but seldom causes any problems at greater depths.

Initial but far from complete petrographic and X-ray studies of the ores indicate that tremolite is not present to any significant degree. Dolomite, however, is so finely admixed with the talc as to render it extremely unlikely that pure talc can ever be produced in significant quantities from known ore bodies by presently known beneficiation techniques. There is little indication of a hydrothermal origin for these ores.

The talc ore (ceramic-type) is generally strongly foliated, with the individual foliae ranging from paper-thin to as thick as ¼ in. This dark Texas crude looks little like talc ore, even to the trained observer, when one first visits the district. The first impression is to identify it as black shale or perlite or some other similar nontalc-bearing rock. However, despite its dark—or indeed even black—color and its striking untalclike appearance, this talc ore is a superior ceramic crude with superb pressing qualities and excellent firing characteristics.

Flawn (1958) describes the district in a stage of infancy and King and Flawn (1953) describe in detail the overall geology of the district and surrounding areas.

All of the production has been from large open pits, with the exception of minor amounts of light-colored (generally pink to white) talc which have been mined in small underground workings and then finely ground into filler and extender products. Almost all of the talc ore produced in the Allamoore district is shipped out of the district to the east, and even into Mexico, for use in the ceramic industry, particularly for the manufacture of wall tile.

Mining costs probably are the lowest anywhere for talc ores. Flawn (1958) gave the costs of mining, transportation, and loading into cars as ranging from $1.75 to $3.00 per ton.

This is by far the youngest of all the major US talc-mining districts for production commenced only in 1952. The US Bureau of Mines credits Texas with the production of 207,000 tons of talc ore in 1979, but this is sharply down from immediately prior years.

California-Nevada

Of the major talc-mining districts in the United States, the one which combines the largest geographical area with the greatest number of productive commercial deposits is that of southeastern California, which barely extends northward into Nevada. It is about 200 miles long and has an average width of 30 miles, but is locally as much as 75 miles wide. Engel and Wright (1960) divide this long belt
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done during the 1940s by Henry Mulryan, then with Sierra Talc Co., and Walter K. Skeoch, then with Southern California Minerals Co.

The earliest significant work in the geological literature is that of Perry (1948), an excellent field study which was compiled in the very early days of the Montana talc industry. Subsequent works worthy of consultation for further and more timely details on this district are Olson (1976), whose work mainly concerns the Ruby Range, and Berg (1979), whose work covers the remainder of the district.

High-purity talc deposits in southwestern Montana are totally restricted in their occurrence to dolomitic marble in the Prebeltian Cherry Creek Series. The talc, which is generally white to pale green, commonly occurs as conformable lenses and stringers within the marble; if the talc is anywhere discordant, such a relationship is usually at low angles to the foliation of the bedrock. Structural control in the strictest sense has not been widely recognized, but there is an apparent restriction of talc mineralization to that part of the dolomitic marble which is spatially close to large bodies of the Dillon Granite Gneiss.

The following reaction is thought to account for the formation of these talc deposits:

$$3 \text{ dolomite} + 4 \text{ quartz} + H_2O = \text{talc} + 3 \text{ calcite} + 3\ CO_2.$$

Inasmuch as the host dolomite normally is not notably siliceous adjacent to the talc, it is likely most of the silica required for formation of the talc was metasomatically introduced. Although this is merely the writer's opinion, it is in part substantiated by Garihan (1973).

All of the pre-Cherry Creek rocks, the rocks of the Cherry Creek Series, and most of the rock types of the Dillon Granite Gneiss have been subjected to upper amphibolite grades of metamorphism, part of a long-lived metamorphic event in Prebeltian time, which included the development of intense isoclinal deformation. It is the writer's opinion that the talc most likely was formed during the period of regional metamorphism of greenschist grade, which postdated the amphibolite period and predated the intrusion of the diabase dikes. These vertical or near-vertical dikes, which are now best referred to as metadiabase, have a consistent northwesterly strike which coincides with the main direction of high-angle faulting.

Precambrian structural deformation was extreme and is characterized by isoclinal folding and refolding and the flowage of less competent rocks, rather than by faulting. Post-Precambrian folding has been negligible. The characteristic Laramide structure is high-angle block-faulting along northwest trends.

The talc was almost certainly formed in Precambrian time. Evidence is the relationship of the talc to the metadiabase and the fact that no talc whatsoever is known to have been formed in the thick dolomite units of the Cambrian and Devonian systems in the northern third of the Ruby Range, even though some of these dolomite units are within only a mile or so of talc deposits in the Precambrian dolomitic marble. Garihan (1973) feels that this lack of talc formation in the Paleozoic dolomites, plus the fact that the Paleozoic rocks are completely unmetamorphosed, speaks strongly for the talc having been formed in Precambrian time. Okuma (1971) also feels that the most likely age of the talc mineralization is Precambrian.

Several major talc deposits are known in the Ruby Range and one major deposit is known in the Gravelly Range. One relatively small deposit and several minor occurrences are known in the Greenhorn Range; several minor occurrences are also known in the Tobacco Root Mountains. Virtually all of Montana's talc production comes from three large mines—two in the Ruby Range and one in the Gravelly Range.

Ross, et al. (1955) have mapped the unit in which all of the known commercial talc deposits occur as covering an area about 180 miles long in an east-west direction (from Red Lodge to Bannack) and 85 miles wide (from Three Forks south to the Idaho border). The dolomitic marble which is the only host rock for the formation of the talc, however, does not occur over the entire extent of this unit. As known today, admittedly from still incomplete and extremely fragmental information, the dolomitic marble is probably significant only in the Ruby Range, the Gravelly Range, the Greenhorn Range, the Tobacco Root Mountains, and possibly in small areas of the Madison Range.

The mechanism of the formation of Montana talc bodies was probably similar to that postulated by Van Horn (1948) for the Murphy, NC talc ores. The geology of the southwestern Montana talc district is similar in many ways to that of the Murphy area and many of Van Horn's conclusions concerning the genesis of the Murphy talc ores also appear to apply to the genesis of Montana talc ores.

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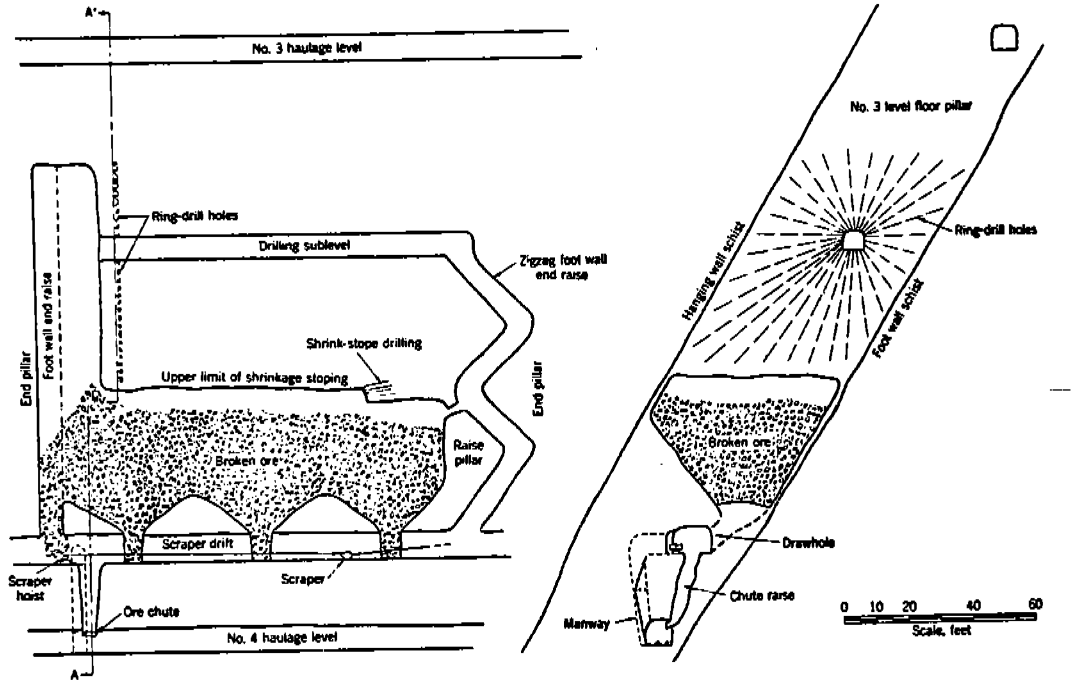

FIG. 1—*Drifts, raises, and combined shrinkage and sublevel stopes (Burmeister, 1963).*

The larger California talc mines are being converted to open pit mining.

Processing

Talc milling has traditionally involved dry-processing operations. Since much of the talc market is supplied with a relatively impure talc product, beneficiation is not usually carried out. The talc milling industry is slowly changing from uncomplicated grinding plants to sophisticated processing operations.

The new generation of talc mills includes complex froth flotation, sedimentation, hydrocycloning, dry and wet magnetic separation, centrifugal sizing, spray drying, and new grinding techniques. It should be noted that grinding is required both to prepare the ore for processing as well as to finish off the final product which must usually meet stringent particle size demands.

The processing of talc ores is complicated by the fact that extreme white color is a very desirable feature. Therefore, the grinding equipment used should not discolor the talc in any way. This generally rules out conventional rod and ball milling with steel grinding media. Fortunately, most talc ores are very soft and reasonably good grinding rates can be obtained with ceramic grinding media.

Some very sophisticated grinding facilities are often required for final preparation of processed talc sold to specific markets. For example, when talc is sold for paper filler and coating applications, it is generally designed to meet an average particle size of less than 5μ. In some special products this may be lowered to less than 1μ. This ultrafine grinding requirement is met with vertical-shaft pulverizing mills (3500 rpm) and jet-milling equipment. The latter utilizes the fluid energy principle with either compressed air or steam providing the energy. Fig. 2 is a sketch of a fluid energy type grinding mill.

In pioneer plants talc was ground in flour-grinding mills equipped with buhrstones and then sized on silk bolting reels (Parsons, 1948). The operation of such a mill grinding both wheat and talc was recorded as late as 1922.

Porcelain-lined flint-pebble mills were used at Gouverneur, NY, as early as 1885. In Vermont, where softer talc ore was ground, vertical emery mills, disintegrators, pulverizers, and roller mills were used. Cosmetic-grade talcs were sized by bolting through cloth.

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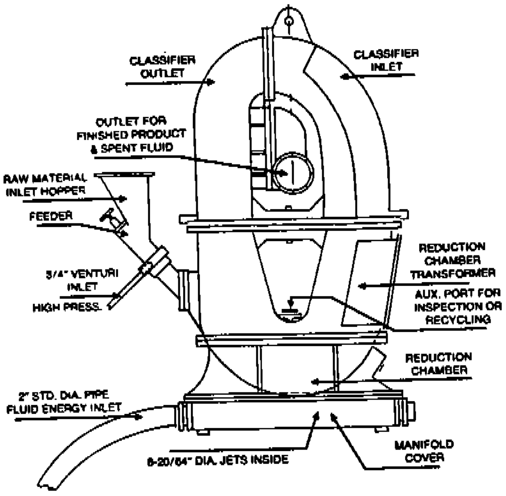

FIG. 2—*Sketch of fluid energy grinding mill.*

At present, little information has been published on wet grinding of talc ores. A pertinent reference to the subject appeared in Russian literature in 1971 (Karmazin, et al., 1972). The authors found that grinding in rod and ball mills did not result in "opening" of the mineral intergrowths even when grinding to a 5 to 10μ particle size. Jet mill grinding did accomplish intramineral grinding without the overgrinding resulting from impact mill grinding.

Windsor Minerals, Inc., a totally owned subsidiary of the Johnson and Johnson Co., operates two talc mines in Vermont. The Chester mine and the Hammondsville mine are both in Windsor County. The two talc processing plants serving these mines are located at Gassetts and West Windsor, VT. The plant at West Windsor utilizes sophisticated wet-process technology and has contributed toward better understanding of the basic problems involved in the beneficiation of talc ores.

Ore is delivered by trucks to the flotation plant where several high-grade talc products are manufactured. Fig. 3 is a flowsheet of the plant as reported in 1964 (Trauffer, 1964).

A Canadian talc processing facility using modern wet-processing equipment is operated by Baker Talc Ltd. Ore is produced from an underground operation at the Van Reet mine, in Potton Township about 80 miles southeast of Montreal. Talc was first mined here in 1871 (Anon., 1969).

The Baker talc plant utilizes froth flotation and high-intensity magnetic separation to produce high quality talc products. This ore could not be sufficiently beneficiated by froth flotation alone due to the presence of iron-bearing minerals which discolored the products. The magnetic separator in use is a modified high-intensity Jones wet magnetic separator which is now also finding major application in the beneficiation of many industrial minerals.

Eastern Magnesia Talc Co., Inc. (now Engelhard Minerals and Chemicals Corp.), was a pioneer in the Vermont talc industry. After a 1902 discovery of an ore body, a dry mill was constructed in 1904 to process 25 stpd (Harrah, 1956). This plant operated until 1920 when a 100-stpd dry plant was placed in operation. In 1932, wet methods of beneficiation were investigated. This work, along with US Bureau of Mines and the Missouri School of Mines development work, led to installation of a flotation pilot plant in 1937. Modification and enlargement of the pilot plant in 1938 resulted in commercial application of the froth flotation process. The ore is ground to 72 to 77% −200 mesh in dry pebble mills prior to flotation and shaking table concentration. The tables remove a high-gravity product containing a small quantity of nickel, iron, and cobalt minerals. A talc-magnesite mixture is floated at 18 to 21% solids in 21 Fahrenwald-type flotation cells.

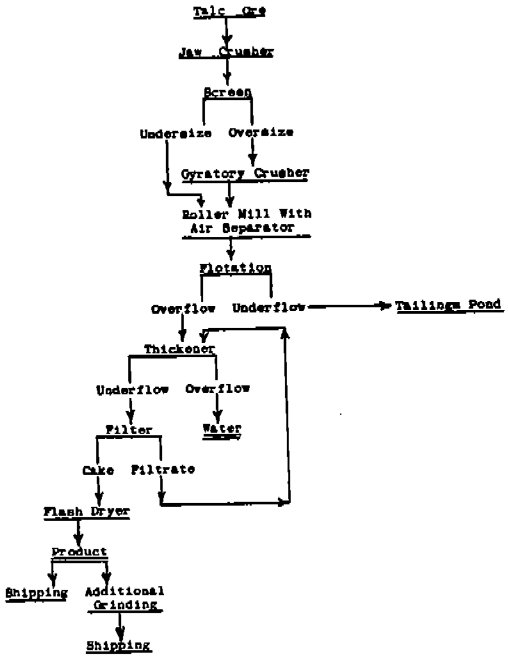

FIG. 3—*Flowsheet for Windsor Minerals, Inc., Vermont.*

The talc froth product contains talc particles of sufficiently coarse size that a rotary vacuum drum filter can be used for dewatering to 18% moisture. The filter cake is flash dried, pulverized, and air classified prior to shipping. Fig. 4 is a mill flowsheet as of 1962.

Naturally hydrophobic minerals such as talc, sulfur, graphite, and molybdenite will often respond positively to froth flotation without the addition of collector reagents. Lepetic (1972) has reported on the flotation of copper and molybdenum sulfides without collector reagents. Klassen and Mokrousov (1963) point out the striking similarity of talc and molybdenite as regards water wettability of the cleavage planes and the faces of these layered minerals.

A detailed report on a laboratory test program involving a Dadeville, AL, talc-asbestos deposit was issued in 1967 by Neathery, et al. (1967). The report concludes, "it is technically feasible to obtain good grade talc concentrates by flotation concentration of each of the five samples examined." Pine oil was the favored flotation reagent, and at least four flotation cleaning stages were necessary for optimum results. It was not considered feasible to produce a commercial anthophyllite concentrate for use as an asbestos product.

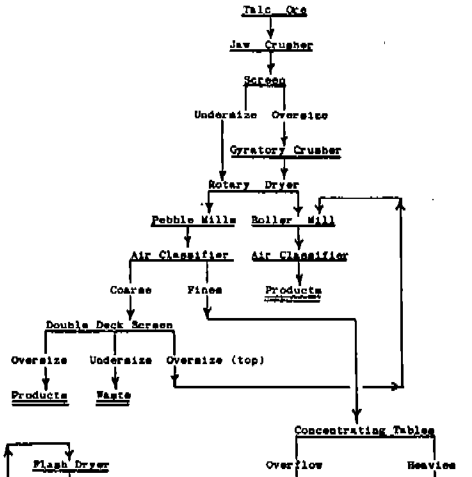

FIG. 4—*Flowsheet for Eastern Magnesia Talc Co., Vermont.*

The Johnson and Johnson Co. is an important producer and consumer of cosmetic-grade talc. In 1963, they were issued two patents (Brown and Macdonald, 1963; Chase, 1963), which constitute a good review of the art of flotation of platy talc ores. While platy talc is easily floated, many problems are encountered when the process is applied commercially. For good selectivity, when finely pulverized ores are used, the flotation cell pulp density is usually around 6 to 10% solids. This results in very low capacity per unit of cell volume. Further, when a major portion of the flotation froth concentrate product consists of particles finer than 325 mesh (44μ), it is difficult to dewater prior to the drying step. The platy talc particles effectively blind even the finest mesh filler fabrics. Centrifugal dewatering methods have proved effective when all conventional filtration methods fail.

There is no publication of commercial applications of the froth flotation process to tremolitic-talc ores. Norman, et al., (1939) published results of a detailed laboratory investigation on the flotation of talc ores from Gouverneur, NY, in 1939. These data indicate that a clean separation of soft, platy talc from tremolite is difficult. With a feed containing 36% tremolite, a cleaner concentrate containing 13.2% tremolite was floated. The underflow, or rougher tailing from this test, contained 47.3% tremolite.

Fig. 5 is a flowsheet showing typical dry-processing of New York tremolitic-talc ores.

Adaptation of a noncomplicated sedimentation process to the beneficiation of certain soft, platy talc ores was announced by Roe in 1972. A pilot plant operation on a talc-dolomite ore from the Death Valley-Kingston Range district, California, was successful in decreasing the carbonate mineral content from over 40% to less than 4%. The beneficiated product had a Valley Abrasion number of 4, a G.E. brightness of 93 to 95, 3.3% acid solubles, and 1.6% carbon dioxide. This, and similar processes, hold promise of the future development of similar low-grade talc ores and other filler minerals.

As wet processing is accepted by talc producers, the interest in specialized delamination equipment increases. Some talc deposits include a small percentage of naturally occurring, discrete, thin plates. For the most part, talc is in the form of booklets of plates which require physical effort to split into sheets for greater utility in paint, paper, plastics, and cosmetics.

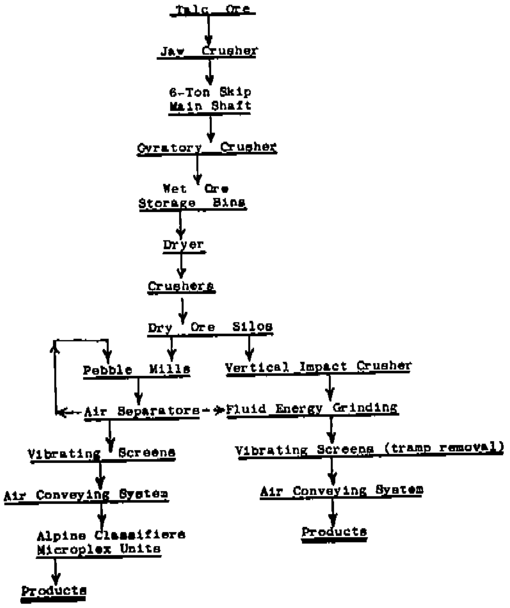

FIG. 5—*Flowsheet for Gouverneur Talc Co., Inc., New York.*

The mica industry has a long history of evaluating delamination processes. Mica used in joint cement (for wallboard, etc.) should have a low bulk density; the degree of delamination is generally directly proportional to the bulk density. A good mica will have a bulk density of less than 10 lb per cu ft. Several types of high-shear wet process equipment for delamination have been tested on mica and talc. In general, the processing usually involves the use of high-pressure pumps, such as those used on mineral-slurry pipelines, to force the mica or talc through a restricted orifice thus causing delamination. The same process is also used for size reduction of sulfur particles. It is reported that a pressure homogenizer can produce sulfur dispersions containing 99% of the particles in the 1μ range, with none larger than 3μ (Anon., 1966).

Ashton and Russell (1972) describe a useful method for study of delaminated talc platelets in two dimensions, area and thickness. In this method a thin film of talc particles is dusted onto the surface of distilled water and a section of the monolayer is picked up on a microscope glass slide. A precisely trimmed 10 cm^2 area of the talc film is examined photographically. By subtracting the void areas a total area of talc is determined on a projected image. The weight of the talc film is determined to 0.10 mg on a microbalance. The average thickness of the talc particles was calculated from the foregoing data as follows:

$$\text{Volume } (V) = \frac{\text{weight } (w)}{\text{density } (d)}$$

$$\text{Volume } (V) = \text{thickness } (t) \times \text{area } (a)$$

$$t = \frac{w}{ad}$$

$$t \times 10^{-4} = \text{thickness } (t) \text{ in microns}$$

where d is density of talc in grams per cubic centimeters$=2.7$, w is weight of talc on slide in grams, a is actual area covered by talc in square centimeters, and t is average thickness of talc in centimeters. By using the described technique, talc platelet thicknesses of 1.4 to 10.1μ were measured.

Quality control in many talc plants consists of uncomplicated test procedures. For example, the former Eastern Magnesia Talc Co. reported (Burmeister, 1963), "Quality control is largely based on percentage of contained talc (insolubility test in hydrochloric acid) and particle size and brightness or color."

In larger talc plants (+100,000 stpy production) very sophisticated laboratory procedures are used to control product quality. Those talc plants supplying the larger segments of the talc market, such as paint, paper, and cosmetics, will have facilities for chemical and instrumental analysis, surface area determination, color, oil absorption, abrasivity, particle size and shape determination, packing quality, resistivity, lubricity, bacterial count, melting point, vitrification range, and fired shrinkage.

Production and Markets

The total world production figures for talc, soapstone, and pyrophyllite have generally been compounded. This addition of quantities results from lack of both mineralogical and definitive production data.

As the talc industry grows, uses more sophisticated beneficiation methods, and meets stringent product specifications, there is evolving a more logical statistical reporting system. Production statistics should list, for example, figures for paper filler grade talc, cosmetic talc for face and body powders, cosmetic talc for use in aerosol applications, talc used in many types of lubricants, and talc used in agricultural applications.

US mine production of talc exceeded 1 million tons for the first time in 1969. World production averaged 1.7 million tons for the period 1945–1960 but by 1969 world production rose to 5 million tons.

Many of the important large tonnage uses for talc are closely related to the degree of sophistication of industrialization of a given country. Over the 15-year period 1945 to 1960, the United States produced about 38% of the total world production of talc, soapstone, and pyrophyllite; by 1962, this had dropped to 26%. For the ten years preceding 1973, US production stabilized to average about 22% of the total world production.

In 1980, talc was produced by 21 companies from mines in 12 states. Vermont, Montana, New York, and Texas were the top producing states, accounting for 90% of the year's output. Georgia, North Carolina, Arkansas, Nevada, Oregon, Virginia, and California produced the remaining tonnage. Iowa is listed as a producer but actually, it has only a grinding facility processing ores from other areas. The 1979 US production of talc was 1,268,000 tons.

Table 5 shows tonnages of ground talc sold or used by US producers in 1978, 1979, and 1980.

TABLE 5—End Uses for Ground Talc

Use	Thousand short tons 1978	1979	1980
Ceramics	257	260	282
Cosmetics*	69	74	59
Insecticides	13	13	11
Paint	192	237	197
Paper	87	105	102
Plastics	147	112	110
Refractories	6	6	2
Roofing	18	19	20
Rubber	36	39	37
Other uses⁺	92	95	83
Total‡	917	960	903

Source: Clifton, 1980, 1981.

* Incomplete data. Some cosmetic talc known to be included in "Other uses."

⁺ Includes art sculpture, asphalt filler, crayons, floor tile, foundry facings, rice polishing, stucco, and other uses not specified.

‡ Data may not add to totals shown because of independent rounding.

Future Trends

The uses for talc in putties, caulks, and many types of sealants and adhesives are rapidly increasing. This is especially true in those products requiring close control of color (white and tinted) and dependence on high quality through adherence to strict control of talc specifications.

Talc has several competitive minerals which are sold for similar uses. Feldspar, wollastonite, and nepheline syenite compete in ceramics. Mica competes in the roofing markets. Titanium dioxide is losing ground as a competitive filler in some markets due to its high cost. Specially purified, calcined, and compounded clays compete with talc in paint, paper, and plastics.

One important factor to consider in future competition for the talc filler markets in paint, paper, and plastics is the rapid penetration of these markets by limestone and dolomite-filler products. Calcium carbonate is often considered to be the most versatile commercially produced mineral filler. The United States market for calcium carbonate fillers and extenders exceeds the total domestic market for talc and pyrophyllite.' The world market for carbonate fillers is growing at a faster rate than any other mineral filler. The widespread availability of large carbonate deposits strategically located for low-cost transportation will encourage continuing competition in the white-mineral filler market. A detailed comparison of calcium carbonate and talc fillers is presented by Roe (1980).

As more industrial minerals operations change over to wet beneficiation methods, especially flotation, there may be considerable amounts of byproduct talc produced. The very successful introduction of wet high-intensity magnetic separation in the beneficiation of kaolin clays and other industrial minerals has added another dimension to the options in talc ore processing.

Bibliography and References

Anon., 1956, "Talc," California Mineral Information Service, Vol. 9, No. 11, Nov. 1, 8 pp.

Anon., 1966, "An Alternate Route to Size Reduction," *Chemical Processing*, Aug., p. 82

Anon., 1969, "Process Break-Through Revitalizes 100 Year Old Mine," *Mining in Canada*, Oct., pp. 27–30.

Anon., 1970, "Standard Method of Test for Fineness of Dispersion of Pigment-Vehicle Systems," ASTM Designation D1210–64 (reapproved 1970).

Anon., 1971a, "The Operations of A/S Norwegian Talc," *Industrial Minerals* (London), Jan., pp. 27–28.

Anon., 1971b, "Pyrenean Producer: S.A. des Talcs

---

de Luzenac,"
Jan., p. 25.
Anon., 1971c, "
Way," *Industr*
9–18.
Anon., 1971d.
Minerals and
(London), N
Anon., 1971e,
Gradual Rise
Jan., pp. 19–2
Anon., 1971f, "
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oxide," *Chem.*
No. 24, Dec. 1
Anon., 1982, "
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References

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1210–64 (reapproved

ons of A/S Norwegian
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oducer: S.A. des Talcs

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de Luzenac," *Industrial Minerals* (London), Jan., p. 25.

Anon., 1971c, "Talc: Micronized Grades Lead the Way," *Industrial Minerals* (London), Jan., pp. 9–18.

Anon., 1971d, "Talc Operations of Engelhard Minerals and Chemicals," *Industrial Minerals* (London), No. 41, Feb., p. 46.

Anon., 1971e, "Talc: UK Consumption Shows Gradual Rise," *Industrial Minerals* (London), Jan., pp. 19–24.

Anon., 1971f, "Windham Plant Grinds Talc for Specialized Applications," *Rock Products*, Vol. 74, No. 6, June, p. 59.

Anon., 1972, "Chemical Profile—Titanium Dioxide," *Chemical Marketing Reporter*, Vol. 202, No. 24, Dec. 11, p. 9.

Anon., 1982, "Talc, Stability in a Soft Market," *Industrial Minerals*, No. 183, Dec., pp. 59–73.

Ashton, W.H., and Russell, R.S., 1972, "Talc Beneficiation," US Patent 3,684,197, Aug. 15.

Barnes, D.F., 1958, "Infrared Luminescence of Minerals," Bulletin 1052-C, US Geological Survey, p. 113.

Bennett, F.E., 1972, "Tile Council of America Research in the Seventies," American Ceramic Society, Fall Meeting, Sept. 27–29, Bedford, PA.

Berg, R.B., 1979, "Talc and Chlorite Deposits in Montana," *Memoir 45*, Montana Bureau of Mines and Geology, 65 pp.

Blount, A.M., and Vassiliou, A.H., 1980, "The Mineralogy and Origin of the Talc Deposits Near Winterboro, Alabama," *Economic Geology*, Vol. 75, No. 1, pp. 107–116.

Bourbon, W.B., 1981, "The Origin and Occurrences of Talc in the Allamoore District, Texas," in Program with Abstracts, 17th Annual Forum on the Geology of Industrial Minerals, Albuquerque, NM, May.

Brindley, G.W., and Santos, P. de S., 1971, "Antigorite—Its Occurrence as a Clay Mineral," *Clays and Clay Minerals*, Vol. 19, pp. 187–191.

Brown, J.S., and Engel, A.E.J., 1956, "Revision of Grenville Stratigraphy and Structure in the Balmat-Edwards District, Northwest Adirondacks, New York," *Bulletin*, Geological Society of America, Vol. 67, No. 12, pp. 1599–1622.

Brown, W.E., and Macdonald, R.D., 1963, "Talc Beneficiation," US Patent 3,102,855, Sept. 3.

Burmeister, H.L., 1963, "Mining Methods and Costs, Eastern Magnesia Talc Co., Johnson Mine, Johnson, Vermont," Information Circular 8142, US Bureau of Mines, 44 pp.

Campbell, M.E., 1972, "Solid Lubricants, A Survey," NASA SP-5059(01) publication prepared under contract by Midwest Research Institute, Kansas City, MO, 126 pp.

Campbell, W.J., et al., 1980, "Chemical and Physical Characterization of Ampite, Chrysotile, Crocidolite, and Nonfibrous Tremolite for Oral Ingestion Studies by the National Institute of Environmental Health Sciences," Report of Investigations 8452, US Bureau of Mines, 63 pp.

Cawood, E.E.C., 1962, "Fire Extinguishing Composition," US Patent 3,063,940, Nov. 13.

Chase, W.E., 1963, "Platy Talc Beneficiation," US Patent 3,102,856, Sept. 3.

Chidester, A.H., Billings, M.P. and Cady, W.M., 1951, "Talc Investigations in Vermont," Preliminary Report, Circular 95, US Geological Survey, 33 pp.

Chidester, A.H., et al., 1964, "Talc Resources of the United States," Bulletin 1167, US Geological Survey, pp. 1–61.

Christman, R.A., 1959, "Geology of the Mount Mansfield Quadrangle, Vermont," Bulletin 12, Vermont Geological Survey, 70 pp.

Christman, R.A., and Secor, D.T., Jr., 1961, "Geology of the Camels Hump Quadrangle, Vermont," Bulletin 15, Vermont Geological Survey, 70 pp.

Clifton, R.A., 1980, "Talc and Pyrophyllite," Preprint 1978–1979, US Bureau of Mines, 7 pp.

Clifton, R.A., 1981, "Talc and Pyrophyllite," *Minerals Yearbook 1980*, US Bureau of Mines, pp. 815–820.

Cooper, J.D., and Hartwell, J.W., 1970, "Talc, Soapstone and Pyrophyllite," *Mineral Facts and Problems*, Bulletin 650, US Bureau of Mines, pp. 1267–1281.

Dickson, T., 1982, "North American Talc," *Industrial Minerals*, No. 183, Dec., pp. 75–78.

Dillender, R.D., Jr., and Gower, I.W., 1953, "Preliminary Report on the Froth Flotation of Wake County Talc," Bulletin No. 7, Dept. of Engineering Research, North Carolina State College, Raleigh, NC, Nov., 16 pp.

Drake, M.J., and Brett, B.A., 1962, "Talc, Soapstone and Pyrophyllite," *Minerals Yearbook 1962*, US Bureau of Mines, pp. 1189–1198.

Edwards, G., 1980, "Tumbledown Mountain Talc Deposit, Allamoore District, Culberson County, Texas," *Guidebook*, 31st Field Conference, New Mexico Geological Society, pp. 245–250.

Elstron, L.W., 1961, "Slipping and Sliding," *Research Engineer*, Georgia Institute of Technology, Feb., pp. 15–18.

Engel, A.E.J., 1949, "New York Talcs, Their Geological Features, Mining, Milling and Uses," *Transactions AIME*, Vol. 184, pp. 345–348.

Engel, A.E.J., and Wright, L.A., 1960, "Talc and Soapstone," *Industrial Minerals and Rocks*, 3rd ed., J.L. Gillson, ed., AIME, New York, pp. 835–850.

Erdman, G.R., 1973, "Dust Control at Gouverneur Talc Company," *Trans. SME-AIME*, Vol. 254, No. 2, June, pp. 161–165.

Faust, G.T., and Fahey, J.J., 1962 "The Serpentine-Group Minerals," Professional Paper 384–A, US Geological Survey, pp. 80–82.

Flawn, P.T., 1958, "Texas Miners Boost Talc Output," *Engineering and Mining Journal*, Vol. 159, No. 1, pp. 104–105.

Frommer, P.W., and Fine, M.M., 1956, "Laboratory Flotation of Talc from Arkansas and Texas Sources," Report of Investigations 5241, US Bureau of Mines, June, 5 pp.

Furcron, A.S., Teague, K.F., and Calver, J.L., 1947, "Talc Deposits of Murray County, Georgia," *Bulletin 53*, Georgia Geological Survey, 75 pp.

Garihan, J.M., 1973, "Geology and Talc Deposits of the Central Ruby Range, Madison County, Montana," PhD dissertation, Pennsylvania State University, 209 pp.

Gillingham, W.P., 1950, "Grinding Talc to Superfine Size," *Compressed Air Magazine*, Feb., pp. 32–37.

Harrah, H.W., 1956, "Eastern Magnesia Talc

Company, Inc." *Deco Trefoil*, Denver Equipment Co., May–June, pp. 7–14.

Harrell, G.O., and Harrell, D.E., 1971, "Survey of Mineral Fillers in Selected Industries, Phase I—Plastics and Textiles," The Industrial Extension Service, School of Engineering, North Carolina State University, Raleigh, NC, Apr., 105 pp.

Herod, B.C., 1954, "Pioneer Talc Leads Way in West Texas Field," *Pit and Quarry*, Vol. 54, Apr., pp. 134–135, 156.

Heystek, H., and Planz, E., 1964, "Mineralogy and Ceramic Properties of Some California Talcs," *Bulletin*, American Ceramic Society, Vol. 43, No. 8, pp. 555–561.

Hunt, R.E., 1969, "How to Select Fillers and Reinforcements for Thermoplastics," *Plastics Technology*, Nov., pp. 38–43.

Karmazin, V.I., et al., 1972, "Grinding and Concentrating Capacity of Talc-Magnesite Rocks of the Pravda Deposit of the Ukranian SSR," Obogasheh, Polez, Iskop, 1971, No. 9, p. 28–29 (Russ.); *Chemical Abstracts*, Vol. 77, 92190c, p. 262.

Katz, H.S., and Mileski, J.V., 1978, *Handbook of Fillers and Reinforcements for Plastics*, Van Nostrand Reinhold Co., New York, 652 pp.

King, P.B., and Flawn, P.T., 1953, "Geology and Mineral Deposits of Precambrian Rocks of the Van Horn Area, Texas," No. 5301, Texas University Publications, 218 pp.

Klassen, V.I., and Mokrousov, V.A., 1963, *An Introduction to the Theory of Flotation*, London, 493 pp.

Lamb, F.D., and Ruppert, J., 1950, "Flotation of a North Carolina Pyrophyllite Ore," Report of Investigation 4674, US Bureau of Mines, Apr., 7 pp.

Lepetic V.M., 1972, "Flotation of Copper and Molybdenum Sulfides Without Collector," Preprint 72B308, SME-AIME Fall Meeting, Birmingham, AL, Oct. 18–20, pp. 1–23.

Lundquist, J.D., 1970, "Talc Treatment and Talc-Containing Pigments," US Patent 3,533,821, Oct. 13.

McMurray, L., and Bowles, E., 1941, "The Talc Deposits of Talladega County Alabama," Circular 16, Geological Survey of Alabama, 31 pp.

Miller, C.R., and Holtzapfel, P.J., 1970, "Corrosion Proofing Composition and Method," US Patent 3,549,391, Dec. 22.

Mulryan, H.T., 1971, "World-Wide Operations of United Sierra," *Industrial Minerals* (London), No. 41, Feb., pp. 43–45.

Neathery, T.L., 1968, "Talc and Anthophyllite Asbestos in Tallapoosa and Chambers Counties, Alabama," Bulletin 90, Geological Survey of Alabama, 98 pp.

Neathery, T.L., 1970, "Geology and Mining of Low Grade Talc Deposits, Tallapoosa County, Alabama," Preprint 70H311, SME-AIME. Fall Meeting, St. Louis, MO, 15 pp.

Neathery, T.L., et al., 1967, "Talc and Asbestos at Dadeville, Alabama," Report of Investigations 7045, US Bureau of Mines, 57 pp.

Needham, R.E., 1972, "The Geology of the Murray County, Georgia Talc District," Master's thesis, Pennsylvania State University, 107 pp.

Norman, J.E., et al., 1939, "Froth Flotation of Talc Ores from Gouverneur, New York," *Bulletin*, American Ceramic Society, Vol. 18, No. 8, pp. 292–297.

Okuda, S., et al., 1969, "Negative Surface Charges of Pyrophyllite and Talc," *Proceedings of the International Clay Conference*, Tokyo, Vol. 1, pp. 31–44, Vol. 2, pp. 14–16.

Okuma, A.F., 1971, "Structure of the Southwestern Ruby Range near Dillon, Montana," PhD dissertation, Pennsylvania State University, 122 pp.

Olson, R.H., 1976, "The Geology of Montana Talc Deposits," Spec. Publ. 74, Montana Bureau of Mines and Geology, pp. 99–143.

Owens, M.H., 1968, "Petrologic Study of Talc Mineralization in the Murphy Marble in Southwestern North Carolina," Master's thesis, Tennessee University, 64 pp.

Papke, K.G., 1975, "Talcose Minerals in Nevada—Talc, Chlorite, and Pyrophyllite," Bulletin 84, Nevada Bureau of Mines and Geology, 62 pp.

Parsons, A.B., 1948, *Seventy-Five Years of Progress in the Mineral Industry, 1871–1946*, AIME, New York, p. 355.

Pence, F.K., 1955, "Commercially Proven White-Firing Talc Occurring in West Texas," *Bulletin*, American Ceramic Society, Vol. 34, No. 4, pp. 122–123.

Perry, A., 1972, "Supply and Demand for Ceramic Tile in the Seventies," American Ceramic Society, Fall Meeting, Sept. 27–29, Bedford, PA.

Perry E.S., 1948, "Talc, Graphite, Vermiculite and Asbestos in Montana," Memoir 27, Montana Bureau of Mines and Geology, 44 pp.

Poppe, W., et al., 1972, "Talc Filled Metallizable Polyolefins," US Patent 3,663,260, May 16.

Povarennykh, A.S., 1972, *Crystal Chemical Classification of Minerals*, Vol. 1, trans. from Russian by J.E.S. Bradley, Plenum Press, New York, pp. 415–416.

Ranney, M.W., et al., 1972, "Silane Coupling Agents in Particulate Mineral-Filled Composites," 27th Reinforced Plastics Technical and Management Conference, SPI, Washington, DC, Feb. 8–11, pp. 1–29.

Rayner, J. H., and Brown, G., 1966, "Structure of Pyrophyllite," *Clays and Clay Minerals*, Proceedings, 13th National Conference on Clays and Clay Minerals, Pergamon Press, New York, pp. 73–84.

Roe, L.A., 1972, "High-Purity Talc from Western Ores," Preprint 72H312, SME-AIME Fall Meeting, Birmingham, AL, Oct. 18–20, 16 pp.; US Patent 3,806,043, Apr. 23, 1974.

Roe, L.A., 1980, "A Comparison of Calcium Carbonate and Talc Fillers," Preprint 80–301, SME-AIME Fall Meeting, Minneapolis.

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, "Geologic Map of Montana," US Geological Survey.

Ross, M., and Smith, W.L., 1968, "Triclinic Talc and Associated Amphiboles from Gouverneur Mining District, New York," *American Mineralogist*, Vol. 53, May-June, pp. 751–769.

Seymour, R.B., et al., 1972, "Fibrous Reinforcements for Polymers," *1972–73 Modern Plastics Encyclopedia*, pp. 365–394.

Trauffer, W.E., 1964, "New Vermont Talc Plant Makes High-Grade Flotation Product for Special Uses," *Pit and Quarry*, Vol. 57, No. 6, Dec., pp. 72–76, 101.

Troll, G., and Gilbert, M.C., 1972, "Fluorine-Hydroxyl Substitution in Tremolite," *American Mineralogist*, Vol. 57, pp. 1386–1403.

rface Charges
edings of the
okyo, Vol. 1,

; Southwestern
na," PhD dis-
/ersity, 122 pp.
Montana Talc
ana Bureau of

Study of Talc
arble in South-
r's thesis, Ten-

als in Nevada—
:," Bulletin 84,
Geology, 62 pp.
Years of Prog-
'1-1946, AIME,

/ Proven White-
Texas," *Bulletin*,
.. 34, No. 4, pp.

;and for Ceramic
:an Ceramic So-
:9, Bedford, PA.
, Vermiculite and
oir 27, Montana
·, 44 pp.
illed Metallizable
,3,260, May 16
Chemical Classi-
trans. from Rus-
Press, New York.

"Silane Coupling
eral-Filled Com-
tics Technical and
SPI, Washington,

, 1966, "Structure
'lay Minerals, Pro-
nference on Clays
ı Press, New York.

Talc from Western
E-AIME Fall Mee-
18–20, 16 pp.; U
974.
on of Calcium Car-
print 80-301, SME-
polis.
Witkind, I.J., 195
ıa," US Geologic

968, "Triclinic Ta
s from Gouverne
:," *American Min*
pp. 751–769.
"Fibrous Reinforc-
-73 Modern Plasti

Vermont Talc Pl
n Product for Spec
. 57, No. 6, Dec.,

C., 1972, "Fluorine
Tremolite," *Ameri*
1386–1403.

Van Horn, E.C., 1948, "Talc Deposits of the Murphy Marble Belt," Bulletin 56, North Carolina Dept. of Conservation and Development, Division of Mineral Resources, 54 pp.

Wells, J.R., 1973, "Talc, Soapstone, and Pyrophyllite in 1973," Annual Advance Summary, US Bureau of Mines, 2 pp.

Winkler, H.G.F., 1974, *Petrogenesis of Metamorphic Rocks*, Springer-Verlag, New York, 320 pp.

Wright, L.A., 1950, "California Tâlcs," *Trans. AIME*, Vol. 187, pp. 122–128.

Wright, L.A., 1968, "Talc Deposits of the Southern Death Valley-Kingston Range Region, California," Special Report 95, California Division of Mines and Geology, 79 pp.

Zen, E-an, 1961, "Mineralogy and Petrology of the System AL_2O_3-SiO_2-H_2O in Some Pyrophyllite Deposits of North Carolina," *American Mineralogist*, Vol. 46, Jan.-Feb., pp. 52–66.