

DIATOMITE

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Production of diatomite in the United States decreased by about 9% to 677,000 metric tons (t), and its value decreased by about 3% to \$173 million free on board (f.o.b.) plant in 2000, compared with 747,000 t valued at \$178 million f.o.b. plant in 1999 (table 1). U.S. production of diatomite in 2000 was the lowest since 1994. The decline in production of diatomite can be attributed in part to the decline of growth of the economy and increased energy costs in late 2000 and early 2001. Mining operations that include energy costs associated with calcining, such as diatomite, were affected, particularly in California (Industrial Minerals, 2001). Despite the production decrease, the United States remained the world's largest producer and consumer of diatomite. Used primarily for filtration, major diatomite products were sold as various grades of calcined powders (table 2).

Description and Terminology

Diatomite is a chalk-like, soft, friable, earthy, very fine-grained, siliceous sedimentary rock, usually light in color (white if pure, commonly buff to gray in situ, and rarely black). It is very finely porous, very low in density (floating on water at least until saturated), and essentially chemically inert in most liquids and gases. It also has low thermal conductivity and a rather high fusion point. Diatomaceous earth (often abbreviated as D.E.) is a common alternate name but more appropriate for the unconsolidated or less lithified sediment. The deposits result from an accumulation in oceans or fresh waters of the amorphous hydrous silica (opal, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$) cell walls of dead diatoms, which are microscopic single-cell, often colonial aquatic plants (algae). The diatom cells contain an internal, elaborate siliceous skeleton consisting of two valves (frustules), which fit together much like a pill box. The diatom's fossilized

skeletal remains vary in size from less than 1 micrometer to more than 1 millimeter but are typically 10 to 200 micrometers across and have a broad variety of delicate, lacy, perforated shapes from spheres and cylinders to discs, ladders, feathers, and needles. Each deposit has characteristic assemblages that have been used to identify the source of material for forensic purposes. There are more than 10,000 species of extinct and living diatoms, some of which live in ice or hot springs as well as marshes or even on moist bark, but they are most abundant in sunlit water—fresh or salt—constantly enriched with suitable nutrients and dissolved silica. Live cells are covered by a jelly, and masses appear as brownish water or films on-stream bottoms. Extensive blooms of diatoms (algae) in coastal waters have caused severe pollution and anoxic conditions, and some species produce domoic acid, a nerve poison that, if ingested, quickly causes death to many animals (Eureka, November 12, 1998, Diatoms—Nature's marbles, accessed May 4, 2000, at URL <http://hjs.geol.uib.no/diatoms>).

Diatomite is also known as kieselgur (a German name compounded from the words for flint and for an earthy sediment in water) and as tripolite after a diatomite occurrence near Tripoli, Libya. Tripolite is used in some government trade documents as the short name for a longer description of "siliceous fossil meals and similar siliceous earths...;" the short name is used more generally in the various tariff codes that cover diatomite (U.S. International Trade Commission, January 25, 2001, Harmonized Tariff Schedule of the United States—Section V—Chapter 25, accessed June 13, 2001, at URL <http://dataweb.usitc.gov/scripts/tariff/0101c25.pdf>). An impure (up to 30% clay) Danish variety of diatomite is called moler.

Analysis of oven-dried samples of crude ore from many commercial operations typically shows 80% to 90% (in some

Diatomite in the 20th Century

By 1900, diatomite already had a variety of uses such as in building materials, polishing compounds, filtration, filler material in rubber, paint, roofing, and paper—a prelude to its worldwide use in the 20th century. The first discovery of diatomite in North America was made by J.W. Bailey in 1839 near West Point, NY. Alfred Nobel's invention of dynamite in 1867 resulted in the development of the world's first significant diatomite industry, as diatomite was used as an absorbent and stabilizer for dynamite and nitroglycerine. Dynamite and nitroglycerine explosives required significant amounts of diatomite and operations began to flourish. In 1900, the first U.S. patent was issued for the use of diatomite in beer filtration, which is one of diatomite's primary applications in modern times. Production of diatomite in the United States for 1900 was about 3,280 metric tons. The

development of processing techniques during the 1920s (such as calcination, flux calcination, grade and sizing technologies) enabled diatomite to be used in a variety of market applications and end uses.

In 2000, the United States was the world's largest producer and consumer of diatomite, producing 677,000 tons, which accounted for about 36% of global production. Western States were the primary source of U.S. production of diatomite, the largest amount coming from the diatomite deposits of Lompoc, CA. Major diatomite products were sold as various grades of calcined powders. Diatomite continued to be used primarily for filtration (beer, cooking oils, wine), while other major uses were as absorbents, filler applications, insulation, and in cement manufacturing. China was the United States' main production competitor.

cases 95%) silica (SiO₂) plus alumina (2% to 4%, attributed mostly to clay minerals) and hematite (0.5% to 2%), with an analytical ignition loss of 4% to 6%. Apparent oven-dry block density is 320 to 640 grams per liter (g/L) (compared to 1,000 g/L for water) with 80% to 90% voids. In-place ore contains from 10% to as much as 65% water (2% to 10% in the opaline structure). Dry crude rock can absorb from 1.5 to more than 3 times its weight in water. Dry powdered natural rock has an apparent density of 80 to 250 g/L. The melting point of diatomite ranges from 1,000° C to 1,750° C (Durham, 1973; Breese, 1994).

World reserves are estimated to be 800 million metric tons (Mt), which is 400 times the current estimated annual world production of 2 Mt (table 5). Of the 800 Mt, 250 Mt are in the United States (Antonides, 1999). The world reserve base was estimated by the U.S. Bureau of Mines in 1985 to be almost 2 billion tons (Meisinger, 1985). A resource estimate based just on the dimensions of the deposits near Lompoc, CA, suggests that collectively they could meet the world's current needs for centuries. Data on reserves, however, which are defined as being currently economic using proven practices among other qualifications (U.S. Bureau of Mines and U.S. Geological Survey, 1980), are not readily available and are difficult to calculate because, in addition to considerable variation in physical and chemical properties between and even within deposits, the particular potential use and proximity to a market are major considerations.

Commercial deposits worldwide are reported as mostly freshwater lake (lacustrine) deposits of Miocene to Pleistocene age, formed between 24 million to 10 thousand years ago. The reputed world's largest producing deposit that outcrops near Lompoc is a huge marine deposit of Miocene age. Although known marine occurrences generally appear to be larger than the lacustrine deposits, a very large diatomite deposit reported in China appears to be lacustrine (Lu, 1998, p. 53). The oldest marine occurrences are believed to be of Cretaceous age, about 138 million to 66 million years ago; any older occurrences would presumably have been changed into other forms of silica. The oldest lacustrine deposits are believed to be 55 million to 38 million years old, of Eocene age. Many deposits worldwide, especially of the older marine type, have been found in uplifted coastal areas exposed to some volcanic effects (such as the Pacific Rim from Chile to Japan). Lacustrine deposits, especially in mountainous localities, also often show some association with volcanic activity (such as the Pacific Northwest). However, there are lacustrine environments where diatomite deposits are presently forming in lowlands far removed from volcanic activity (such as Florida).

Production

Recovery of diatomite from most deposits is by low-cost open pit mining because many occurrences are at or near the surface and the topography allows for open pit mining. To remove overburden and excavate ore, different combinations of rippers, dozers, scrapers, front-end loaders, power shovels, and dump trucks are used. Outside the United States, however, underground mining is fairly common (such as in Chile, China, and France) owing to deposit form and depth and topographic and other constraints. Usually, room and pillar methods are used, often with equipment similar to that used in open pits, but the smallest mines are excavated with hand tools. Explosives are not normally needed at surface or underground mines

because of the rock's soft, friable nature. In Iceland, dredging is used to recover diatomaceous mud from the bottom of a lake. As climate permits, at many mines the ore is stockpiled in the open to segregate it by grade and to reduce the normally high moisture content before delivering it to the processing facility.

Diatomite processing is usually done near the mine to reduce the cost of hauling up to 65% water, but the cost of delivering energy (electric power and fuel) to the site is an offsetting consideration. Processing typically involves a series of crushing, drying, size reduction, and calcining operations, using heated air for conveying and classifying within the plant. Commonly, spiked rolls and hammer mills are used for primary crushing to a size of -1.25 centimeters (0.5 inches), while limiting damage to the diatomite structure. With the heated air and multiple passes through special "milling" fans and air cyclones, further drying, size reduction, and classifying are accomplished. The cyclones not only classify for size but also remove undesirable components in the raw feed based on density differences. Size reduction aims at separating individual frustules without destroying their delicate structure. Fines, especially from baghouses used to remove particulates from the cyclone discharge waste or recycle air, are used mostly for filler grade products, and the coarser bottom discharge particles are used for filter grades. In the latter stages of processing, calcining is normally done in rotary kilns to effect the physical and chemical changes previously mentioned. Plant operators take special precautions to overcome any free crystalline silica health hazards, particularly to the lungs, by containing dust within enclosures and requiring employees to use respirators. Although the generally high moisture in the ore reduces the free crystalline silica health hazards in mining areas, precautions are still taken.

Production cost allocations were reported for the United States in 1983 as 10% mining, 60% processing, and 30% packing and shipping; a 1990 report stated energy costs were 25% to 30% of direct costs (Breese, 1994, p. 405). The proportion of the product that is calcined directly affects energy consumption.

For the United States, the diatomite production data used to prepare table 1 were collected by a survey sent by the U.S. Geological Survey (USGS) to all known mine producers who voluntarily gave a 100% response as to the tonnage and value sold or used, which historically has been considered in these statistics as production. The survey for 2000 covered 7 diatomite-producing companies with 13 separate mining areas and 12 processing facilities in California, Nevada, Oregon, and Washington. Two of these operations were reported as inactive. Major producers were Celite Corp. (Lompoc, CA, and Quincy, WA); Eagle-Picher Industries Inc. (Lovelock and Fernley, NV, and Vale, OR); and Grefco Minerals, Inc. (Burney and Lompoc, CA, and Mina, NV). Smaller producers were Calveras Cement Co. (Burney, CA); CR Minerals Corp. (Fernley, NV); Moltan Co. (Fernley, NV); and Oil-Dry Production Co. (Christmas Valley, OR). California continued to be the leading producing State, followed by Nevada. The combined production of these two States accounted for about 87% of the U.S. production in 2000.

Consumption

Apparent domestic consumption (production sold or used based on USGS's survey plus imports minus exports using trade data furnished by the Department of Commerce; stock data are

not available) of diatomite in 2000 was about 547,000 t, a 12% decrease from 625,000 t in 1999.

According to data from the USGS survey, total domestic and export quantities of filter-grade diatomite sold or used by U.S. producers was 446,000 t in 2000, 4% less than in 1999. For absorbents, the second largest category, 96,000 t was consumed, 21% less than in 1999. Filler applications accounted for 95,000 t, 17% more than in 1999, and insulation use increased by 20% to 18,000 t. Other consumption applications decreased by 69% to 21,000 t, special product sales and cement manufacturing constituting the majority of that amount (table 2). Comparing 2000 data with 1995 data for percentage of total use, filter use declined, filler use increased, insulation use remained the same, while absorbent and other uses (mostly special product sales and cement manufacture) increased slightly.

In antiquity, diatomite was used by the Greeks as an abrasive and in making lightweight building brick and blocks. In A.D. 535, blocks of diatomite were used for the 30-meter-diameter dome of the Church of St. Sophia in Istanbul, Turkey (Maurrasse, 1978). However, it only became of industrial interest in Western Europe in the mid-1800s. One of the first uses at that time was as cut blocks and bricks for heat-insulation. In the 1860s, pulverized diatomite became the preferred absorbent and stabilizer of nitroglycerine used by Alfred Nobel to make dynamite. The site of the first U.S. production of diatomite was in Maryland in 1884. By the late 1880s, the very pure, huge deposit near Lompoc became the focus of interest and has continued to dominate the world markets. Diatomite is now used principally as a filter aid; but it has many other applications, such as an absorbent for industrial spills and for pet litter, a filler in a variety of products from paints to dry chemicals, as an insulation material in sawn and molded shapes and as loose granules, a mild abrasive in polishes, and a silica additive in cement and various other compounds.

Commercial diatomite products provide fine-sized, irregular-shaped porous noncaking particles having a large surface area and a high liquid absorption capacity. They are chemically relatively inert, have a low refractive index, are mildly abrasive, have low thermal conductivity with a reasonably high fusion point, can be slightly pozzolanic, are very high in silica, and can be produced and delivered at a cost consistent with customers applications. Sawn shapes have long been used as lightweight building material (especially in 20th century China) and for insulation, primarily thermal (especially the high-clay-containing Danish moler), and continue to account for a significant part of world diatomite production. Dried natural products and calcined products are used in the aforementioned applications. Particulate products are more widely used and can be tailored to fit desired uses by blending various grades of calcined and natural material. The major use, in a great variety of grades, is as a filtration medium for beverages (especially beer and wine), sugar and sweetener liquors, oils and fats, petroleum and chemical processing (including waste drycleaning fluids), pharmaceuticals, and water (potable, industrial process, waste, and swimming pool). A large and growing application is use as an absorbent for industrial spills (oil and toxic liquids) and for pet litter. Another important broad category of use is as a filler, often serving a dual purpose such as an extender and flattening agent in paints and coatings, a bulking and anticaking agent in granular materials, a multieffect component in plastics (including preventing films from

sticking), and an extender/absorbent carrier for dry pesticides, pharmaceuticals, catalysts, and other chemicals. Significant other products include an insulation material in bulk (loose), in molded shapes, and in calcium silicate; other insulation products as a component; and a silica additive in various compounds including mortar and portland cement where it is used also for its pozzolanic properties. Worldwide use, including moler, was estimated in 1993 to be almost 50% for filtration, more than 25% for fillers, 17% for insulation, and about 10% for absorption and other applications (Roskill Information Services Ltd., 1994, p. 3).

Commercial diatomite products are offered in a great variety of grades. Principal factors are the size, shape, overall arrangement and proportions of the various types of frustules (particularly the effect on filtration rate, product clarity, and absorption capacity), and content of silica and various impurities, such as certain minerals and chemicals (especially the form of iron, a major impurity), clay, sand, and organics. There are a number of additional specialized application specifications (brightness/whiteness and abrasive hardness). Free crystalline silica content, although normally low, is also required by some environmental regulations, particularly for calcined products. A major influence on the grade is the extent of processing within three broad classifications: naturally milled and dried; plain ("straight") calcined (to 1,000° C); and flux-calcined (to 1,200° C with the addition of up to 10% of sodium compounds, such as soda ash, salt, or sodium hydroxide). Calcining removes organics, increases filtration rate (surface area is reduced by fusing more delicate structures of particles and sintering them into small clusters resulting in larger particle size and increased pore size), oxidizes iron (changing the buff to gray colors common in crude ore feed to pink or white), increases specific gravity, and increases particle hardness; but also disadvantageously produces free silica. Flux-calcining significantly affects the physical and chemical properties and makes a white product. Most filter grades are calcined.

Prices

The calculated weighted average unit value of diatomite sold or used by U.S. producers during 2000, using USGS survey data, was \$256 per metric ton f.o.b plant, an 8% increase compared with \$238 per ton in 1999 (table 3). Concomitantly, the average value per ton for filter use was down about 11% from the 1999 value. The average values per ton in 2000 for filler use and absorbent use decreased by about 16% and 19%, respectively. Comparing unit values in 2000 with those in 1995, in current 2000 dollars, the calculated weighted average unit value has increased by \$7 per ton from \$249. The filter grade product price per metric ton in 2000 was \$29 less than in 1995. The filler grade unit value in 2000 was \$45 less than the \$302 price in 1995. Data on other grades are insufficient for accurate comparisons, although unit values for insulation grades appear to have decreased, and unit values for absorbent grades appear to have increased.

Foreign Trade

Export and import data presented herein are from the U.S. Census Bureau and of limited accuracy because of producer-reported inconsistencies as well as lack of detail for the various

materials specified in the 2000 Harmonized Tariff Schedule (HTS) of the United States issued by the U.S. International Trade Commission.

Exports of diatomite from the United States in 2000 were 131,467 t according to the census data, which accounted for about 19% of all grades of domestic production sold or used as shown in the USGS survey and were 7% greater than 1999 exports (table 4). The data are issued under code 2512 of the HTS, described as applying to natural and straight-calcined diatomite, but industry sources indicate that exports also include some flux-calcined material. Flux-calcined material, however, according to HTS explanatory notes issued by the World Customs Organization of which the United States is a signatory member, is included under another code (code 3802.90.20.00) where, unfortunately, it cannot be separately identified from activated clays. Similarly, heat-insulating mixtures and sawn and molded unfired shapes of diatomite are in an "other" data classification (code 6806.90.00.90) and are not exclusively identified as diatomite. Also, fired sawn and molded shapes of diatomite are covered in a separate category with data (code 6901) that are not exclusively diatomite.

Industry information indicates that actual total exports of diatomite products can be estimated as a minimum of 300,000 metric tons per year (t/yr), which is about 44% of domestic mine production sold or used in 2000 according to the USGS survey. Industry sources suggest that 75% or more of exports are flux-calcined with the balance being mostly natural or straight calcined grades and only a small portion being material described in codes 6806 and 6901 of the HTS.

Products were exported to 74 countries according to the U.S. Census Bureau data. Main export markets were Germany (32,472 t), Canada (19,625 t), Japan (11,892 t), Belgium (9,136 t), Australia (8,698 t), and the United Kingdom (5,351 t), making up slightly more than 66% of the total exports reported. Based on the available data, the average unit value of exported diatomite was \$310 per ton free alongside ship, compared with \$324 per ton in 1999 and \$360 per ton in 1994. Because the data may not include all the higher value material, as discussed above, actual average unit values may be higher.

Import data available for diatomite show 529 t coming from five countries. In descending order, France provided 34%, followed by China with 30%, with the remainder coming from Italy, Spain, and Mexico.

World Review

China continued to show steady growth in diatomite production in 2000, averaging an increase of 7,500 t/yr since 1998. Japan's production remained essentially the same in 2000 as that of 1999. For 2000, world output was estimated to be 1.89 Mt, which was a decrease compared with 1999 and the lowest global tonnage since 1995 (table 5). Major producers in 2000 were the United States at 36%, followed by China at 18%, Japan with 10%, Denmark at about 10% (all molar products), some former Soviet Union countries and France, each with about 4%. Mexico, Spain, Peru, and the Republic of Korea, in decreasing order of production, were the next ranking producers.

Outlook

The diatomite market appears to remain mature and generally stable at the close of the 20th century. Industry representatives expect the next 5 years to be similar to the past 5 years; increased energy costs and possible global overcapacity, however, may represent impediments to future expansion. The past encroachments into filter applications by more advanced technology (ceramic, polymeric, and carbon membranes) apparently are not of major concern to producers, possibly because of cost factors. Disposal of diatomite waste, however, is a problem not fully resolved by recycling. Emerging markets for diatomite include use in biotechnology and pharmaceuticals and as a nontoxic insecticide (Crossley, 2000, p. 135). The problem of free crystalline silica associated with diatomite, particularly when calcined, continues to be of concern.

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TABLE 1
DIATOMITE SOLD OR USED, BY PRODUCERS IN THE UNITED STATES 1/

(Thousand metric tons and thousand dollars)

	1999	2000
Domestic production (sales)	747	677
Value	\$178,000	\$173,000

1/ Data are rounded to no more than three significant digits.

TABLE 2
DIATOMITE SOLD OR USED, BY MAJOR USE 1/

(Percent of U.S. production by metric tons)

	1999	2000
Absorbents	16	14
Fillers	11	14
Filtration	62	66
Insulation	2	3
Other 2/	9	3

1/ Includes exports.

2/ Includes silicate admixtures (especially for cement and unspecified uses).

TABLE 3
AVERAGE ANNUAL VALUE PER METRIC TON OF DIATOMITE, BY MAJOR USE 1/

	1999	2000
Absorbents	\$201.82	\$162.09
Fillers	305.60	257.44
Filtration	270.52	240.14
Insulation	36.79	35.71
Other 2/	43.72	1197.16
Weighted average	238.12	256.09

1/ Based on unrounded data.

2/ Includes absorbents and silicate admixtures.

TABLE 4
U.S. EXPORTS OF DIATOMITE 1/ 2/

(Thousand metric tons and thousand dollars)

Year	Quantity	Value 3/
1999	123	39,700
2000	131	40,800

1/ Harmonized Tariff System (HTS) code 2512.00.00.00, natural and straight-calcined grades, but in practice probably includes an undetermined quantity of flux-calcined product HTS code 3806.90.20.00.

2/ Data are rounded to no more than three significant digits.

3/ Free-alongside-ship (f.a.s.) U.S. customs value.

Source: U.S. Census Bureau.

TABLE 5
DIATOMITE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Thousand metric tons)

Country	1996	1997	1998	1999	2000 e/
Algeria	4 e/	2 r/	2 r/	3 r/	3
Argentina e/	9 3/	9	10	9	9
Australia e/	11	11	20	20	20
Brazil (marketable) e/	14 3/	14	14	14	14
Chile	12	12	15	14 r/	15
China e/	300	330	335	340	350
Colombia e/	4	4	4	4	4
Costa Rica	2 r/ e/	1 r/	2 r/	2 r/ e/	2
Czech Republic	35	--	-- e/	--	--
Denmark e/ 4/	185	185	185	185 r/	185
France e/	85	80	80	80	75
Iceland e/	26 3/	25	25	26	26
Iran e/ 5/	(6/)	(6/)	1 r/	4 r/ 3/	5
Italy e/	25	25	25	25	25
Japan e/	194 3/	194	190	190	190
Kenya	(6/)	(6/)	(6/)	(6/)	(6/)
Korea, Republic of	70	54	38	30 r/	32
Macedonia e/	5	5	5	5	5
Mexico	52	59	67	72 r/ 3/	75
Peru e/	35	35	35	35	35
Poland	2	1	2	2	2
Portugal e/	2	2	2	2	2
Romania	57	24	30	30	30
Spain e/ 7/	34 3/	36	36	36	35
Thailand	2	(6/)	--	2 r/ 3/	(6/)
U.S.S.R., former e/ 8/	100	90	80	80	80
United States 9/	729 e/	773	725	747	677
Total	1,990 r/	1,970 r/	1,930 r/	1,960 r/	1,890

e/ Estimated. r/ Revised. -- Zero.

1/ World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown. Purity and moisture content are generally not reported or estimated.

2/ Table includes data available through March 8, 2001.

3/ Reported figure.

4/ Data represent "extracted moler" (reported cubic meters times 1.5). Contains about 30% clay.

5/ Data are for Iranian years beginning March 21 of that stated.

6/ Less than 1/2 unit.

7/ Includes tripoli.

8/ U.S.S.R. dissolved December 1991; however, information is inadequate to formulate reliable estimates for individual countries.

9/ Sold or used by producers.