DIATOMITE

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The United States is the world's largest producer and consumer of diatomite. U.S. production sales increased about 3% to 747,000 metric tons (t) and its value decreased about 1% to around $178 million f.o.b. plant in 1999, compared with 1998 production of 725,000 t valued at $180 million f.o.b. plant (table 1). Although there have been fluctuations from 1994 to 1999, diatomite production tonnage has increased by about 20,000 metric tons per year (t/yr) on average during this period. Additionally, total value has increased about 17% from 1994 to 1999. 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 shortened to "D.E.") is a common alternate name but logically 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, $SiO_2 \bullet nH_2O$) cell walls of dead diatoms that are microscopic single-cell aquatic plants (algae). The fossilized skeletal remains—pairs of symmetrical shells (frustules) that fit together like a pill box—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 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 a short term for a longer description of "siliceous fossil meals...and similar siliceous earths," which is used more generally in the various tariff codes that cover diatomite. An impure (up to 30% clay) Danish variety is called moler.

Analysis of oven-dried samples of crude ore in-place at many commercial operations typically shows 80% to 90% (in some cases 95%) silica (SiO_2) 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 (compared to water at 1,000 grams per liter) 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 1.5 to more than 3 times its weight of water. Dry powdered natural rock has an apparent density of 80 to 250 grams per liter. The melting point of diatomite occurs in temperatures ranging from 1,000° C to 1,750° C (Durham, 1973, p. 192; Breese, 1994, p. 398).

Estimated world reserves are 800 million metric tons (Mt) of which 250 Mt are in the United States (Antonides, 1999, p. 61). This is equivalent to almost 400 times current estimated annual world production of about 2 Mt (table 5). The world reserve base was estimated by the U.S. Bureau of Mines in 1985 to be almost 2 billion tons (Meisinger, 1985, p. 250). A resource estimate based just on the dimensions of the deposits near Lompoc, Santa Barbara County, CA, suggests that collectively they could meet the world's current needs for centuries. However, data on reserves, defined as being currently economic using proven practices among other qualifications (U.S. Bureau of Mines and U.S. Geological Survey, 1980, p. 2), 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, that is, formed 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, that is, formed 138 million to 66 million years ago, and any older occurrences would presumably have been changed into other forms of silica. The oldest lacustrine deposits are believed to be of Eocene age, that is, 55 million to 38 million years old. Worldwide, many deposits, especially 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 is suitable. 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, often with equipment similar to that in open pits, are used, but the smallest mines use 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 permitted by climate, 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, multiple steps of further 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 minus 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. 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; and 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 has historically been considered in these statistics as production. The survey for 1999 covered 7 diatomite-producing companies with 13 separate mining areas and 12 processing facilities in California, Nevada, Oregon, and Washington. One of these operations was 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 80% of the U.S. production in 1999. Lake-type deposits are the source of U.S. production except for the major marine deposit at Lompoc, CA.

In early 1999, CR Minerals completed the sale of all the industrial minerals business of Canyon Resources Corp. to a Texas-based investment group for $6 million. In 1998, Eagle-Picher Minerals, Inc. was part of an acquisition of its parent Eagle-Picher Industries by Granaria Holdings BV of the Netherlands (Crossley, 2000, p. 123).

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 1999 was about 625,000 t, a 6% increase from 588,000 t in 1998.

Based on the USGS survey, in 1999, total domestic and export quantities of filter-grade diatomite sold or used by U.S. producers was 463,000 t, 1% less than in 1998. For absorbents, the second largest category, 121,000 t was consumed, 16% more than in 1998. Filler applications accounted for 81,000 t, 7% less than in 1998, and insulation use increased 5% to 15,000 t. “Other” applications increased 15% to 67,000 t, most of which was used in cement manufacturing (table 2). For several years, no sales have been reported for abrasives or lightweight aggregate applications. Comparing 1999 with 1994 data for percentage of total use, filter use has declined, filler and insulation uses have remained about the same, while absorbent and “Other” uses (mostly for cement manufacture) have increased slightly.

In antiquity, diatomite was used by the Greeks as an abrasive and in making lightweight building brick and blocks. In 535 A.D., blocks of diatomite were used for the 30-meter-diameter dome of the Church of St. Sophia in Istanbul, Turkey (Maurrasse, 1978, p. 263). However, it only became of industrial interest in Europe in the mid-1800's. One of the first uses at that time was as cut blocks and bricks for heat insulation. In the 1860's, pulverized diatomite became the preferred absorbent and stabilizer of nitroglycerine used by Alfred Nobel to make dynamite. Maryland was the site of the first U.S. production of diatomite in 1884. By the late 1880's, the very pure, huge deposit near Lompoc became the focus of interest and has continued to dominate the world's markets. Diatomite is now used principally as a filter aid; but it has many other applications, such as an absorbent for industrial spills and as pet litter, a filler in a variety of products from paints to dry chemicals, an insulation material as sawn and molded shapes as well as loose granular, 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 high liquid absorptive capacity. They are relatively inert chemically (especially when iron is naturally low or altered in calcining), have 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 China today) and for insulation, primarily thermal (especially the high-clay-containing Danish moler), and continue to comprise a significant factor in world diatomite production. Dried natural product as well as 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 category of use is in a great variety of grades as a filtration medium for beverages (especially beer and wine), sugar and sweetener liquors, oils and fats, petroleum and chemical processing (including waste dry-cleaning fluids), pharmaceuticals, and water (potable, industrial process and waste, as well as 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/or flatting agent in paints and coatings, a bulking and/or anticaking agent in granular materials, a multi-effect 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 and other insulation products as a component, a mild abrasive in polishes, 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 as almost one-half for filtration, more than one-quarter for fillers, one-sixth for insulation, and about one-tenth for absorption and other applications (Roskill Information Services Ltd., 1994, p. 3). Lack of reliable data prevents a more current estimate but available data do not indicate any major changes.

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 and product clarity, and absorptive 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 proper-ties 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 1999, using USGS survey data, was $238 per metric ton f.o.b. plant, a 4% decrease compared with $248 per ton in 1998 (table 3). Concomitantly, the average value per ton for filter use was down about 4% from the 1998 value. The average values per ton in 1999 for filler use and absorbent use increased by about 7% and over 20%, respectively. Comparing 1999 unit values with those for 1994, in current dollars, the total average has decreased by $9 per ton from $247. The filter grade product price per metric ton in 1999 was $33 higher than in 1994—prices have steadily increased over this period. The filler grade unit value for 1999 was $14 less than the $319 price for 1994. 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 Bureau of Census and of limited accuracy because of producer-reported inconsistencies as well as lack of detail for the various materials specified in the 1999 Harmonized Tariff Schedule (HTS) of the United States issued by the U.S. International Trade Commission.

Exports of diatomite from the United States in 1999, for comparison with previously published data, were 122,620 t according to the Census data. This is less than 17% of all grades of domestic production sold or used as shown in the USGS survey and 11% less than 1998 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 it actually includes some flux-calcined material. However, flux-calcined material, according to HTS Explanatory Notes issued by the World Customs Organization of which the United States is a signatory member, is included in other data (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 separate 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 t/yr, which is about 40% of domestic mine production sold or used in 1999 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.

Products went to 69 countries according to Bureau of the Census data. Main export markets were Canada (21,449 t), Germany (14,327 t), Belgium (12,575 t), Japan (8,856 t), Australia (7,964 t), and the United Kingdom (6,743 t), making up more than 58% of the total exports reported. Based on the available data, the average unit value of exported diatomite was $324 per ton f.a.s., comparable with values of $316 per ton in 1998 and $303 per ton in 1993. 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 387 t coming from four countries. In descending order, France provided 51%, followed by Italy with 46%, with the remainder coming from Spain and Japan.

World Review

China continued to show steady growth in diatomite production in 1999, averaging an increase of 5,000 t/yr since 1997. Japan’s production remained essentially the same in 1999 as that of 1998. For 1999, world output was estimated at 1.96 Mt, a modest increase over 1998 (table 5). Major producers in 1999 were the United States at 38%, followed by China at 17%, Japan with about 10%, Denmark at 9% (all moler products), and France and the former Soviet Union countries, each with 4%. Mexico, Spain, the Republic of Korea, and Peru were the next ranking producers. A new 20,000-t/yr mine was expected to be operational in Badgingara, north of Perth, Western Australia, by late 1998 according to owner Mallina Holdings Ltd., reputedly the holder of the country’s largest diatomite deposits (Crossley, 2000, p. 129).

Outlook

The diatomite market appears to remain mature and generally stable with industry representatives expecting the next 5 years to be similar to the past 5 years. 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, even though disposal of diatomite waste is a problem not fully solved 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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[1] Prior to January 1996, published by the U.S. Bureau of Mines.

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

(Thousand metric tons and thousand dollars)

	1998	1999
Domestic production (sales)	725	747
Value	$180,000	$178,000

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)

	1998	1999
Absorbents	14	16
Fillers	12	11
Filtration	64	62
Insulation	2	2
Other 2/	8	9

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/

	1998	1999
Absorbents	$156.39	$201.82
Fillers	285.87	305.60
Filtration	280.22	270.52
Insulation	35.77	36.79
Other 2/	153.53	43.72
Weighted average	248.82	238.12

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/
1998	138	43,800
1999	123	39,700

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: Bureau of the Census.

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

(Thousand metric tons)

Country	1995	1996	1997	1998	1999 e/
Algeria e/	4 3/	4	4	4	4
Argentina	5	9	9 e/	10 e/	9
Australia e/	11	11	11	20	20
Brazil (marketable) e/	14 3/	14	14	14	14
Canada e/ 4/	-- r/	-- r/	-- r/	-- r/	--
Chile	11	12	12	15 r/	12
China e/ 5/	250	300	330	335	340
Colombia e/	4	4	4	4	4
Costa Rica e/	7	8	8	8	8
Czech Republic	29	35	--	-- e/	--
Denmark: e/ 6/	186 r/ 3/	185 r/	185 r/	185 r/	185
France e/	80	85	80	80	80
Germany e/	50	--	--	--	--
Iceland	28	26	25 e/	25 e/	26
Iran e/ 7/	(8/)	(8/)	(8/)	(8/)	(8/)
Italy e/	25	25	25	25	25
Japan	175	194	194 e/	190 e/	190
Kenya	(8/)	(8/)	(8/)	(8/)	(8/)
Korea, Republic of	81	70	54	38 r/	35
Macedonia e/	5	5	5	5	5
Mexico	50	52	59	67 r/	70
Peru e/	35	35	35	35	35
Poland	2	2	1 r/	2 r/	2
Portugal e/	2	2	2	2	2
Romania	50	57	24	30 e/	30
Spain e/ 9/	45 r/	34 r/	36 e/ r/	36 e/ r/	36
Thailand	6	2	(8/)	-- r/	--
U.S.S.R., former e/ 10/	110	100	90	80	80
United States 11/	722 e/	729	773	725	747
Total	1,990 r/	2,000 r/	1,980 r/	1,930 r/	1,960

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 February 29, 2000.

3/ Reported figure.

4/ Includes an unknown quantity of fuller's earth.

5/ May not include building and insulating brick estimated as 150,000 metric tons (in 1994) to 200,000 metric tons (in 1998).

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

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

8/ Less than 1/2 unit.

9/ Includes tripoli.

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

11/ Sold or used by producers.