SILICA

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Four silica categories are covered in this report: industrial sand and gravel, quartz crystals, special silica stone products, and tripoli. Most of the stone covered in the special silica stone products section is novaculite. The section on tripoli includes tripoli and other fine-grained, porous silica materials that have similar properties and end uses, such as rottenstone. Certain silica and silicate materials, such as pumice and diatomite, are covered in other chapters of the U.S. Geological Survey (USGS) Minerals Yearbook.

Industrial Sand and Gravel

Industrial sand and gravel production increased 2.5% to 28.5 million metric tons in 1997 compared with 1996. The last time this production was exceeded was in 1979, when 30.4 million tons was sold or used. Exports dropped dramatically in 1997, falling over 31% to 980,000 tons, and while imports were still minor, they increased to 39,000 tons. *(See table 1.)*

Industrial sand and gravel, often termed "silica," "silica sand," and "quartz sand," includes sands and gravels with high silicon dioxide (SiO_2) content. These sands are used in glassmaking, for foundries, abrasives, and hydraulic fracturing applications, and for many other uses. The specifications for each use varies, but silica resources for most markets are abundant. The leading producing States, in descending order, were Illinois, Michigan, California, Texas, Wisconsin, North Carolina, and New Jersey. In almost all cases, silica mining employs open pit or dredging mining methods with standard mining equipment. Sand and gravel mining, in most cases, has little environmental impact except for temporarily disturbing the immediate environment while mining operations are active.

Production increases were the result of higher demand for sand for many uses including: blasting, container, fiber (whole grain) and specialty glass, recreational, and whole grain filler/building products. There was also a significant increase in demand for silica gravel which is used for the production of silicon and ferrosilicon.

Legislation and Government Programs.—The regulation of respirable silica continued to concern miners and consumers of many minerals that contain crystalline silica, especially the industrial sand and gravel industry. Crystalline silica was recently reclassified as a known carcinogen. Threshold exposure levels were being reviewed and proposals were made to reduce the level by one-half. Various techniques were being researched by the Pittsburgh Research Facility of the National Institute for Occupational Safety and Health (NIOSH) to help alleviate silica exposure (John Murphy, NIOSH, written comm., 1997). The National Industrial Sand Association (NISA) initiated a program to review the medical literature regarding silicosis cases to determine what other contributing factors may not have been taken into account (Ceramic Industry, 1997d). Additionally, NISA has put in place a six-point voluntary program; key components are medical monitoring of employees and dust surveillance (Pit and Quarry, 1997). In California, a group of individuals has filed suit against a material distributor and others claiming violation of Proposition 65. Among other things, Proposition 65 states, "No person in the course of doing business shall knowingly and intentionally expose any individual to a chemical known to the state to cause cancer or reproductive toxicity without first giving clear and reasonable warning to such individual...". The hazardous material in this case is silica. Because the State has declined to take up the case, the plaintiffs were reportedly going forward with the case (Ceramic Industry, 1997h).

In the trade arena, a Thai glass manufacturer has called on the Thai government to introduce measures that will cut flat glass imports. U.S. flat glass producers have encountered similar problems elsewhere in Asia. For example, an agreement was reached several years ago that was to have opened up the Japanese market to more imports, but recent market study reviews have indicated that little progress has been made (Glass International, 1997a).

Production.—Domestic production data for industrial sand and gravel were developed by the USGS from a voluntary survey of U.S. producers. The USGS canvassed 80 producers of industrial sand and gravel with 151 operations. Of the 151 operations surveyed, 141 (93%) were active and 10 were idle. 113 (75%) of the surveyed companies reported to the USGS and their combined production represented about 87% of the U.S. total published in table 1. Production for nonrespondents was estimated based on previously reported information or other factors.

The Midwest (East North Central and West North Central divisions) continued to lead the Nation with about 42% of the 28.5 million metric tons of industrial sand and gravel produced in the United States, followed by the South (South Atlantic, East South Central, and West South Central divisions) with about 36%, and the West (Pacific and Mountain divisions) with 14%. *(See table 2 and figure 1.)*

The seven leading States in the production of industrial sand and gravel, in descending order, were Illinois, Michigan, California, Texas, Wisconsin, North Carolina, and New Jersey. Their combined production represented 56% of the national total. Notable production changes took place in all these States, except Michigan, which was virtually unchanged from 1996 to 1997. In 1997, 13 States had increased production, 8 States had decreased production, and 16 States stayed about even compared with 1996. Georgia, Tennessee, and Texas reported the largest increases and Alabama, Ohio, Minnesota, and New Jersey reported the largest decreases. *(See table 3.)*

About 76% of the total industrial sand and gravel was produced by 48 operations, each with an annual production of more than 200,000 tons. *(See tables 4 and 5.)* The 10 leading producers of industrial sand and gravel were, in descending order, Unimin Corp., U.S. Silica Co., Fairmount Minerals Ltd., Oglebay Norton Industrial Sands Co., Badger Mining Corp., Nugent Sand Co. Inc., Simplot Industries Inc., Owens-Illinois, Inc., Construction Aggregates Corp., and W.R. Bonsal Co. Their combined production, from 56 operations, represented 71% of the U.S. total.

In June, Unimin Corp. opened a new mine and plant at Voca, TX, which will concentrate on the production of hydraulic fracturing sand. Other new operators surveyed include Elmore Sand and Gravel, Elmore, AL, producing gravel for ferrosilicon and silicon metal production; Silica Resources Inc., Marysville, CA; and Feldspar Corp., producing in Monticello, GA, and Spruce Pine, NC.

Operations deleted for the 1997 survey include APAC Arkansas, Inc., Fort Smith, AR, now producing only construction sand and gravel at this location; Custom Aggregates and Grinding, Inc., Terrebonne Parish, LA, which processes silica from Mississippi but does not mine in Louisiana; Evans Mining Corp., which reported its operation in St. Clair County, MI, was permanently shut down; and Keener Sand and Clay Co., Columbus, OH, which went out of business on December 1, 1997.

Corona Industrial Sands, Inc. reportedly shut down in 1997, after producing for part of the year. Corona only operated for about a decade and had been the object of a possible takeover by other silica producers who declined to buy the operation.

Consolidation of the industry continued in 1997 as Oglebay Norton Industrial Sands purchased Colorado Silica Sands, Inc., Colorado Springs, CO. Oglebay, the fourth largest producer in the United States, now operates six silica mines. Their other mines and plants are in California, Ohio, and Texas. U.S. Silica purchased Nicks Silica Co., Jackson, TN, in May 1997. U.S. Silica, the second largest producer in the United States, has 13 operations encompassing an area from New Jersey to Illinois and south to Texas.

Consolidation in this and other mining industries has a number of causes. Some of the consolidation is a response to consolidation within the consuming industries, such as the glass container industry. Not only has there been a decrease in the number of companies that control the glass container industry, but there has also been a trend towards larger and fewer glass plants (Glass Industry, 1997a).

***Consumption.*—**Sand and gravel production reported by producers to the USGS was actually material used by the companies or sold to their customers. Stockpiled material was not reported until consumed or sold. Of the 27.8 million metric tons of industrial sand and gravel sold or used, 37% was consumed as glassmaking sand and 23% as foundry sand. Other important uses were hydraulic fracturing sand (6%) and abrasive sand (5%). *(See table 6.)*

The production of industrial sand and gravel in the United States has developed in response to market location and vice versa as industry is sometimes located near silica resources. Because silica deposits are found throughout the United States, locating a consuming industry to be near a silica source was not always a priority, although it certainly was a consideration. The auto industry was originally located in the Midwest near iron, coal, clay, and silica resources. Therefore, foundry sands were greatly exploited in Michigan, Ohio, Indiana, Illinois, and other Midwest States. Thus, in 1997, over 81% of foundry sand was produced in the Midwestern region.

The glass industry, somewhat conversely, had to locate plants where it could minimize the shipping distance of finished glass products. Hence, glass plants were more evenly distributed and 39% of glass sand was produced in the Southern region, 33% in the Midwest, 16% in the West, and 12% in the Northeast, in 1997. To varying degrees, all silica production was similarly influenced as markets and consuming industries either forced the silica mining location or were forced to locate near the silica source.

The share of silica sold for all types of glassmaking as a percentage of all silica sold was 38%. This is slightly more than in 1996 and is mostly attributable to increased sales of silica for flat and fiber glass production. However, sales to container glass manufacturers also increased in 1997, rising 2.5% from 1996. This increase represents the first significant improvement in sand sales for glass container production since sales began falling in 1989 (from over 7.3 million tons in 1988). There were some reports of a shortage of cullet (post-consumer glass and scrap glass) for glass mixes in 1997, which may have caused the greater demand for silica sand for container glass manufacture, although glass container shipments fell from 257 million to 255 million from 1996 to 1997. One producer cited the use of cullet as a concern for future silica sales, especially on the west coast, where some recycling is mandatory (Glass Industry, 1997a). Especially over the last several decades, sales of glass containers have been adversely affected by competition from plastics, metals, and other packaging materials. All types of glass sand sales are hampered by this competition and by the recycling of containers, because they can be substituted in batch mixes for various types of glass. One report highlighted the 76% drop in container glass production for nonalcoholic beverage containers in the United States between 1990 and 1997. Beer bottle production has faired much better and reportedly rose over the same period (Glass, 1997c). Also contributing to the decrease in domestic glass container sales, imported glass containers supplied between 6% and 8% of domestic consumption in 1997 (Glass Packaging Institute, 1998). Another report concluded that imports of containers increased by nearly one-sixth from 1996 to 1997 (Glass Industry, 1998).

In 1997, there were a total of 66 container plants in the United States and they produced an estimated 9.34 million tons of glass containers. Additionally, an estimated 590,000 tons of glass containers were imported into the United States, accounting for about 6% of consumption. U.S. container manufacturers used 2.3 million tons of cullet in 1996 and 2.2 million tons in 1995. In 1997, the United States produced 23% of the world's glass containers (Ceramic Industry, 1997g).

Flat glass, unlike container glass, continued to be a good growth prospect for silica sales. Sales of sand in 1997 for flat glass production increased nearly 6% compared with 1996. The U.S. flat glass industry consisted of six manufacturers that represented 21% of the global industry in 1997. Flat glass demand was estimated to have grown about 2.4% in 1997 from 1996 (Ceramic Industry, 1997f).

Specialty glass consists of many segments, but the largest portion of it is lighting and laboratory glass. Sales volumes for lighting glass were up in 1997 compared with 1996 (Ceramic Industry, 1997g).

Osram Sylvania, Inc. expanded capacity at its Exeter, NH, plant that manufactures quartz glass materials for the semiconductor industry. The quartzware is a critical component for furnace liners and silicon wafer carriers. The plant also performs quartz sand purification on-site (Glass Industry, 1997d).

The U.S. fiberglass industry consist of four major insulation manufacturers and six major textile producers. In 1997, the United States accounted for 26% of the global production of fiberglass (Ceramic Industry, 1997g).

Fiberglass is used in a variety of applications, including use as a reinforcing material in various resins. Westfall Co., Inc., St. Louis, MO, produces fiberglass-reinforced plastic. The company reported that an elevated section of Interstate 70 in St. Louis that contained this plastic remained free of corrosion, unlike its steel predecessor. Fiberglass forms produced by Molded Fiber Glass Construction Products Co., Union City, PA, were used in the construction of Matsushita Semiconductor Corp.'s silicon chip plant at Puyallup, WA (Engineering News Record, 1997c).

PPG Industries, Inc. dedicated a new fiberglass plant in Chester, SC, and is producing continuous strand reinforcement products. PPG also announced increased production of fiberglass at other plants throughout the world (Glass Industry, 1997f).

Silica is used in ceramics in whole grain and ground form. Generally, whole grain silica is used in the ceramic body, while ground silica is used to decrease viscosity and expansion coefficient in ceramic glazes and other ceramic applications. Beyond traditional ceramics, advanced ceramics, such as silicon nitride and silicon carbide, represent a growing market for silica and silica-based chemicals. During 1996 and 1997, Ceradyne, Inc. doubled its sintered-reaction-bonded silicon nitride capacity by installing a second furnace. Other advanced ceramic producers also expanded capacities for various materials (Ceramic Industry, 1997c).

Silica is used in plastics as a filler, extender, and reinforcer. Both whole grain and ground silica are used in filler-type applications. Ground silica is used to thicken liquid systems and to avoid plateout in polyvinyl chloride and as a thixotropic and flatting agent and in many other filler applications. Whole grain silica is used in stucco, putty, paints, nonskid flooring, and other building product applications. As segregated for this survey, consumption of ground silica for filler was 193,000 tons and whole grain filler sales amounted to 1.77 million tons in 1997.

Cristobalite, a high-temperature silica mineral, is artificially made from quartz by heating quartz to above 1,470° C, where the quartz changes into cristobalite. Cristobalite consists of small octahedral crystals, which aggregate into rounded particles. The crystal structure is more open than quartz, resulting in lower specific gravity. The major market for cristobalite is in the solid mold industry, but it is also used in traffic paints, reflective coatings, ceramics, refractories, and grinding products (Paint and Coatings Industry, 1997).

Sodium silicate, produced primarily by reacting sand and soda ash in a furnace, is one of the traditional chemicals made with silica sand. One of the forces driving increased demand for sodium silicate is the zeolite industry, which uses sodium silicate in its synthetic zeolite production. PQ Corp., one of the largest producers of sodium silicate, mothballed its operations at Rahway, NJ, and Anderson, IN, partially in response to bringing on-line its new silicate plant in Gurnee, IL, in April 1997. The Gurnee plant will have a capacity of 450 million kilograms, whereas the U.S. markets in 1997 was about 1.6 billion kilograms. PQ Corp. also closed its plant in Berkeley, CA. PQ continues to operate silicate producing plants in Chester, PA, and Baltimore, MD. Occidental Chemical Co. has closed its sodium silicate plants in Lockport, NY, and Oxnard, CA. However, PPG Industries, Inc. has 36 million kilograms of captive capacity planned, and Occidental Chemical Corp. has completed incremental expansion at its Mobile, AL, plant and capacity was expected to be increased at its Augusta, GA, plant as well (Chemical Market Reporter, 1997b).

Specialty silicas are usually produced by means of chemical and thermal processing of natural silica, silicon metal, or as a byproduct of other mineral or chemical processing. Although the USGS did not specifically collect information for specialty silicas, consumption does affect natural silica sales. Specialty silicas and silanes (silica chemicals), included, but were not limited to, colloidal silicas, fumed silica, fused silica and quartz, organofunctional silanes, precipitated silica, silica gels, silicones, and ultrahigh purity silica. These silicas are used in a variety of industries and products, including abrasives, adhesives, beverages, catalysts, coatings, electronics, encapsulants, food, health care, optics, paper and packaging, plastics, refractories, rubber, sealants, specialty coatings, textiles, thermoplastics, water treatment, and others.

High-purity fused silica used by the electronics industry is typically at least 99.95% SiO_2 and has a very low expansion coefficient, high electromagnetic radiation transparency, and good insulation properties.

On table 6, industrial sand and gravel that would find its way into these specialty silicas is most likely reported in the categories "chemical", "silicon metal," and possibly "specialty glass." Silica sales for chemical production in 1997 dropped by 4.5% to 614,000 tons, compared with 1996. Reported sales of silica gravel for silicon and ferrosilicon production increased over 15% in 1997 compared with 1996. The main uses for silicon metal are in the manufacture of silanes and semiconductor grade silicon and in the production of aluminum alloys.

An important and growing use for silanes is in the manufacture of silicon chips. However, the rapid, double-digit growth of the early- and mid-1990's was tempered in 1997 as sales growth slowed to 6.8%. Air Products and Chemicals, Inc. has started its first commercial on-site silane bulk specialty gas system at White Oak Semiconductor's new fabrication facility near Richmond, VA. This system delivers silanes in gaseous form to White Oak Semiconductor. The liquid silanes originate from a plant in Moses Lake, WA, and are converted to a gas at the White Oak Semiconductor facility (Chemical Marketing Reporter, 1997a).

Precipitated silica, another product derived from silanes, has been used increasingly in tires, but more so in Europe than in the United States. European consumers seem to prefer the "green tires" made with precipitated silica. The tires reportedly produce greater gas mileage. Deficiencies in tread wear and higher costs to consumers and manufacturers accounts for their lack of popularity in the United States. Some new silicas, which aim to alleviate these problems, are being produced. If these problems are solved, the "green tire" will probably become more popular in the United States. Precipitated silica is also used in battery separators and as flatting agents in coatings, mainly high-solids, low-volatile organic compound coatings. Degussa AG, brought an additional 15,000 tons of new capacity on-line at its Chester, PA, site (Chemical Market Reporter, 1997d).

Rhône-Poulenc, Inc. has expanded capacity for silanol production at its Troy, NY, specialty silicone elastomers facility. The additional 150% capacity initially will be dedicated to the manufacture of silanols, which in this case are two-component room temperature vulcanizers primarily used as moldmaking agents (Chemical Market Reporter, 1997h).

Northeast.—Cumberland County, NJ, continued to be the largest source for glass and foundry sand markets in the region. Unimin and U.S. Silica, which operated plants in the county, were among the largest producers of sand for these markets. U.S. Silica's plant in Huntingdon County, PA, also produced significant amounts of sand for the glass market. Unimin and Ricci Brothers Sand Co. Inc., Cumberland County, produced most of the abrasive blast sand in the region. Whibco's operation, also in Cumberland County, was a major producer of foundry sand in the region.

Midwest.—Unimin's plants in La Salle and Ogle Counties, IL; LeSueur County, MN; Jefferson County, MO; and Columbia County, WI, were among the leaders in producing sand for all four major markets: the blast, foundry, hydraulic fracturing, and glass sand markets. Fairmount Minerals, with major operations in Berrien and Van Buren Counties, MI, Geauga County, OH, and La Salle County, IL, were also major producers of sand for the four major markets in the region. U.S. Silica's plant in La Salle County, IL, was a major supplier for the glass and foundry markets, and their St. Louis County, MO, operation was a large producer for the glass market. Other major producers for the foundry industry were Construction Aggregates Corp., Ottawa County, MI; Nugent Sand Co. Inc., Muskegon County, MI; and Wexford Holding Co., Wexford County, MI. Badger Mining, Jackson and Green Lake Counties, WI, was a major producer for the foundry and hydraulic fracturing markets. Oglebay Norton's plants in Knox and Perry Counties, OH, and Manley Brother's of Indiana, La Salle County, IL, were significant producers for the blasting and glass markets, respectively.

South.—Unimin and U.S. Silica were two of the largest producers of sand for the glass and foundry markets. Unimin's major plants were in Izard County, AR; Marion County, GA; Richmond County, NC; Pontotoc County, OK; Carroll County, TN; Johnson County, TX; and Frederick County, VA. Major contributors for these markets were U.S. Silica's plants in Bullock County, AL; Johnston County, OK; Lexington County, SC; Limestone County, TX; and Morgan County, WV. Cobb Industrial Corp., Red River Parish, LA; TEC Minerals Co., Liberty County, TX; Huey Stockstill Inc., Pearl River County, MS; Mid-State Sand and Gravel Co., Allen and East Baton Rouge Parishes, LA; and Specialty Sand Co., Newton County, TX, were large producers of blasting sand. B.V. Hedrick Gravel and Sand Co. and W.R. Bonsal and Co., Anson County, NC, Elmore Sand and Gravel, Elmore County, AL, and Martin Marietta Aggregates, Macon County, AL, produced a large percentage of the industrial gravel used in the production of silicon and ferrosilicon. Oglebay Norton, McCulloch County, TX, was the largest producer of hydraulic fracturing sand and an important contributor of blast sand for the region. Whibco, Kershaw County, SC, was an important producer of foundry sand. APAC Arkansas Inc., Muskogee County, OK, and Short Mountain Silica Co., Hawkins County, TN, were important producers of glass sand.

West.—Owens-Illinois, Simplot Industries, Unimin, and Lane Mountain Silica Co. were the largest producers of glass sand in the region, with major operations in Amador County, CA; Clark County, NV; Contra Costa County, CA; and Stevens County, WA, respectively. The major suppliers for the sand blasting industry in the region were Lane Mountain Silica; Lone Star Industries Inc., Monterey County, CA; and P.W. Gillibrand Co., Ventura County, CA. Simplot Industries also supplied a large portion of the foundry sand consumed. FMC Corp., Power County, ID; Rhône-Poulenc Basic Chemicals Co., Beaverhead County, ID; and Solutia Inc., Caribou County, ID, each produced industrial gravel for use as a flux in elemental phosphorus production. The Ashton Co., Pinal County, AZ, was the largest producer of silica for metallurgical flux in the region.

***Recycling.*—**Recycling of silica sands was limited to some foundry sands, particularly those used for making cores and molds with no-bake resin-bonded sands, some abrasive and airblasting sands and, increasingly, post-consumer and scrap glass (cullet) that substitutes for batch mix (including industrial sand). Most glass recycling was restricted to container glass, with green and amber cullet consumed in greater amounts for container glass production because it is more difficult to use cullet in flint batch mixes. However, all types of container glass are suitable for fiberglass production, and, in 1997, the manufacturers of fiberglass insulation represented the largest secondary market for recycled glass containers in the United States. Recent data are unavailable, but, in 1995, over 424 million kilograms of recycled glass was used in the manufacture of fiberglass insulation. For 1996, the estimated use was over 450 million kilograms. The industry average for glass in fiberglass batch mixes is about 30% but some producers are using about 40% (Glass Industry, 1997b).

Recycling of glass containers was estimated at 35.2% of consumption in the United States in 1997, down from 37.9% in 1996. This included glass used in glascrete (cullet used in portland and asphalt concrete) and glass containers that were refilled (Glass Packaging Institute, Americans continue to recycle more than one in three glass containers, Glass Packaging Institute press release, accessed April 28, 1998, at URL http://www.gpi.org/98rate.htm). The price for cullet varied based on region and grade [flint (clear), brown (amber), or green]. Cullet from consumers generally passes through a processor, who receives it from municipalities, counties, etc., and the processor then provides it to the glassmaker. Green cullet prices were quoted in the $10/ton to $15/ton range, nationally. This range was considerably lower than prices for flint and brown glass and was due to the limited use of green glass in most bottling facilities in the country. Recyclers found it difficult to sell the green glass because domestic demand was low. However, exporting may be a solution. In the first 3 months of 1997, over 25,000 tons of cullet left the United States and this is six times greater than the volume exported in the first 3 months of 1996 (Glass Industry, 1997a).

As the level of cullet used in glass production increases, so does the level of quality required. Contamination of cullet by ceramics and nonmagnetic materials is an increasing concern. Because of the increased use of recycled glasses, restrictions on the iron and chromium levels in glass sands have become stricter and the proportion of refractory particles allowed has been reduced to almost zero. The acceptable iron oxide content of a typical glass silica sand is now as low as 0.015% to 0.02% for flint glass manufacture and 0.1% to 0.15% for colored glass. Additionally, recycling of amber and green glass was substantially greater than flint glass and, therefore, lower grade silica sands are in less demand.

As the value of cullet to the glassmaker increases, the demand for tools that improve the quality of cullet increases as well. As the volume of cullet increases, the level of contamination increases, and better technology is needed to separate impurities from the cullet. The first type of separators employed magnetism and electrical induction to clean up the cullet. This allowed for the removal of aluminum, ferrous metals, and lead. The latest breakthroughs for separation involve a combination of laser and pneumatic technologies. These newer systems allow for the removal of ceramics, stone, porcelain (CSP), and smaller metal particles. Acceptable levels in processed cullet were reportedly less than 25 grams per ton for CSP and less than 5 grams per ton for metal content. This was achievable with the new technologies (Glass, 1997a).

Besides the removal of impurities from cullet, sometimes the cullet must be separated based on color. One system that separates by color is an optoelectronic system developed by Mogensen GmbH and Co., Wedel, Germany. The device can monitor material composition and resolution and aims to minimize the loss of flint glass. The system can also be set for amber or green glass or for CSP separation (Glass International, 1997b).

Recycling of silica refractories is hardly ever done. Because recycling these refractories requires crushing and grinding, silica dust is generated. The dust must be controlled according to hazardous material regulations and this makes the recycling prohibitively expensive.

International trends toward increased recycling of glass and foundry sands and innovative ideas on recycling other materials should influence greater recycling of silica products.

Transportation.—Of the total industrial sand and gravel produced, 62% was transported by truck from the plant to the site of first sale or use, up from 61% in 1996; 36% was transported by rail, up from 35% in 1996; 2% by waterway; and 1% was not transported. Because most of the producers did not report shipping distances or cost per ton per mile, no transportation cost data are available.

Transportation plays an important part in the industrial sand and gravel industry. Consolidation in the railroad industry has had some effect on the 35% of silica that is shipped by rail. Union Pacific's acquisition of Southern Pacific Railroad in 1996 caused a delay in the shipment of many mineral materials in 1997. However, one producer reported that although transportation costs are a major factor in raw material cost, transportation costs have remained fairly stable (Glass Industry, 1997a).

Prices.—Compared with that of 1996, the average value, f.o.b. plant, of U.S. industrial sand and gravel increased slightly to $18.17 per metric ton. Average unit values for industrial sand and industrial gravel were $18.67 and $12.10 per ton, respectively. The average price for sand ranged from $4.58 to $127.88 per ton. For gravel, prices ranged from $7.82 to $16.64. Reported silica prices, commonly range from several dollars to hundreds of dollars and occasionally prices exceed the $1,000 level. Nationally, ground sand used as fillers for rubber, paint, and putty, etc., had the highest value per ton ($127.88), followed by ground sand used in ceramics ($52.78), silica for well packing and cementing ($52.13), silica for swimming pool filters ($49.19), ground sand for scouring cleansers ($44.17), and ground sand for fiberglass ($41.72).

Industrial sand and gravel price changes were mixed; some markets remained level, others had small increases or decreases, and still others experienced large increases or decreases. This situation was possible because, although the silica was essentially the same, most markets were independent of each other and price competition was influenced by availability, regulations, health concerns, and competition from other materials. Compared with 1996, only the following five markets decreased in average price per ton, nationally: chemicals, fiberglass (ground), recreational, silicon carbide, and whole grain fillers. The average unit value increased for all other markets, except roofing granules which was essentially unchanged.

The average value per ton of industrial sand and gravel was highest in the South ($20.21), followed by the West ($18.83), the Northeast ($17.99), and the Midwest ($16.22). Prices can vary greatly for similar grades of silica at different locations in the United States. For example, the average value per ton of glass sand varied markedly, from $19.38 in the West to $12.40 in the Midwest. Tighter supplies and higher production costs in the West and much greater competition in the Midwest caused the difference in the cost of sand and gravel in these two regions. *(See table 6.)*

Foreign Trade.—Exports of industrial sand and gravel decreased about 31% from 1996, but the associated value increased nearly 17%. Most of the loss in exports was attributable to decreased shipments to Canada, where exports dropped by two-thirds. Traditionally, the majority of these shipments have been foundry sands and to a lesser degree hydraulic fracturing sands. Based on the change in average price of the exports to Canada, it is likely that the decreased exports resulted from lower foundry sand sales. And, although exports to Canada dropped, exports to Mexico doubled to over 308,000 tons, making Mexico the largest recipient of silica from the United States. Export distribution is as follows: 31.4% went to Mexico, 31.1% went to Canada, 17.1% went to Asia, 14.4% went to Europe, and the remainder went to Central and South America, the Middle East, and Oceania.

Imports for consumption of industrial sand and gravel rose to 39,000 tons, over five times the amount of imports for 1996. Silica imports vary greatly from year to year, but are always rather insignificant. Australia supplied 46% of the silica imports for 1997, averaging about $35 per ton (including insurance and freight cost to the U.S. port). The total value of imports was $3.2 million, with an average of $82 per ton. Higher priced imports came from Belgium, Canada, Germany, Italy, Japan, Sweden, Switzerland, and the United Kingdom. *(See tables 7 and 8.)*

World Review.—World production of industrial sand and gravel, based on information usually provided by foreign Governments, was estimated to be 119 million metric tons, unchanged from 1996's revised world total. The United States was the leading producer, followed by, in descending order, the Netherlands, Austria and France (tied), Germany, and Paraguay. Most countries in the world had some production and consumption of industrial sand and gravel, because it is essential to the glass and foundry industries. However, because of the great variation in descriptions and usage for silica sand and gravel, it was difficult to get reliable information. Beyond those countries listed, many other countries were thought to have had some type of silica production and consumption. *(See table 9.)*

Current Research and Technology.—In a development that could cause a rapid rise in the growth of computer manufacture and silicon consumption, IBM announced a switch from aluminum to copper in computer semiconductors. Aluminum has been the standard for 30 years, but IBM was set to begin commercial production of copper-based semiconductor chips in early 1998. Copper would allow producers to gain speed in computing that was not possible with aluminum (Chemical & Engineering News, 1997c).

Dow Corning carries out research into silicone-based, high-technology products at its plant in Williams Township, Bay County, MI. The plant also manufactures some products here and services the aerospace, automotive, electrical, and semiconductor industries. In 1997, Dow Corning announced a series of expansions at the plant that will include 3,000 square feet for offices, new "clean rooms," and a two-story production facility to house equipment for select products (Chemical Market Reporter, 1997c).

The new silicon-based mirrors continued to be featured in 1997. These mirrors employ a reflective coating of silicon made by the chemical vapor deposition process. The finished mirror is tough and durable, does not corrode in humid atmospheres, and can be bent and tempered in normal glass fabricating furnaces. This process also decreases environmental releases because it avoids the usual fumes and waste liquids that are generated in silver-based mirror production. (Glass Magazine, 1997b).

Harvard scientists continued research into silicon carbide nanorods and determined that they were stronger than multiwall carbon nanotubes. They concluded that defect-free silicon carbide nanorods appear to be the strongest materials known (Chemical & Engineering News, 1997d).

Another advanced ceramic, silicon nitride was improved by researchers at the University of Michigan. By causing the alpha form of silicon nitride to form a fibrous microstructure that resembles wood, the scientists have added strength and toughness to the inherent hardness of the ceramic, yielding a material that is as hard as silicon carbide but much less brittle (Chemical & Engineering News, 1997e).

A new material composed of mesoporous silica coated with functionalized monolayers demonstrates a remarkable ability to soak up heavy metals from contaminated water, making it a promising tool for environmental cleanup. The mesoporous silica was developed over 5 years ago, but this is the first practical application (Chemical & Engineering News, 1997a).

Researchers at Rochester Institute of Technology (RIT) have developed a tough new form of porous silicon for optoelectronic applications. Conventional porous silicon is too weak to withstand chipmaking operations. To make the material stronger, RIT researchers have developed a process that heats silicon wafers to 900° C in nitrogen instead of air (Ceramic Industry, 1997e).

OSi Specialties Group has introduced a new vinyl silane monomer for crosslinking vinyl and acrylic latexes. The product reportedly offers improved chemical and abrasion resistance and better adhesion for substrates. When used in emulsions, it allows formulations of formaldehyde-free, one-component waterborne coatings (Chemical Market Reporter, 1997f).

Silica gel may stabilize radioactive material, according to the Russian Research Institute of Chemical Technology. The gel is used to stabilize high-level liquid radioactive waste as it absorbs a liquid waste and produces a stable solid product (Environmental Protection, 1997).

Candescent Technologies Corp., San Jose, CA, and Schott Corp., Yonkers, NY, have established a broad ranging development and supply agreement for flat panel display glass and glass-related technologies. The two companies will jointly develop glass processing and finishing technologies to tailor an economical glass material and supply channel for Candescent's product (Glass Industry, 1997e).

Work continues into the use of fiberglass reinforcements. A Buffalo Creek bridge in McKinleyville, WV, is the world's first to use glass-fiber-reinforced plastic rebar to strengthen its concrete deck. These bridge decks may last centuries if the material performs the way experts predict (Engineering News Record, 1997b).

Silica blast sand has a potential new competitor in dry ice as research into using dry ice was performed by the U.S. Department of Energy (DOE). The breakthrough system uses dry ice pellets to strip paint and other contaminants from structures and was slated to be tested in 1997 on a bridge in North Carolina. The process was developed by Oak Ridge National Laboratory, Oak Ridge, TN, part of DOE (Engineering News Record, 1997a).

Outlook.—The forecast range of total U.S. demand for industrial sand and gravel in the year 2000 is expected to be 26 to 30 million metric tons. Probable demand is expected to be about 29 million tons. All forecasts are based on previous performances for this commodity within various end uses, on contingency factors considered relevant to the future of the commodity, and on forecasts made by analysts and producers in the various markets.

Sales of glass sand are expected to vary from market to market. Growth that might come in some segments, like flat and specialty glass will be tempered by reductions in sales for container glass and possibly fiberglass. The state of the container industry in the United States, as discussed earlier, indicates that the trend towards decreasing market share for container glass is expected to continue. Still, one study of the container industry predicted that the glass container industry will grow by 2.6% per year through 2001, compared with 6.1% for plastic, 2.5% for paper, and just 0.2% for metal containers. The study also predicted growth in fiberglass sales through 2001 at 2.6% per year (Glass Industry, 1997g).

Other studies predicted flat glass sales in the United States, spurred on by demand from the construction market (3.6% per year) and the motor vehicle market (1.3% per year), are expected to grow about 2.8% per year for the next several years (Ceramic Industry, 1997f). Fiberglass sales are expected to grow by 2.2% per year and lamp glass sales by 2.7% per year through 2000 (Ceramic Industry, 1997g).

Guardian Industries Corp. continued expansion plans as it constructed two float glass plants in Brazil and New York and a fiberglass plant in Martinburg, WV (Glass Industry, 1997c).

Additionally, AFG Industries, Inc., Kingsport, TN, announced plans to build a new flat glass plant in Richmond, KY. The plant is slated to produce glass primarily for the automotive market, with some glass being produced for the architectural market (Glass Magazine, 1997a).

Total demand for glass sand is expected to grow slowly through 2000. Probable demand for glass sand in 2000 is forecast to be 11.0 million tons, with a range of 9.5 to 12.0 million tons.

The use of foundry sand is dependent mainly on automobile and light truck production. Another important factor for the future consumption of virgin foundry sand is the recycling of used foundry sand. The level of recycling, though not clear, is thought to be increasing. Other materials or minerals compete with silica as foundry sand but these other "sands" usually suffer a severe price disadvantage. Based on these factors (foundry activity (mainly auto related), competing materials, and recycling) consumption of silica foundry sand in 2000 is expected to be 6.8 million tons, and the demand range is expected to be 6 to 7 million tons.

Hydraulic fracturing sand sales in 1997 decreased significantly from those of 1996. This despite the fact that the Baker-Hughes' cumulative drilling rig count, which compares year-to-year data, shows that 1997 stayed ahead of 1996's rig count throughout the year and ended the year about 17% ahead of 1996's week-by-week comparison. The other side of the story is that oil prices remained low in 1997, which discourages the stimulation of marginal oilfields, the primary consumer of hydraulic fracturing sand. As has been the case, U.S. production of oil will likely suffer as imports continue to control a higher percentage of supply. But natural gas production will likely maintain steady increases. Exports, an important market for hydraulic fracturing sand, were down in 1997, in response to lower oil prices and the downturn in the Asian economy. Traditionally, U.S. sand was shipped to locations throughout the world.

Based on these factors, demand for hydraulic fracturing sand is expected to grow slowly during the last years of the decade. Growth will be in response to rebounding exports and growing demand for natural gas, but it will be tempered by limited U.S. oil well activity. Probable demand for hydraulic fracturing sand for 2000 is expected to be 1.6 million tons, with a range of 1.4 to 1.7 million tons.

For specialty silicas, the silica route will usually be through the chemical and silicon metal categories, and it is expected that these categories will probably see better than average growth, probably in the 2% to 4% annual growth range. This positive forecast would be tempered if the specialty silicas producers used a silica source other than industrial sand and gravel. The process for each type of silica is highly variable and certainly not well advertised, and, therefore, it is difficult to determine the natural source and the processing route for the silica or silicate.

Silicates are the subject of extensive research and development, with new uses targeted in cement, construction, and pulp and paper industries. PQ Corp. expects double-digit growth in these markets (Chemical Market Reporter, 1997g).

Precipitated silica used in tires, battery separators, coatings, and other markets has seen good growth. Growth is expected to continue through the next several years (Chemical Market Reporter, 1997d).

Millennium Chemicals Inc., will expand its production of fine particle amorphous silica by 100% to provide the global brewing industry with a filtration media. The expansion, at the company's Baltimore, MD, plant, will come on-stream in 1998 (Chemical Market Reporter, 1997e).

A recent report on the advanced ceramics market projected some market growth as a whole, although some slowdowns will occur in particular markets. One problem discussed involved the declining number of large corporations willing to underwrite advanced structural ceramics research. Because of this, several grades of silicon nitride are no longer available and will likely hamper the development of a specific application by a number of years if there are no alternative materials (Ceramic Industry, 1997c).

The worldwide semiconductor industry has recently experienced a slowdown in the rate of growth compared with the mid-1990's. Sales were thought to have increased about 6.8% in 1997, and growth is expected to continue well into the next century (Ceramic Industry, 1997i).

IBM announced on November 17, 1997, that it will build a $700-million-microchip- development facility in East Fishkill, NY. The facility will produce 12-inch-diameter silicon wafers using the firm's new copper chip-wiring process (Engineering News Record, 1997d).

Shin-Etsu Chemical Co. plans to build a $70-million-semiconductor-materials plant in Freemont, TX, and the entire output will be exported to Japan. It will produce 240 tons of synthetic quartz per year, which is about 20% of the global demand for the material that is used in making lenses for stepper chip-making equipment (Chemical Market Reporter, 1997i).

A joint-venture agreement was to be signed between The Quartz Group, Inc., CA, and WON IK Quartz Corp., the Republic of Korea, to manufacture a complete line of high-purity, fused quartz glass products. The new company, WON IK Quartz Group, USA, will manufacture a range of quartz glass products for the worldwide semiconductor market. Production will be based in Morgan Hill, Silicon Valley, CA (Industrial Minerals, 1997a).

Also, Corning, Inc. has announced plans to construct a new fused silica plant, 15 miles north of Charleston, SC. The plant will manufacture high-purity fused silica for specialized high-tech optical applications, such as lens assemblies used in the manufacture of semiconductors. The company also recently doubled its capacity at its other fused silica plant at Canton, NY (Industrial Minerals, 1997b).

Dow Corning is planning a $50-million expansion in trichlorosilane capacity at its Midland, MI, plant. Trichlorosilane is a feedstock for silicone products and for polycrystalline silicon used in the manufacture of semiconductors (Chemical & Engineering News, 1997b).

For the fiberoptic market, a study by Frost and Sullivan predicts that the current $7.3-billion fiberoptic telecommunications equipment market will more than double, to $15.4 billion by the year 2000 (Ceramic Industry, 1997a). Another study forecasted that the North American market for single-mode fiberoptic cable will reach $2.3 billion by 2001 (Fiberoptic Products News, 1997a). Silica is used to produce not only the actual fiberoptic material but also the equipment used to produce the fiberoptics. Promising new technologies appear likely to reduce the cost of materials and installations that would increase the use of fiberoptics, particularly in local-area-network and desktop applications. Some growth may not benefit silica, however, because of competition from other fiberoptic materials, particularly plastic optical fiber (POF). Although POF has proven itself in many short-distance applications, its use has not grown much in recent years because of manufacturing and, perhaps, some technical problems (Fiberoptic Products News, 1997b).

Lucent Technologies, a fiberoptics maker, plans to spend $350 million in 1998-99 to expand plants near Atlanta, GA. A small percentage of the investment will be made at other locations (Ceramic Industry, 1997b).

Corning is planning to build a 17,000-square-meter plant for the production of optical fiber components, probably at Erwin, NY. The company also revealed that its second U.S. optical fiber plant will be at Concord, NC (Glass, 1997b).

The United States is the largest producer and consumer of silica sand among the market economy countries and it is self-sufficient in this commodity. Most of it is produced in the eastern United States, near the premier deposits and major markets. A significant amount of silica sand is also produced in the West and Southwest, mostly in California and Texas. Domestic production is expected to continue to meet more than 99% of demand well beyond 2000. Imports, mostly from Australia, Canada, and Europe, are expected to remain minor.

Because the unit price of silica sand is relatively low, except for a few end uses that require a high degree of processing, the location of a silica sand deposit in relation to the market is an important factor that may work for or against a sand producer. Consequently, a significant number of relatively small operations supply local markets with a limited number of products.

Several factors could affect supply and demand relationships for silica sand. Further increases in the development of substitute materials for glass and cast metals could reduce demand for glass sand and foundry sand. These substitutes, mainly polymers and ceramics, would likely increase demand for ground silica, which is used as a filler in plastics; for glass fibers, which are used in reinforced plastics; and for silica (chemical, whole grain, or ground) which is used to manufacture ceramics. Also, increased efforts to reduce waste and increase recycling could hinder demand for glass sand. However, with advances in high-tech materials, consumption of silica sand may increase for fiberoptics and other silicon and glass compounds. Although developments could cause demand for silica sand to decrease, the total value of production could increase because of the increased unit value of the more specialized sands.

An increase in the price of oil on the international market would stimulate domestic drilling and extraction from new and old oil deposits. This would increase demand for domestic hydraulic fracturing sand.

Health concerns about the use of silica as an abrasive, and stricter legislative and regulatory measures concerning silica exposure could decrease demand in many silica markets. The use of silica sand in the abrasive blast industry was being questioned as a health hazard as marketers of competing materials, including garnet, slags, and olivine, pushed the use of their "safer" abrasive media.

Development of more efficient mining and processing methods is expected to continue. This will encourage the development of lower grade silica sand deposits that are located closer to markets but not presently mined. Such developments are expected to increase silica sand reserves.

Quartz Crystals

Electronic-grade quartz crystal is single-crystal silica with properties that make it uniquely useful for manufacturing accurate frequency controls, timers, and filters in electronic circuits. These devices are utilized for a variety of electronic applications in communications equipment, computers, aerospace hardware, military and commercial navigational instruments and consumer goods (e.g., clocks, television receivers, games, and toys). Such uses generate practically all of the demand for electronic-grade quartz crystal. A lesser amount of optical-grade quartz crystal is used for windows and lenses in specialized devices, including some lasers.

Natural quartz crystal primarily was used in electronic and optical applications until 1971, when it was surpassed by cultured quartz crystal. The use of natural quartz crystal for carvings and other gemstone applications continued. The use of quartz crystal for such applications is covered in the Gemstones Mineral Industry Survey published annually by the USGS.

Legislation and Government Programs.—The strategic value of quartz crystal was demonstrated more than 50 years ago when it gained wide use as an essential component of military communication systems during World War II. After the war, natural electronic-grade quartz crystal was officially designated as a strategic and critical material for stockpiling by the Federal Government. Cultured quartz crystal, which eventually supplanted natural crystal in nearly all applications, was not commercially available when acquisition of the latter for a national stockpile began.

As of December 31, 1997, the National Defense Stockpile (NDS) contained about 107,000 kilograms of natural quartz crystal with a reported market value of more than $2.1 million. The stockpile has 11 weight classes for natural quartz crystal ranging from 200 grams to more than 10,000 grams. However, the stockpiled crystals primarily are in the larger weight classes. The larger pieces are suitable as seed crystals for cultured quartz crystal production. In addition, many of the stockpiled crystals could be of interest to the specimen and gemstone industry. Little, if any, of the stockpiled material is likely to be utilized in the same applications as cultured quartz crystal.

As cultured quartz crystal displaced natural quartz crystal in most applications, the Federal Government continued to assess its stockpile goals for the latter material. In the latest reports on the inventory of stockpile material, no quartz crystals were designated for disposal. Based on the figures reported for 1996 and 1997, no sales of natural quartz crystal occurred in 1997. Previously, only individual crystals in the NDS inventory that weighed 10 kilograms or more and could be used as seed material to generate cultured quartz crystal were sold. Brazil traditionally has been the source of such large natural crystals, but changes in mining operations have reduced its output.

Readers should refer to the "legislation and government affairs" section of the industrial sand and gravel section of this report that discusses the issues of silicosis and cancer in relationship to crystalline silica. Quartz crystal, a crystalline silica, is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Production.—The USGS collects production data for quartz crystal through a survey of the domestic industry. In 1997, the industry consisted of four cultured quartz crystal producers and one company that mined feed material, called lascas, for producing cultured crystal. Four of the five producers responded to the industry survey, representing over 63% of the lascas and cultured quartz crystal output shown in table 1.

Lascas Products, Inc., Jessieville, AR, was the only domestic company known to supply lascas for producing cultured quartz crystal. However, this operation was abruptly shut down at yearend 1997, when the operator, Thermo Dynamics Corp., decided not to renew its lease of Lascas Products. Thermo Dynamics reportedly has decided to import lascas from Madagascar to replace the material from Arkansas. The material from Madagascar is reported to be significantly cheaper than the Arkansas lascas (Tony Speers, Lascas Products, Inc., oral commun., 1998).

The following four U.S. companies produced cultured quartz crystal during 1997: Sawyer Research Products Inc. of Eastlake, OH; Thermo Dynamics Corp. of Merriam, KS; Motorola Inc. of Chicago, IL; and P. R. Hoffman Material Processing Co. of Carlisle, PA. Sawyer and Thermo Dynamics produced crystal bars for domestic and foreign firms in the crystal device fabrication industry. Motorola produced quartz crystal for internal consumption and domestic device fabricators. P. R. Hoffman reported external sales.

The aforementioned companies produce cultured quartz crystal using a hydrothermal process in large pressure vessels, known as autoclaves. Seed crystals (very thin crystals cut to exact dimensions) are mounted on racks and suspended in the upper growth region of the vessel. Lascas is loaded in an open-mesh wire basket that is placed in the bottom of the autoclave.

A solution of sodium hydroxide or sodium carbonate (the mineralizer), with additives such as lithium salts and deionized or distilled water, is used to fill the vessel from 75% to 85% of its volume. The bottom half of the growing vessel is heated to temperatures averaging between 350° C and 400° C; the temperature of the top portion is maintained at 5° C to 50° C less, depending upon the mineralizer used. At these temperatures, the solution expands and creates an internal pressure in the vessel between 10,000 and 30,000 pounds per square inch. Under these conditions, the lascas dissolves to create a solution saturated with silica. Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed crystals in the top half of the autoclave. The process continues until the growing crystals reach their desired size. The process normally takes 30 to 60 days for a 1-inch-thick bar and longer for other types of crystal; at least one producer has made runs of about 180 days. The cultured crystals can be custom grown with specific properties.

The processing of quartz crystal for various end uses is the same whether natural or cultured seed crystal is used. However, producers must avoid seed crystals with defects that would pass on to new generations of cultured crystal. Natural quartz crystal is preferred as seed material to ensure that genetic defects will not be repeated in the succeeding generations.

Once produced, cultured crystals are examined for physical defects before cutting. They are then cut, usually with diamond or slurry saws, along a predetermined crystallographic plane to a thickness slightly larger than that desired. Each wafer is inspected and diced into blanks of the desired dimensions. The blanks then progress through a series of lapping stages until they reach the final thickness; electrodes are attached and the crystals are mounted in suitable holders. The final assembly, called a quartz crystal unit, is ready for insertion into an electronic circuit.

Consumption.—The USGS collected 1997 domestic consumption data for quartz crystal through a survey of 30 U.S. operations in 10 States that fabricate quartz crystal devices. These companies represented virtually all of the domestic consumption. Fifteen companies responded to the survey. Consumption for nonrespondents was estimated based on previous years' reports.

Quartz crystal is used in piezoelectric and optical applications. The piezoelectric effect is achieved when a suitable electrical signal applied to a quartz wafer makes the wafer vibrate mechanically throughout the bulk of the material at a characteristic natural resonance frequency. Quartz resonators are uniquely suitable for military, aerospace, and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate stability, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators also are used for many less demanding applications, such as providing timing signals for electronic circuits in industrial, automotive, and consumer products.

Cultured quartz is used almost exclusively by the crystal device industry because of the cost advantages. For resonator applications, raw quartz must be cut into thin wafers oriented precisely with the raw material crystal axes. The uniformity and convenience of cultured quartz have made its use almost universal. Unlike cultured quartz, natural electronic-grade quartz requires special orientation, cutting, grading, and sizing to produce a quartz wafer. As a result, most device manufacturers that cut natural quartz in the past have discontinued its use. One of the remaining uses of the natural electronic-grade material is in pressure transducers used in deep wells.

The quartz wafer must be cut too thinly for practical use at very high frequencies (above 100 megahertz). Quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than by wafer thickness, have become more important at these higher frequencies. These structures are called surface acoustical wave devices.

Most optical applications use quartz in the fused form as silica glass. Relatively small quantities of cultured quartz crystal are used directly for special optical considerations. Quartz crystal also has uses involving normally polarized laser beams; quartz retardation plates (especially quartz wave plates), Brewster windows and prisms, birefringent filters, and tuning elements are utilized in laser optics.

Prices.—The average value of as-grown cultured quartz was $48 per kilogram in 1997. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, was about $241 per kilogram. (Also note market value cited above for natural quartz crystal in the NDS.)

Foreign Trade.—The U.S. Department of Commerce, which is the major Government source of U.S. trade data, does not provide specific import or export statistics on lascas. Some lascas reportedly was imported from Brazil and Germany in 1997. Imports and exports of all electronic-grade quartz crystal are shown in table 12.

World Review.—Cultured quartz crystal production is concentrated in China, Japan, Russia, and the United States, with several companies producing crystal in each country. Smaller production capacity exists in Belgium, Brazil, Bulgaria, France, Germany, South Africa, and the United Kingdom. Details concerning quartz operations in China, nations that formerly comprised the U.S.S.R., and Eastern European countries are unavailable. However, it is known that operations in Russia have significant capacity to produce synthetic quartz.

Outlook.—Demand for quartz crystal devices will probably continue to grow and, consequently, quartz crystal production will probably remain strong well into the future. Growth of the consumer electronics market (e.g., automobiles, personal computers, cellular telephones, and electronic games), particularly in the United States, will continue to provide markets for domestic production. The growing global electronics market may require additional production capacity worldwide.

Special Silica Stone Products

Silica stone products are abrasive tools-materials, such as hones, whetstones, oilstones, stone files, grindstones, grinding pebbles, tube-mill liners, and deburring media. These products are manufactured from novaculite, quartzite, and other microcrystalline quartz rock. However, this report excludes products that are fabricated from such materials by artificially bonding of the abrasive grains.

Readers should refer to the “legislation and government affairs” section of the industrial sand and gravel section of this report that discusses the issues of silicosis and cancer in relationship to crystalline silica. Special silica stone, a crystalline silica, is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Production.—In response to a USGS production survey, 10 domestic firms reported that they quarried certain silica materials and manufactured silica stone products during 1997. Arkansas accounted for most of the value and quantity of production reported. Plants in Arkansas manufacture oilstones, whetstones, files, and deburring-tumbling media. Elsewhere, grindstones were manufactured in Ohio and tumbling-grinding media were produced in Wisconsin. *(See table 11.)*

The industry has produced four main grades of Arkansas whetstone in recent years. The grades range from the high-quality Black Hard Arkansas Stone down to the Washita Stone. In general, the Black Hard has a porosity of 0.07% and a waxy luster, while Washita Stone has a porosity of 16% and resembles unglazed porcelain.

Consumption.—The domestic consumption of special silica stone products is a combination of household, industrial, leisure, and craft uses. Major household uses include the sharpening of knives and other cutlery, such as scissors, shears, and lawn and garden tools. Leading industrial uses include the sharpening and honing of cutting surfaces, the polishing of metal surfaces, and the deburring of metal and plastic castings. Recreational uses include the sharpening of sports knives, arrowheads, spear points, and fish hooks. Craft applications include sharpening tools for wood carving, jewelry making, and engraving work. Also, silica stone files are used in the manufacture, repair, and modification of firearms.

Price.—The reported value of crude material suitable for cutting into finished products varied from $220 per ton to $450 per ton in 1997. The average value was $266 per ton. The average value of stone products made from crude material was $5.75 per kilogram.

Foreign Trade.—Silica stone products exported in 1997 had a value of at least $6.03 million, down slightly from 1996. These exports were categorized as “hand sharpening or polishing stones” by the U.S. Department of Commerce, which collects trade data. This category accounted for most, if not all, of the silica stone products exported in 1997.

The value of imported silica stone products in 1997 was at least $3.09 million, up slightly from 1996. These imports were hand sharpening or polishing stones, which accounted for most or all of the imported silica stone products in 1997. A portion of the finished products that were imported may have been made from crude novaculite produced within the United States and exported for processing.

Outlook.—Consumption patterns for special silica stone are not expected to change significantly over the next several years. Most of the existing markets are well defined and the probability of new uses is low.

Tripoli

Tripoli, broadly defined, is composed of extremely fine-grained crystalline silica in various stages of aggregation. Grain sizes usually range from 1 to 10 micrometers, but particles as small as 0.1 to 0.2 micrometers are common. Commercial tripoli contains 98% to 99% silica and minor amounts of alumina (as clay) and iron oxide. Tripoli may be white or some shade of yellow, brown, or red, depending upon the percentage of iron oxide.

Production.—In the United States, five firms are known to produce and process tripoli. American Tripoli Co. produces crude material in Ottawa County, OK, and finished material in Newton County, MO. Keystone Filler and Manufacturing Co. in Northumberland County, PA, processes rottenstone, a decomposed fine-grained siliceous shale purchased from local suppliers. Malvern Minerals Co., Garland County, AR, produces crude and finished material. Malvern also produces a black material from novaculite. Harbison-Walker Refractories Co., Hot

Springs County, AR, produces crude and finished tripoli that is consumed in the production of refractory bricks and shapes. Unimin Specialty Minerals Inc. in Alexander County, IL, produces crude and finished material. All of the aforementioned firms responded to the USGS survey.

Consumption.—The 1997 USGS annual survey of producers indicates that sales of processed tripoli increased slightly in quantity to 81,300 tons with a value of $16.4 million. *(See tables 1 and 10.)*

Tripoli has unique applications as an abrasive due to its hardness and because its grain structure lacks distinct edges and corners. It is a mild abrasive, making it suitable for use in toothpaste and tooth polishing compounds, industrial soaps, and metal and jewelry polishing compounds. The automobile industry uses it in buffing and polishing compounds for lacquer finishing.

The end-use pattern for tripoli has changed significantly in the past 27 years. In 1970, nearly 70% of the processed tripoli was used as an abrasive. In 1997, slightly more than 30% of tripoli output was used as an abrasive. The remainder was used as filler and extender in paint, plastic, rubber, caulking compounds, enamel, and in brake linings, friction products, refractories, or other products.

Tripoli primarily is used as a filler and extender in paints. These applications may account for as much as 85% of the tripoli used as a filler and extender. In exterior latex paints, tripoli also aids in tint retention, durability, leveling, and flowability. In enamels, it eases application and improves sheen. The controlled grain and particle size of tripoli in paints improves dispersal and promotes a more uniform coating. Additionally, paints with tripoli resist chemical agents and wear better than those in which water-ground whitings and other softer or more reactive fillers are used.

Plastics, rubbers, and resins each account for about 5% of the tripoli used as a filler and extender. Tripoli is used extensively in plastics for electrical uses because of its dielectric characteristics and its effects on flexibility and compression properties. Its chemical resistance, weatherability, and resistance to salt spray also are important to its use in plastics. The physical properties of tripoli allow high loading in most compounds, but its abrasiveness results in high wear in extruding nozzles and molds. The same properties that make tripoli useful as a filler and extender in plastics makes it valuable to the rubber and resin industries.

Readers should refer to the "legislation and government affairs" section of the industrial sand and gravel section of this report that discusses the issues of silicosis and cancer in relationship to crystalline silica. Tripoli, a crystalline silica, is also affected by the regulation of crystalline silica, as discussed in the earlier section.

Price.—The average reported value of all tripoli sold or used in the United States was $202 per ton in 1997. The average reported value of abrasive tripoli sold or used in the United States during 1997 was $194 per ton; the average reported value of filler tripoli sold or used domestically was $240 per ton.

Outlook.—Consumption patterns for tripoli are not expected to change significantly over the next several years. Most of the existing markets are well defined and the probability of new uses is low.

References Cited

Ceramic Industry, 1997a, Fiber-optic market to double by 2003: Ceramic Industry, v. 147, no. 12, p. 8.

———1997b, Lucent Technologies to invest $350 million: Ceramic Industry, v. 147, no. 13, p. 8.

———1997c, Markets thrive despite challenges: Ceramic Industry, v. 147, no. 9, p. 40-42.

———1997d, Meeting the demands of today's regulatory environment: Ceramic Industry, v. 147, no. 12, p. 52-54.

———1997e, New porous silicon for optoelectronic chips: Ceramic Industry, v. 147, no. 2, p. 19.

———1997f, New products will maintain demand for flat glass: Ceramic Industry, v. 147, no. 9, p. 35-36.

———1997g, Other glass markets issue mixed signals: Ceramic Industry, v. 147, no. 9, p. 38-39.

———1997h, Silica attacked in California suit: Ceramic Industry, v. 147, no. 6, p. 9.

———1997i, Worldwide semiconductor sales: Ceramic Industry, v. 147, no. 6, p. 14.

Chemical & Engineering News, 1997a, Coated mesoporous silica–Supersoaker for heavy minerals: Chemical & Engineering News, v. 75, no. 20, p. 46-47.

———1997b, Dow Corning to expand trichlorosilane plant: Chemical & Engineering News, v. 75, no. 31, p. 15.

———1997c, Electronic chemicals: Chemical & Engineering News, v. 75, no. 47, p. 25-39.

———1997d, SiC nanorods stronger than carbon nanotubes: Chemical & Engineering News, v. 75, no. 39, p. 23.

———1997e, α-silicon nitride made tougher, stronger: Chemical & Engineering News, v. 75, no. 42, p. 37.

Chemical Market Reporter, 1997a, Air Products opens bulk silane system: Chemical Market Reporter, v. 252, no. 16, p 28.

———1997b, Canadian sodium silicate price hike blamed on rising cost of soda ash: Chemical Market Reporter, v. 252, no. 18, p. 5.

———1997c, Dow Corning is expanding: Chemical Market Reporter, v. 251, no. 3, p. 16.

———1997d, 'Green' tires are driving growth for precipitated silicas worldwide: Chemical Market Reporter, v. 252, no. 20, p. 4.

———1997e, Millennium shifts, boosts silica output: Chemical Market Reporter, v. 252, no. 14, p. 23.

———1997f, OSi vinyl silane offered for latexes: Chemical Market Reporter, v. 251, no. 3, p. 16.

———1997g, PQ boosts silicate capacity with an eye to global markets: Chemical Market Reporter, v. 251, no. 14, p. 19.

———1997h, Rhone-Poulenc expands its niche player role in U.S. silicone market: Chemical Market Reporter, v. 252, no. 9, p. 3.

———1997i, Shin-Etsu plans U.S. plant: Chemical Market Reporter, v. 252, no. 26, p. 4.

Engineering News Record, 1997a, Blasted dry ice strips cost: Engineering News Record, v. 238, no. 16, p. 21.

———1997b, Composite rebar gains ground: Engineering News Record, v. 238, no. 12, p. 11.

———1997c, Fiberglass pipe drain systems prove impervious to corrosion: Engineering News Record, v. 239, no. 13, p. H12-H13.

———1997d, IBM to build $700-million chip plant in New York: Engineering News Record, v. 239, no. 21, p. 7.

Environmental Protection, 1997, Radioactive waste stabilizer: Environmental Protection, v. 8, no. 5, p. 8.

Fiberoptic Products News, 1997a, North American market for singlemode fiberoptic cable to reach $2.3 billion by 2001: Fiberoptic Products News, v. 12, no. 3, p. 13.

———1997b, Plastic optical fiber's time has come, but when? Is this the year: Fiberoptic Products News, v. 12, no. 12, p. 16.

Glass, 1997a, Advancing waste glass recycling: Glass, v. 74, no. 12, p. 466.

———1997b, More optical fibre capacity planned: Glass, v. 74, no. 5, p. 170.

———1997c, World glass industry survey: Glass, v. 74, no. 1, p. 4.

Glass Industry,1997a, Consolidating market creates hurdles for the raw materials suppliers: Glass Industry, v. 78, no. 13, p. 21-23.

———1997b, Fiber glass insulation uses more recycled glass: Glass Industry, v. 78, no. 1, p. 32.

———1997c, News briefs: Glass Industry, v. 78, no. 13, p. 10.

———1997d, Osram Sylvania expands: Glass Industry, v. 78, no. 10, p. 38.

———1997e, Partnership formed for U.S. flat panel display manufacturing: Glass Industry, v. 78, no. 9, p. 32.

———1997f, PPG increases fiberglass production: Glass Industry, v. 78, no. 9, p. 36.

———1997g, Two new studies survey the container and glass fiber markets: Glass Industry, v. 78, no. 10, p. 15-17.

Glass Industry, 1998, Slight fall in recycling rate: Glass Industry, v. 79, no. 7, p. 7.
Glass International, 1997a, Imports threaten domestic market: Glass International, v. 20, no. 3, p. 6.
———1997b, Technology improves the colour purity of recycled glass: Glass International, v. 20, no. 3, p. 51.
Glass Magazine, 1997a, AFG plant finds new Kentucky home: Glass Magazine, v. 47, no. 4, p. 17.
———1997b, More than a mirror: Glass Magazine, v. 47, no. 12, p. 33-35.
Industrial Minerals, 1997a, Glass joint venture for Quartz Group: Industrial Minerals, no. 360, p. 34.
———1997b, New fused silica plant for Corning: Industrial Minerals, no. 361, p. 25.
Paint and Coatings Industry, 1997, Cristobalite a unique form of silica: Paint and Coatings Industry, v. 13, no. 8, p. 58-62.
Pit and Quarry, 1997, Silicosis—Proactive prevention: Pit and Quarry, v. 89, no. 9, p. 22-24.

SOURCES OF INFORMATION

U.S. Geological Survey Publications

Abrasives, manufactured. Ch. in Minerals Yearbook, annual.[1]
Abrasives, manufactured. Mineral Industry Surveys, quarterly.[1]
Garnet, industrial. Ch. in Minerals Yearbook, annual.[1]
Pumice. Ch. in Minerals Yearbook, annual.[1]
Quartz crystal. Ch. in Mineral Commodity Summaries, annual.[1]
Silica sand. Ch. in United States mineral resources, U.S. Geological Survey Professional Paper 820, 1973.

[1]Prior to January 1996, published by the U.S. Bureau of Mines.

Other

A Stockpile Primer (U.S. Department of Defense, Directorate of Strategic Materials Management; August 1995).
Aggregates Manager Magazine.
Ceramics Industry Magazine.
Electronic Component News, monthly.
Electronic News, weekly.
Electronics, biweekly.
Engineering and Mining Journal.
Glass International Magazine.
Industrial Minerals Magazine.
Pit & Quarry Magazine.
Rock Products Magazine.
Sand and gravel. Ch. in Minerals facts and problems, U.S. Bureau of Mines Bulletin 675, 1985.

TABLE 1
SALIENT U.S. SILICA STATISTICS 1/

		1993	1994	1995	1996	1997
Industrial sand and gravel: 2/						
Sold or used:						
Sand:						
Quantity	thousand metric tons	24,500	25,500	26,300	25,500	26,300
Value	thousands	$436,000	$466,000	$480,000	$473,000	$492,000
Gravel:						
Quantity	thousand metric tons	1,700	1,790	1,880	2,240	2,170
Value	thousands	$18,500	$22,400	$21,900	$24,100	$26,300
Total industrial:						
Quantity	thousand metric tons	26,200	27,300	28,200	27,800	28,500
Value	thousands	$454,000	$488,000	$502,000	$497,000	$518,000
Exports:						
Quantity	thousand metric tons	1,750	1,880	1,870	1,430	980
Value	thousands	$91,000	$102,000	$106,000	$113,000	$134,000
Imports for consumption:						
Quantity	thousand metric tons	44	24	59	7	39
Value	thousands	$2,440	$1,790	$2,730	$1,500	$3,200
Processed tripoli: 3/						
Quantity	metric tons	78,300	82,300	80,100	79,600	81,300
Value	thousands	$15,500	$10,900	$10,500	$18,400	$16,400
Special silica stone:						
Crude production:						
Quantity	metric tons	528	328 r/	501 r/	854 r/	843
Value	thousands	$240	$221 r/	$270 r/	$222 r/	$224
Sold or used:						
Quantity	metric tons	267	487	419 r/	410	445
Value	thousands	$3,770	W	W	$4,050 r/	$2,560
Electronic and optical-grade quartz crystals:						
Production:						
Mine	thousand kilograms	454	544	435	435	450
Cultured	do.	394	294	351 r/	327	355

r/ Revised. W Withheld to avoid disclosing company proprietary data.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Puerto Rico excluded from all industrial sand and gravel statistics.
3/ Includes amorphous silica and Pennsylvania rottenstone.

TABLE 2
INDUSTRIAL SAND AND GRAVEL SOLD OR USED IN THE UNITED STATES, BY GEOGRAPHIC REGION 1/

	1996				1997			
Geographic region	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total	Quantity (thousand metric tons)	Percent of total	Value (thousands)	Percent of total
Northeast:								
New England	110	(2/)	$1,770	(2/)	218	1	$2,130	(2/)
Middle Atlantic	2,280	8	42,000	9	2,170	8	40,300	8
Midwest:								
East North Central	10,200	37	159,000	32	10,300	36	161,000	31
West North Central	1,820	7	39,800	8	1,530	5	30,100	6
South:								
South Atlantic	3,820	14	73,400	15	4,160	14	82,200	16
East South Central	1,620	6	23,900	5	1,890	7	32,500	6
West South Central	4,100	15	86,300	17	4,330	15	94,900	18
West:								
Mountain	1,820	7	24,800	5	1,800	6	24,400	5
Pacific	2,010	7	46,000	9	2,160	8	50,300	10
Total	27,800	100	497,000	100	28,500	100	518,000	100

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Less than 1/2 unit.

TABLE 3
INDUSTRIAL SAND AND GRAVEL SOLD OR USED
IN THE UNITED STATES, BY STATE 1/

(Thousand metric tons and thousand dollars)

State	1996		1997	
	Quantity	Value	Quantity	Value
Alabama	799	8,380	734	9,730
Arizona	323	2,890	330	3,160
Arkansas	W	W	W	W
California	1,760	40,500	1,920	44,900
Colorado	W	W	W	W
Florida	515	6,340	507	5,800
Georgia	313	5,650	520	9,330
Idaho	646	8,510	630	7,950
Illinois	4,460	66,400	4,610	67,900
Indiana	W	W	W	W
Iowa	W	W	W	W
Kansas	W	W	W	W
Louisiana	706	12,100	644	11,200
Maryland	W	W	W	W
Massachusetts	W	W	W	W
Michigan	2,680	29,400	2,680	30,000
Minnesota	W	W	W	W
Mississippi	W	W	W	W
Missouri	W	W	W	W
Montana	W	W	W	W
Nebraska	W	W	W	W
Nevada	W	W	W	W
New Jersey	1,680	30,300	1,530	28,300
New York	W	W	W	W
North Carolina	1,500	21,700	1,600	26,400
North Dakota	W	W	W	W
Ohio	1,270	29,800	1,140	28,600
Oklahoma	1,350	27,200	1,380	28,200
Pennsylvania	W	W	W	W
Rhode Island	W	W	W	W
South Carolina	761	19,500	770	19,300
Tennessee	747	13,900	898	16,500
Texas	1,420	38,200	1,830	48,800
Virginia	W	W	W	W
Washington	W	W	W	W
West Virginia	W	W	W	W
Wisconsin	1,660	32,300	1,710	33,800
Other	5,190	104,000	3,660	70,200
Total	27,800	497,000	28,500	518,000

W Withheld to avoid disclosing company proprietary data; included with "Other."
1/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 4
INDUSTRIAL SAND AND GRAVEL PRODUCTION IN THE UNITED STATES IN 1997, BY SIZE OF OPERATION 1/

Size range	Number of operations	Percent of total	Quantity (thousand metric tons)	Percent of total
Less than 25,000	22	15	261	1
25,000 to 49,999	11	8	355	1
50,000 to 99,999	29	21	1,850	7
100,000 to 199,999	31	22	4,330	15
200,000 to 299,999	12	9	2,610	9
300,000 to 399,999	6	4	1,990	7
400,000 to 499,999	10	7	3,980	14
500,000 to 599,999	9	6	4,350	15
600,000 to 699,999	3	2	1,770	6
700,000 and over	8	6	7,030	25
Total	141	100	28,500	100

1/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 5
NUMBER OF INDUSTRIAL SAND AND GRAVEL OPERATIONS AND PROCESSING PLANTS IN THE UNITED STATES IN 1997, BY GEOGRAPHIC REGION

	Mining operations on land					
Geographic region	Stationary	Portable	Stationary and portable	No plants or unspecified	Dredging operations	Total active operations
Northeast:						
New England	1	--	--	--	1	2
Middle Atlantic	6	--	2	1	4	13
Midwest:						
East North Central	30	--	--	1	3	34
West North Central	5	--	--	--	6	11
South:						
South Atlantic	19	--	1	2	5	27
East South Central	10	--	--	--	2	12
West South Central	9	--	--	1	10	20
West:						
Mountain	5	2	1	2	--	10
Pacific	9	--	1	1	1	12
Total	94	2	5	8	32	141

TABLE 6

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1997, BY MAJOR END USE 1/

(Thousand metric tons and thousand dollars)

	Northeast			Midwest			South			West			U.S. total		
Major use	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/
Sand:															
Glassmaking:															
Containers	877	15,300	$17.45	1,630	16,800	$10.34	1,730	26,300	$15.21	1,080	21,700	$20.12	5,310	80,100	$15.09
Flat (plate and window)	W	W	15.96	973	11,100	11.38	1,590	25,000	15.71	W	W	16.96	3,150	45,900	14.57
Specialty	W	W	23.37	393	6,430	16.34	244	5,280	21.61	W	W	29.47	887	17,700	19.94
Fiberglass (unground)	W	W	14.65	490	6,810	13.90	331	9,560	28.87	W	W	19.81	1,020	20,000	19.65
Fiberglass (ground)	--	--	--	W	W	41.33	326	13,700	41.97	W	W	27.23	401	16,700	41.72
Foundry:															
Molding and core	212	3,860	18.17	5,250	66,700	12.72	948	13,600	14.37	73	1,570	21.46	6,480	85,800	13.24
Molding and core facing (ground)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Refractory	--	--	--	60	1,270	21.09	W	W	47.95	W	W	22.99	69	1,670	24.29
Metallurgical:															
Silicon carbide	--	--	--	99	2,590	26.07	--	--	--	--	--	--	99	2,590	26.07
Flux for metal smelting	--	--	--	--	--	--	W	W	4.84	W	W	5.86	212	1,240	5.85
Abrasives:															
Blasting	59	2,030	34.60	210	5,340	25.47	1,200	26,600	22.23	149	5,250	35.13	1,620	39,300	24.29
Scouring cleansers (ground)	--	--	--	W	W	42.84	W	W	56.96	--	--	--	W	W	44.17
Sawing and sanding	W	W	20.67	--	--	--	W	W	18.75	--	--	--	W	W	20.54
Chemicals (ground and unground)	W	W	19.58	W	W	12.39	W	W	22.53	W	W	21.02	614	10,700	17.35
Fillers (ground): Rubber, paints, putty, etc.	W	W	W	W	W	73.76	W	W	W	W	W	32.52	193	24,600	127.88
Whole grain fillers/building products	223	5,880	26.32	542	14,600	26.92	597	13,800	23.07	410	12,000	29.18	1,770	46,200	26.07
Ceramic (ground): Pottery, brick, tile, etc.	W	W	22.47	W	W	64.63	80	3,620	45.35	W	W	26.46	154	8,130	52.78
Filtration:															
Water (municipal, county, local, etc.)	28	1,240	44.61	67	2,240	33.64	115	1,660	14.51	74	2,830	38.22	283	7,970	28.17
Swimming pool, other	W	W	62.69	W	W	74.46	19	734	37.84	--	--	--	31	1,520	49.19
Petroleum industry:															
Hydraulic fracturing	--	--	--	794	26,900	33.93	563	18,800	33.30	26	975	38.18	1,380	46,700	33.75
Well packing and cementing	--	--	--	10	856	81.72	9	158	17.58	--	--	--	19	1,010	52.13
Recreational:															
Golf course (greens and traps)	78	1,250	15.91	238	3,890	16.37	241	2,420	10.06	168	3,300	19.58	726	10,900	14.97
Baseball, volleyball, play sand, beaches	W	W	2.45	8	86	10.66	34	275	8.02	W	W	21.92	184	841	4.58
Traction (engine)	W	W	13.42	71	721	10.17	66	873	13.20	W	W	20.63	189	2,420	12.96
Roofing granules and fillers	38	760	20.03	W	W	14.37	135	1,970	14.58	W	W	14.96	231	3,590	15.53
Other (ground silica)	(3/)	(3/)	(3/)	169	8,360	55.22	(3/)	(3/)	(3/)	(3/)	(3/)	(3/)	XX	XX	XX
Other (whole grain)	736	11,300	15.41	535	5,760	10.75	1,020	29,700	29.15	1,220	19,500	15.99	XX	XX	XX
Total or average	2,250	41,700	18.51	11,600	189,000	16.22	9,250	194,000	20.99	3,200	67,100	20.97	26,300	492,000	18.67
Gravel:															
Silicon, ferrosilicon	--	--	--	62	1,640	26.47	752	11,900	15.83	--	--	--	814	13,500	16.64
Filtration	11	280	24.83	71	729	10.30	42	743	17.69	--	--	--	124	1,750	14.12
Nonmetallurgical flux	--	--	--	--	--	--	--	--	--	660	6,500	9.84	660	6,500	9.84

See footnotes at end of table.

TABLE 6--Continued

INDUSTRIAL SAND AND GRAVEL SOLD OR USED BY U.S. PRODUCERS IN 1997, BY MAJOR END USE 1/

(Thousand metric tons and thousand dollars)

Major use	Northeast			Midwest			South			West			U.S. total		
	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/	Quantity	Value	Value per ton 2/
Gravel--Continued:															
Other uses, specified	122	491	$4.02	14	15	$1.10	337	2,990	$8.88	102	998	$9.80	575	4,490	$7.82
Total or average	133	771	5.78	147	2,390	16.25	1,130	15,600	13.83	762	7,500	9.84	2,170	26,300	12.10
Grand total or average	2,390	42,400	17.79	11,796	191,364	16.22	10,400	210,000	20.21	3,960	74,600	18.83	28,500	518,000	18.17

W Withheld to avoid disclosing company proprietary data; included with "Other (ground silica)" or "Other (whole grain)." XX Not applicable.

1/ Data are rounded to three significant digits; may not add to totals shown.

2/ Calculated using unrounded data.

3/ Withheld to avoid disclosing company proprietary data; included with "Other (whole grain)."

TABLE 7
U.S. EXPORTS OF INDUSTRIAL SAND AND GRAVEL, BY COUNTRY 1/

(Thousand metric tons and thousand dollars)

Country	1996 Quantity	1996 F.a.s. value 2/	1997 Quantity	1997 F.a.s. value 2/
North America:				
Canada	914	17,100	305	20,700
Dominican Republic	3	104	5	162
Mexico	136	9,300	308	11,200
Panama	15	254	4	131
Other	4	r/ 1,320	r/ 7	490
Total	1,070	28,000	629	32,700
South America:				
Argentina	8	1,140	12	1,410
Brazil	1	580	5	1,060
Peru	1	258	3	473
Venezuela	3	518	4	1,610
Other	17	580	6	1,690
Total	30	3,080	30	6,240
Europe:				
Germany	35	14,100	27	24,400
Italy	4	866	5	690
Netherlands	10	6,750	14	9,280
United Kingdom	4	1,970	4	2,150
Other	165	9,390	91	6,510
Total	218	33,100	141	43,000
Asia:				
Hong Kong	20	1,930	3	687
Japan	36	29,300	76	27,900
Korea, Republic of	16	4,360	13	3,090
Singapore	6	3,630	11	4,830
Taiwan	17	3,510	18	4,370
Other	7	3,240	47	5,670
Total	102	46,000	168	46,600
Middle East and Africa	6	2,050	6	2,430
Oceania:				
Australia	2	1,160	5	3,360
Other	1	45	1	189
Total	3	1,200	6	3,550
Grand total	1,430	113,000	980	134,000

r/ Revised.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Value of material at U.S. port of export; based on transaction price, including all charges incurred in placing material alongside ship.

Source: Bureau of the Census.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF INDUSTRIAL SAND, BY COUNTRY 1/

(Thousand metric tons and thousand dollars)

Country	1996		1997	
	Quantity	C.i.f. value 2/	Quantity	C.i.f. value 2/
Australia	(3/)	63	18	625
Belgium	(3/)	5	(3/)	9
Canada	5	536	7	700
China	--	--	(3/)	27
Germany	(3/)	163	1	710
Italy	(3/)	11	(3/)	10
Japan	(3/)	346	(3/)	251
Mexico	(3/)	4	12	141
Sweden	1	265	2	674
Switzerland	(3/)	3	(3/)	38
United Kingdom	(3/)	51	(3/)	8
Venezuela	(3/)	56	--	--
Total	7	1,500	39	3,200

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Value of material at U.S. port of entry; based on purchase price and includes all charges (except U.S. import duties) in bringing material from foreign country to alongside carrier.
3/ Less than 1/2 unit.

Source: Bureau of the Census.

TABLE 9
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY 1/ 2/

(Thousand metric tons)

Country 3/	1993	1994	1995	1996	1997 e/
Argentina	396	247	286	244 r/	250
Australia e/	2,000	2,500	2,500	2,500	2,500
Austria	4,302	6,457	7,503	6,012 r/	6,500
Belgium e/	2,475	2,475	2,500	2,300	2,300
Bosnia and Herzegovina	50	50	50 e/	50 e/	50
Brazil e/	2,700	2,700	2,700	2,700	2,700
Canada	1,600 e/	1,600 e/	1,689	1,558 r/	1,591 p/
Chile e/	300	300	300	300	300
Croatia	23	31	341	44	98 4/
Cuba e/	400	300	300	300	300
Czech Republic	1,758	1,957	1,993	2,486 r/	2,000
Denmark (sales) e/	315	315	50	50	50
Ecuador	49	34	36	35 r/	35
Egypt 5/	743 r/	740 r/	740 r/	750 r/ e/	750
Estonia e/	25	25	25	25	25
Finland	167	72	30 r/	31 r/	30
France e/	5,400	7,280	6,100	6,550 r/	6,500
Germany	5,841 r/	5,680 r/	7,315 r/	5,503 r/	6,000
Greece	112	80	68	88	90
Guatemala e/	27	27	29	30	30
Hungary 6/	440	512	320	325 e/	328 4/
Iceland e/	5	5	5	4	5
India	1,148	1,252	1,220	1,534 r/	1,500
Indonesia	240	588	279	300 e/	320
Iran e/ 7/	932 4/	950	1,000	1,000	1,000
Ireland e/	7	8	7	6	5
Israel	83 r/	176 r/	223 r/	225 r/ e/	225
Italy e/	3,100	2,700	3,000	2,950 r/ 4/	3,000
Jamaica	21	18	16 r/	16 r/	12 4/
Japan	3,883	3,942	3,734	3,557	3,306 4/
Kenya e/	12	12	12	13 r/	10
Korea, Republic of	1,117 r/	1,452 r/	1,718 r/	1,690 r/	1,222 4/
Latvia	90 e/	76	64	50 e/	50
Lithuania	60 e/	33	46	33 e/	30
Malaysia	355	231	288	269	205
Mexico	1,310	1,360	1,293	1,425 r/	1,564 4/
Netherlands	20,000 e/	25,006	23,159	24,000 e/	24,000
New Caledonia e/	31	39	40	40	40
New Zealand	49	38	31	24 r/	25
Norway	900 e/	891	963	960 r/	900
Pakistan e/	168 4/	170	170	165	165
Panama e/	23	23	23	23	23
Paraguay e/	2,000	2,000	7,000	7,000	5,000
Peru	115	100	100	100 e/	100
Philippines	201 r/	650 r/	800 e/	800 e/	800
Poland	984 r/	1,204 r/	1,143 r/	137 r/	1,300
Portugal e/	5	5	5	5	5
Serbia and Montenegro	270	280 r/	195 r/	239 r/	200
Slovenia	210	210	210 e/	210 r/	210
South Africa	1,738	1,920	2,180	2,167	2,479 4/
Spain	2,506	2,577	2,881	2,800 e/	2,800
Sweden e/	1,500	1,500	1,500	1,500	500
Tanzania e/	4	4	--	--	--
Thailand	459	471	326	447 r/	510
Turkey e/ 8/	350	415	310	385 r/	400
United Kingdom	4,000 e/	4,038	4,200 r/ e/	4,816 r/	4,800
United States (sold or used by producers)	26,200	27,300	28,200	27,800	28,700 4/
Venezuela	822 r/	141	679 r/	748	800
Zimbabwe 9/	61	131 r/	172 r/	96 r/	100
Total	104,000 r/	115,000 r/	122,000 r/	119,000 r/	119,000

See footnotes at end of table.

TABLE 9--Continued
INDUSTRIAL (SILICA) SAND AND GRAVEL: WORLD PRODUCTION BY COUNTRY 1/ 2/

e/ Estimated. p/ Preliminary. r/ Revised.
1/ Table includes data available through July 2, 1998.
2/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.
3/ In addition to the countries listed, Angola, Antigua and Barbuda, The Bahamas and China, among others, produce industrial sand, but current available information is not adequate to formulate estimates of production levels.
4/ Reported figure.
5/ Fiscal years beginning July 1 of that stated.
6/ For the reported volumetric quantity, see the U.S.Geological Survey Minerals Yearbook 1997, v. III.
7/ Fiscal years beginning March 21 of that stated.
8/ Washed product.
9/ Includes rough and ground quartz as well as silica sand.

TABLE 10
PROCESSED TRIPOLI SOLD OR USED BY PRODUCERS IN THE UNITED STATES, BY USE 1/ 2/

Use		1993	1994	1995	1996	1997
Abrasives	metric tons	19,400	39,000	19,300	W	W
Value	thousands	$2,960	$5,170	$2,920	W	W
Filler 3/	metric tons	58,900	42,800	60,700	W	W
Value	thousands	$12,600	$5,640	$7,580	W	W
Total quantity	metric tons	78,300	82,300	80,100	79,600	81,300
Total value	thousands	$15,500	$10,900	$10,500	$18,400	$16,400

W Withheld to avoid disclosing company proprietary data.
1/ Includes amorphous silica and Pennsylvania rottenstone.
2/ Data are rounded to three significant digits; may not add to totals shown.
3/ Includes silica used in brake lining manufacturing, friction products, refractories, and other unspecified uses.

TABLE 11
U.S. PRODUCERS OF SPECIAL SILICA STONE PRODUCTS IN 1997

Company and location	Type of operation	Product
Arkansas Abrasives, Inc., Hot Springs, AR	Stone cutting and finishing	Whetstones and oilstones.
Blue Mountain Whetstone Co., Hot Springs, AR	do.	Do.
Buffalo Stone Corp., Hot Springs, AR	Tumbling and sizing novaculite	Metal finishing media deburring media.
Cleveland Quarries Co., Amherst, OH	Stone cutting and finishing	Grindstones.
Dan's Whetstone Co., Inc.:		
Hot Springs, AR	do.	Whetstones and oilstones.
Do.	Quarry	Crude novaculite.
Hall's Arkansas Oilstones, Inc., Pearcy, AR	Stone cutting and finishing	Whetstones and oilstones.
The Kraemer Co.:		
Baraboo, WI	Crushing and sizing	Deburring media.
Do.	Quarry	Crude silica stone.
Norton Company Oilstones:		
Hot Springs, AR	do.	Do.
Littleton, NH	Stone cutting and finishing	Whetstones and oilstones.
Smith Abrasives, Inc.:		
Hot Springs, AR	do.	Do.
Do.	Quarry	Crude novaculite.
Taylor Made Crafts, Lake Hamilton, AR	Stone cutting and finishing	Whetstones and oilstones.
Pearcy, AR	Quarry	Do.
Do.	do.	Crude novaculite.

TABLE 12
SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS 1/

(Thousand kilograms and thousand dollars)

	1993	1994	1995	1996	1997
Production:					
Mine	454	544	435	435	450
Cultured	394	294	351	327	355
Exports (cultured): 2/					
Quantity	24	38	35	89	74
Value	$2,260	$6,110	$10,900	$22,200	31,100
Imports (cultured): 2/					
Quantity	8	19	47	42	63
Value	$2,250	$5,950	$10,800	$9,480	11,700
Apparent consumption e/	378	275	363	280	343

e/ Estimated.
1/ Data are rounded to three significant digits.
2/ Excludes mounted piezoelectric crystals.

FIGURE 1

PRODUCTION OF INDUSTRIAL SAND AND GRAVEL IN THE UNITED STATES IN 1997, BY GEOGRAPHIC DIVISION