

BORON

By Phyllis A. Lyday

Domestic survey data and tables were prepared by Christopher H. Lindsay, statistical assistant, and the world production table was prepared by Regina R. Coleman, international data coordinator.

Boron produced domestically during 1999 totaled 618,000 metric tons (t) of boron oxide that was valued at \$630 million (table 1). The most common minerals of commercial importance in the United States were colemanite, kernite, tincal, and ulexite (table 2). Boron compounds and minerals sold are produced by surface and underground mining, in situ, and from brine. U.S. consumption of minerals and compounds amounted to 416,000 t of boron oxide (table 3). Boron products are priced and sold on the boron oxide basis, which varies by ore and compound and on the absence or presence of sodium and calcium (table 4). Boron exports totaled about one-half of the domestic production (table 5). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 6). The United States and Turkey are the world's largest producers of boron (table 7).

The glass industry, which remained the largest domestic market for boron production in 1999, accounted for 73%. Insulation-grade glass fibers accounted for an estimated 46% of domestic consumption; textile-grade glass fibers, 17%; sold to distributors, 8%; borosilicate glasses, 6%; soaps and detergents, 6%; miscellaneous uses, 6%; enamels, frits, and glazes, 3%; and other uses, 8%.

Legislation and Government Programs

On October 15, 1998, the International Trade Administration initiated antidumping duty investigations of imports of hot-rolled steel from Brazil, Japan, and the Russian. Steel products that were included in the scope of this investigation, regardless of Harmonized Tariff System U.S. definitions, were products in which iron predominates by weight over each of the other contained elements; the carbon content is 2 % or less, by weight; and none of the [14 metals plus boron] listed exceeds the quantity, by weight, respectively indicated. Boron was listed as 0.012 % (International Trade Administration, 1999).

In 1999, nine energy-intensive industries, which included four that used boron (agriculture, glass, mining, and steel) completed visions statements that described their goals for the next 20 years. The U.S. Department of Energy (DOE) announced four new solicitations for grant proposals that will provide about \$10 million for research, development, or demonstration of new and advanced industrial technologies. Through its Office of Energy Efficiency and Renewable Energy, DOE will solicit proposals from inventors, small businesses, and collaborative industry partnerships to develop and use clean, energy-efficient technologies for U.S. industry. To demonstrate the practicality and cost-effectiveness of these technologies, a grant program will award \$4 million for cost-

shared technology demonstrations by state and industry partnerships. DOE grants fund up to 50% of total project costs for up to 3 years (U.S. Department of Energy, May 7, 1999, DOE invests \$10 million in new industry partnerships to boost energy efficiency of the Nation's most energy intensive industries, accessed June 3, 1999, at URL <http://home.doe.gov/news.htm>).

Production

Domestic data for boron were derived by the U.S. Geological Survey from a voluntary survey of U.S. operations. The majority of boron production continued to be from Kern County, CA, with the balance from San Bernardino and Inyo Counties, CA. Of the four operations to which a survey request was sent, all responded, representing 100% of the total boron produced (tables 1, 3).

More than 200 minerals contain boric oxide, but only a few were of commercial significance (table 2). Four minerals comprised almost 90% of the borates used by industry—borax and kernite, both of which are sodium borates; colemanite, which is a calcium borate; and ulexite, which is a calcium-sodium borate. These minerals were extracted in California and Turkey and, to a lesser extent, in Argentina, Bolivia, Chile, China, and Peru (Simon, 1999).

American Borate Co. mined small amounts of colemanite and ulexite—probertite from the Billie Mine in Death Valley, CA. The ore was transported to Lathrop Well, NV, for processing. Storage and grinding facilities were at Dunn, CA.

Fort Cady Minerals Corp. used an in-situ process near Hector, CA, to produce a product containing 48% boron oxide. Because it is chemically precipitated, this product has advantages in consistency of its chemical composition; that is, high boron oxide content, low impurities, and a consistent physical size. The product contained 25% calcium oxide, 0.8% sulfur, 0.1% chloride, 0.08% iron, and less than 1-part-per-million (ppm) arsenic. In-situ extraction required that wells be drilled 427 meters (m) (1,400 feet) into the ore body. A solution of dilute sulfuric acid was injected into wells in the borate ore. The boron enriched solution was pumped to the surface and then reacted with lime to precipitate a pure calcium borate product. The product was dried and packaged.

In 1998, IMC Global Inc. announced the creation of IMC Chemicals, which was headquartered in Overland Park, KS, to operate the Trona and the Westend plants at Searles Lake in San Bernardino County. IMC Chemicals produced refined sodium borate and boric acid as a coproduct of soda ash and sodium sulfate from the mineral-rich lake brines. A series of

closed systems circulates brines in the upper unit salt layer of the lake to increase the borax grade to a theoretical 1.45%. The brine was processed at the Westend plant and circulated back to the upper salt layer. At yearend 1998, IMC Global announced that it would divest a controlling share of IMC Chemicals to Mincorp LLC, a division of Citicorp Venture Capital, a unit of New York-based Citigroup (Green Markets, 1999). The sale did not materialize, and another group of investors were considering purchasing the Searles Valley facilities at yearend 1999.

U.S. Borax Inc., which was a member of the Rio Tinto Borax Group, mined borate ores at Boron, CA, by open-pit methods and transported the ores to the surface via a conveyor. In 1998, production of borates was reported to be 587,000 t, which was a 1% increase from that of 1997 (Rio Tinto Plc., Rio Tinto production summary, accessed May 25, 1999, at URL http://www.riotinto.com/02_right.shtml). During 1999, production was at 561,000 t (Rio Tinto Plc, Rio Tinto 1999 Annual review, accessed June 23, 1999, at URL <http://www.riotinto.com/ok.html>). During June 1999, technical improvements began with the replacement of 170-t capacity trucks with twenty-five 216-t capacity trucks, two electric shovels with a bucket capacity of 73 t. The shovels can fill one of the new trucks in less than 2 minutes. A third new diesel hydraulic shovel was smaller and more mobile without the electric cord. A reconfiguration of the mining plan to make the mine walls less steep to deter slides will require more overburden to be removed. This will increase the mining rate because more overburden can be removed to expose the ore (Borax Pioneer, 1999b; Review 1999). At Boron, reserves which contain the minerals kernite and tincal, were in excess of 100 million metric tons (Mt). The ore was processed into sodium borate or boric acid products in the refinery complex adjacent to the mine. An on-site plant also produced anhydrous sodium borate and boric oxide. Refinery products were shipped by railcar or truck to North American customers or to the U.S. Borax Wilmington facility in the port of Los Angeles for international distribution.

Cogeneration plants, which are part of the boron-processing facilities at Boron, produced electricity for plant needs and sold excess power to Southern California Edison.

U.S. Borax purchased the assets of Lake Minerals Corp., which was a trona mining operation on Owens Lake near Lone Pine in the central California mountains on May 1, 1999. Now designated U.S. Borax Inc.-Owens Lake Operations, the facility will allow Borax to ensure control of its trona supply used in the borate refining process. Trona provided a cost-effective source of carbonates, which helped reduce scaling in the processing equipment. Borax has been receiving Owens Lake trona since the mid-1960's and has been one of Lakes Minerals' principal customers since 1995 (Borax Pioneer, 1999c).

Consumption

Glass accounts for about one-half of the total annual world consumption of borates. Borate applications for glass consumption include borosilicate glass, glass fiber insulation,

and textile glass fiber. Boron oxide is an important constituent of a wide range of glasses—enamels for steels and other metal substrates, ceramic glazes, glass wool for thermal and acoustic insulation, optical glass, textile fibers for the reinforcement of plastics, and a diverse range of technical borosilicate glasses for cookware, laboratory, lighting, medical, and liquid crystal display screens. Boron oxide allows the formulated glass to have high chemical durability, low thermal expansion, and low electrical conductivity.

Criteria for the selection of borate raw materials for glass manufacture are availability, composition, consistency, impurities, melt properties, and price. Different glass types will have different criteria. Borates are relatively expensive compared with other batch components; each batch is formulated to minimize cost within the constraints of the glass composition. Sodium-containing glass commonly uses borax pentahydrate and is more cost-effective than using boric acid and soda ash. To adjust the sodium-to-boron ratio, two different borates may be used such as borax pentahydrate and boric acid. Boric acid is used where alkali is limited in the glass composition, such as Pyrex-type glasses and electrical glass (E-glass) (Simon, 1999).

Glass fiber thermal insulation, which is primarily used in new construction, is a large area of demand for borates and is the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, fiberglass' purpose is to trap and hold air. Typically, between 4% and 5% of boron oxide is incorporated in its formulation to aid melting, to inhibit devitrification, and to improve the aqueous durability of the finished product.

Borates also are used in a range of products made from high-tensile-strength glass fiber materials. The process of producing glass fiber uses a borosilicate (E-glass) formulation that is continuously drawn through platinum alloy bushings into continuous 9- to 20-micrometer diameter filaments. Calcium aluminoborosilicate, E-glass or textile fiberglass, typically contains between 6% and 10% boron oxide. These glasses were originally used for electrical purposes where low sodium levels were important. The nonconductive and low dielectric properties of high-strength, glass-reinforced materials make them transparent to radar and, thus, invaluable for "stealth" applications. E-glass also has a balance of chemical, electrical, and mechanical properties that are widely applied in composites because of the moderate cost. Modern E-glass formulas for glass fiber typically contain from 6% and 10% boric acid (3% to 6% boron oxide) and can tolerate higher levels of sodium in composite uses. This type of glass fiber is essential as a composite to aircraft, automobile components, boat hulls, printed circuit boards, and surfboards (Baele, 1998).

The minerals colemanite and ulexite are used mainly for the production of ceramic frit on glazed tile, glass wool, and fiberglass. Because of variability of minerals, they must be milled to a fine particle size (200 mesh) and blended prior to use. The fineness of the grind eliminates coarse particles of quartz that could remain undissolved in the glass. Colemanite products will be 75% to 85% pure and contain gangue in minerals that contain the elements aluminum, arsenic, magnesium, iron, silicon, strontium, and sulfur. Water

contained in boron minerals can cause higher energy usage, increase stack emissions, decrease glass quality, and lower production rates. E-glass applications require low arsenic levels to prevent corrosion of the platinum bushings used for drawing fibers. Iron levels in borates for ceramic frit can be a constraint because of color of the final glaze. Anhydrous borax and boric oxide can be used in glass frits. Technical borosilicate glasses can require boron oxide levels of up to 20% (Simon, 1999).

Ceramic wall and floor tiles use boric oxide derived from borax pentahydrate, boric acid, and mineral borates. In the top-of-the-line porcelanic floor tiles used outside, borates included with the clay make vitrification better and produced stronger tiles. Significantly, the firing temperature can be lowered by 20° to 30°C, thus reducing the energy usage and cost. Boric acid delivers a higher percentage of boric oxide without the thickening that occurs with other borates. Lower quality white-body tiles, which have to be glazed, are equivalent to porcelanic tiles when borate is added. The cheapest tile to produce is red-body tile. The addition of borate improves the strength and lowers water absorption and firing temperature (Borax Pioneer, 1999a).

Boric acid is being used in wallboard, also known as drywall, plasterboard, or gypsum board, to increase the production line speeds, to save in raw material, to reduce energy and shipping costs, and to improve the overall board quality. No new wallboard plant has been constructed in North America in the past 10 years. With the rise in residential and commercial building in North America, there has been increased demand for wallboard. Consequently, eight new plants have been announced by 2003, which will use synthetic gypsum from powerplants to increase capacity by 30%. Gypsum is a physical structure rather than a chemical structure. The needle like gypsum crystals form a network to give the board its physical integrity. The trend in boardmaking is toward lighter boards that are easier to handle during installation and less expensive to ship. Lighter weight means less gypsum in the board and particularly less gypsum at the paper/core interface and at the edges and ends. The less gypsum, the easier to overdry or calcine the surface and to revert the gypsum back into a hydrated form with less strength, which causes the bond between the gypsum and the paper to fail. Sag caused by humidified deflection can be a problem in humid environments. The gypsum needles can become wet and slip over each other in response to gravity. Using boric acid can address all these problems in lightweight wallboard by raising the calcination temperature for gypsum, thereby protecting the wallboard from the effects of overdrying. Boric acid also modifies the gypsum crystals by making them larger and thicker and reducing the sagging tendency (McBroom, 1999).

By using boron as one of the essential micronutrients, more soybeans are grown in the United States than anywhere else in the world. Soluble borate fertilizer, which can be used alone or sprayed with insecticides or fungicides, is recommended for application at the onset of the first flowers.. In 1999, 29 States grew soybeans, thus making it the second largest domestic crop in terms of cash sales, exceeded only by corn. Nearly 64 Mt were produced, supplying one-half of the world's demand.

Some 26.5 million hectares of land were under soybean cultivation in the United States. Japan was the second largest consumer, and the European Union made up the largest collective market (Borax Pioneer, 1999e).

Transportation

In 1999, U.S. Borax products from Boron were transported primarily by rail, although trucks were also used. The company ranked as the number one bulk shipper in California on the Burlington Northern Santa Fe Railroad, which had a fleet of more than 700 rail cars. Ocean transport was from the port of Wilmington, CA, where it owned the only remaining privately owned berth in the harbor. It ranked as the largest exporter of high-value dry bulk products and in the top 10 shippers of ocean containers out of the ports of Los Angeles and Long Beach. About 10 ships per year with a capacity of 40,000 deadweight tons each were loaded for locations around the world. In October, Japanese shipping enterprise "K" Line and Borax recognized 20 years of doing business together. During the past 2 years, "K" Line has put into service three new bulk vessels—the Boron Explorer, the Glory Ace and the Lepta Mercury—to take borates from Los Angeles to Rotterdam, Netherlands, and Valencia, Spain (Borax Pioneer, 1999d).

Antwerp, which has the most central port location in Europe, had access to 188 major European cities. The industrial minerals market in Europe was characterized by high volumes of imported materials, mostly forwarded to the industrialized areas of Belgium, France, Germany, or the Netherlands for destinations in Central Europe, such as Austria, the Czech Republic, or Slovenia. The decision to import material was based on the geographic location, the range of service needed, and prices.

U.S. Borax used barges to ship borates from the Rotterdam, Netherlands, to customers in Belgium, Eastern Europe, France, Germany, and farther. For small consignments and locations far from a waterway, trucks can be more competitive than barges. Barges were the most efficient and reliable method of transporting goods in Europe, which had a 25,000-kilometer (km) network of navigable canals and rivers. Most of the large industrial areas can be reached by barge on waterways that link parts of the North, the Baltic, the Black, and the Mediterranean Seas and the Atlantic Ocean. In 1992, the 170-km canal linking the River Main to the Danube was opened in Germany.

IMC Global the Trona Railway, which is a spur that is connect to the Southern Pacific Railroad between Trona and Searles Station. Boron products that are used in ceramics, high-temperature glassware, and insulation.

Prices

Prices of boron minerals and compounds produced in Argentina, Brazil, Turkey, and the United States are listed in table 4.

World Review

Argentina.—The Argentine Infrastructure Development

Trust was created to develop the country's natural resource base by using technology that allowed for the efficient, profitable, and environmentally safe extraction of mineral resources. The Trust was formed by the Office of the Secretary of Mines. The Trust intends to coordinate and seek common users of minerals that will make the mining industry in the region more competitive with the world economy.

Borax Argentina S.A., which was a subsidiary of Rio Tinto Plc., was the country's leading producer of borates. Borates were first discovered in Argentina about 1850 at Salinas Grandes in the north-west of Salt Province in the Andean cordillera. In 1999, the Province was still the center of borate production. Borax Argentina obtained its first borate interests in 1905 when Borax Consolidated Ltd., a former subsidiary of RTZ, which was former Rio Tinto, purchased Cia. Internacional de Boratos (table 6; Industrial Minerals, 1999).

In 1999, Borax Argentina mined borates at three deposits in Salta and Jujuy Provinces. Tincal, which is a sodium borate, was mined at Tincalayu in the Salar del Hombre Muerto, Salta Province, with a capacity of 477,000 metric tons per year (t/yr) at the mine and 95,400 t/yr at the plant. At Sijes near Salar Pozuelos, Salta province, hydroboracite-colemanite capacity was 108,120 t/yr at the mine and 35,000 t/yr at the plant. At Salar Cauchari near Porvenir, Jujuy Province, ulexite capacity was 14,000 t/yr at the mine and 8,000 t-per-year (t/yr) at the plant. The mines lie at an altitude between 3,700 and 4,200 m in an extremely arid environment. The lack of precipitation allows mining and trucking operations for 11 months of the year, weather permitting. Because of the remote location, the operations at Tincal and Sijes are self-contained. Process water at Tincalayu was pumped from 15 km from the plant and recycled as much as possible. All other supplies had to be trucked in from Salta, a journey of 400 km that rises from 1,185 m at Salta to 4,100 m at Tincalayu and passes over a 5,000 m peak (Industrial Minerals, 1999).

Tincalayu was Argentina's largest open pit operation—1.5 km long, 800 m wide, and 100 m deep. The mine is a peninsular shape into the Salar del Hombre Muerto. Ore grade varied from around 16% to 22% boron oxide and was selectively mined. The clay overburden averages 50 m and typically overlies 30 to 40 m of ore. The overburden and ore were removed by the use of hydraulic hammers, primarily for safety reasons. Ore was trucked to a primary crusher with 100-metric-ton-per-hour (t/hr) capacity that reduced the ore to less than 101 millimeters (mm)(less than 4 inches). The ore was blended to a consistent 18% boron oxide to feed the concentrate plant. The blended ore was crushed in a hammer mill and screened to less than 6 mm. The ore was washed to remove the clay and deslimed with hydroclassifiers. The waste clay was flocculated and settled and returned to the salar. The clear liquor was returned to the concentration plant. Sand was the main impurity of the 28% concentrated tincal product. The concentrate was dried in stockpiles before loading into trucks for the rail terminal at Pocitos (Industrial Minerals, 1999).

The mine at Sijes produced colemanite and hydroboracite from an open pit. The overburden is 25 to 26 m thick and overlies the 27 to 29 m of ore that averages 34% boron oxide. After primary crushing, the ore is blended. A secondary cone

crusher reduced to ore from less than 101 to less than 12 mm (4 inches to less than 0.5 inch). After screening, the ore was fed through a three-stage high-intensity magnetic separation circuit that was installed in 1997. The 42% boron oxide hydroboracite was sold in 10 to 70 mesh and 100 mesh. The colemanite was sold as 100 mesh. Most production was bagged on site and dispatched directly to ceramics consumers in Latin America and Spain.

Ulexite was mined from surface deposits of Salar de Caruchari near Porvenir in the south of Jujuy province. Small volumes of crude ulexite were passed through a screening and milling plant in Porvenir. Ulexite was bagged and sold to consumers. Ulexite concentrate was trucked to the Campo Quijano plant (Industrial Minerals, 1999).

Ore concentrates from Tincalayu and Sijes arrived at the Quijano plant by rail or by truck. Ore was trucked from the mine to a rail terminal at Pocitos, 120 km north of Tincalayu and loaded on trains of 11 cars, each with a 30-t capacity. The plant had a storage capacity of 4,000 t of product and normally has sufficient ore for 1 month of production. Campo Quijano had capacity for 43,250 t/yr of borax, 4,500 t/yr of anhydrous borax, 3,000 t/yr of borax decahydrate, 19,000 t/yr of borax pentahydrate, and 13,500 t/yr of anhydrous ulexite. The plant was ISO 9002 certified. Consumption of boron product was used as follows: frits, 63%; glass 14%; fiberglass, 13%; agriculture, 1%; and other 9% (Industrial Minerals, 1999).

The Sucursal Argentina Division of S.R. Minerals (Barbados) Ltd. developed the Loma Blanca Mine in Jujuy Province in 1996. The mine had tincal and ulexite with average ore grades of around 16% boron oxide. A primary concentrator used magnetic separation and mechanical processing to produce concentrates of more than 30% boron oxide. The concentrates were trucked 180 km to a processing plant at Palpalá near San Salvador, Jujuy Province. The concentrates were passed through a rotary kiln. The tincal based feed produced a calcined calcium borate containing 55% boron oxide. The ulexite based feed produced a calcined calcium-sodium borate containing 60% boron oxide. The first phase of the commercial plant came on line in 1997. Output increased to about 4,000 metric tons-per month (t/mo) in June 1999. Production was primarily sold to Brazil and Spain (Kendall, 1999).

Ulex S.A. produced colemanite and hydroboracite from its mine in the Pastos Grandes area of Salta Province. Processing involved crushing, washing, milling, and drying to produce a concentrate at Salta. The ore contains between 27% to 40% boron oxide and about 300 ppm to 600 ppm arsenic. Production capacity was reported to be around 10,000 t/yr for each of the minerals; most was exported. Ulexite, which was found in veins, was hand mined for resale to two boric acid producers. Because production was minor, Ulex was investigating the possibility of increasing production of ulexite to between 40,000 t/yr and 50,000 t/yr. All production was exported (Kendall, 1999).

The newest producer was Procesadora de Boratos Argentinios S.A. owned by Ferro Corp. and Canadian JEM Resources. The project was purchased from S. R. Minerals Ltd., which was an affiliate of Smokey River Coal Ltd, a Canadian coal producer

(Kendall, 1999).

Norquimica was one of the few surviving boric acid manufacturers in Argentina. Ulexite was raked on the surface of the salars in Salta Province, spread out to dry, and trucked to the company's plant in Salta for concentrating. A portion of the ulexite concentrate is used as feed for the boric acid plant. The concentrate is reacted with sulfuric acid. The company's production was about 5,000 t/yr. The concentrated ulexite was sold to agricultural consumers in Brazil (Kendall, 1999).

Bolivia.—Borate production was from companies that mined ulexite from Government concessions around Salar de Uyuni in the Bolivian Altiplano. Cia. Minera Tierra S.A. had large ulexite concessions near the Chilean border and produced dried and washed grades for export. About 50,000 t/yr of boric acid was produced by a process that used 98% sulfuric acid from copper production in Chile. The plant used geothermal steam from a well drilled in 1998 by the Bolivian State Electric Co. that produced 1,300 kilopascals (120 pounds-force per square inch) of steam for reacting, drying, and heating of the ulexite. The plant produced 1,200 t/mo of boric acid and expected to be up to 1,500 t/mo of 99.7% boron oxide by yearend 1999. The capacity of the plant was 40,000 t/yr. The product was primarily used for cellular insulation.

The Pampa borax deposit, which was owned by Champagne Miner Rio Grande S.A., has ulexite ore with a boron oxide content of between 30% and 34% and 1.7 Mt of proven reserves. The deposit included 9 concessions comprising 4,480 mining claims and is located in Nor Lapis Province south of the Salar de Uyuni. About 3.5 t/yr of boron oxide from ulexite ore about 2 m thick and with a high chloride content was produced.

Chile.—Quimica e Industrial del Borax Ltda. (Quiborax) mined ulexite from Salar de Surire, which was the largest ulexite deposit in the world. The salar is located at an altitude of 4,250 m in Monumento Natural de Surire, which is a national park. Production capacity was around 200,000 t of crude ulexite. The ore was trucked to El Aguila production facility north of Arica. Some of the ulexite was dried and sold, and the balance was reacted with sulfuric acid to produce from 25,000 to 36,000 t/yr of boric acid. The majority of production was exported through the ports of Antofagasta, Arica, and Iquique. The National Borax Corp., Cleveland, OH, packaged and distributed boric acid in the United States for Quiborax.

Champagne Minera Salar de Atacama (Minsal) was 100% owned by Sociedad Quimica y Minera de Chile SA. A large integrated facility is planned to begin production of 16,000 t/yr of boric acid in 1998. The plant was reported to be purchasing boric acid for resale during 1999.

China.—Numerous producers of borates were in the Liaodong peninsula in Liaoning Province. The ores are primarily magnesium borates, such as szaibelyite. Other production was from the playa lakes in Qinghai, where borate minerals, such as ulexite, hydroboracite, and borax, were produced from brines. Total Chinese production of borate minerals was estimated to be around 100,000 t/yr, with an additional 20,000 t/yr of boric acid.

India.—Submarginal borax reserves occur in the Puga Valley Districts of Jammu and Kashmir. In the state of Rajasthan, the bitterns from Lake Sambhar were reported to

contain about 0.5% borax.

Kazakhstan.—More than 100 boron deposits have been discovered in northern Prekaspiy. Boron deposits of the Inder groups are concentrated in the gypsum of salt domes and salt rock masses. Borates associated with gypsum include ascharite (szaibelyite), hydroboracite, inyoite, and ulexite. At two sites, dredging by means of drag lines took place at a depth of 15 to 20 m below the water level. Borate ore reserves were estimated to be 2 Mt, but the undiscovered resources could reach 120 Mt of 9% boron oxide.

Mexico.—A geologic study of the borate-bearing sediments in the northern State of Sonora proposed the names "Magdalena," "Cuesta," "El Pterion," and "Tubutama" Formations for mid-Tertiary sedimentary and volcanic rocks of the upper plates in the Magdalena and the Tubutama basins (Miranda-Gasca, Gomez-Caballero, and Eastone, 1998).

Peru.—Cia Miner Ubinas SA and Quimica Oquendo SA, which were subsidiaries under the Inkabor S.A. name and owned by the Italian Colorobbia Group, mined ulexite at Laguna Salinas, which is 80 km east of Arequipa. The open pit operation produced from 150,000 to 180,000 t/yr of ulexite ore during 6 or 7 months of mining. Large stocks were maintained for sales during the winter season. The crude ulexite was washed to produce a concentrate. The calcining plant operated 24 hours per day to produce calcined ulexite in granular and powdered forms. Ulexite was supplied to Oquendo for boric acid production. Oquendo's plant in Arequipa had the capacity to produce 12,000 t/yr of boric acid and 15,000 t/yr of concentrated ulexite. Small quantities of calcined ulexite were sold in Peru for fertilizer, and the rest of the Inkabor output was exported (Inkabor S.A., Mining, accessed May 26, 1999, at URL <http://www.inkabor.com>).

Russia.—Boron ore reserves are concentrated in deposits of magnesite-skarn and lime-skarn formations found in Southern Yakutiya (Tayozhnoye), Buryatiya (Solongo) and the northeast (Nalyodnoye and Titovskoye). The boron-iron deposit at Tayozhnoye is of Archean age. Here, skarn ore bodies are found among dolomite, gneiss, marble, and shale. They were formed from magnetite and, sometimes, aschanite (szaibelyite) and ludwigite. In 1999, the reserves exceeded 100 Mt of 34% boron.

Reserves of commercial boron that have been in production since 1959 are associated with the Paleogene lime-skarn deposit of Dalnegorsk. The deposit consists of calcite, datolite, garnet, hedenbergite, quartz, and wollastonite. Boron oxide content varies from 6% to 16%. The deposit was mined for datolite and limestone by Joint Stock Company Bor (JSC). At the sulfuric acid plant in Komsonolsk (Khabarovsk), datolite was treated to produce boric acid and calcium borate. JSC produced 90% of the Russian output of 220,000 t of boric acid.

The processing involved heating the datolite ore from 980° to 1,020° C, and decomposing the ore into boric acid by reaction with carbon dioxide. Combining a solution of lime with the boric acid solution precipitates calcium borate. After drying, the product contained 45% to 46% boron oxide. Anhydrous boric acid was produced by decomposing datolite in 93% sulfuric acid. The resulting product is 99.9% boric acid. The gypsum waste was used as a gypsum binding agent or

mineral fertilizer.

Sodium perborate was produced by the interaction of solutions of sodium metaborate and hydrogen peroxide. Sodium perborate was produced by a chemical method in which hydrogen peroxide was used and by an electrochemical method in which electrolysis of solutions containing sodium metaborate and sodium carbonate was used. The waste chalk was used to produce construction materials, silicate paints, and soil additives. Technical-grade borax was synthesized from a solution of boric acid and soda.

Serbia and Montenegro.—Ras-Borati Ltd. began drilling the Piskanja boron deposit in the Jarandol Basin, which is located near Baljevac in southern Serbia. Ras-Boratim, which was established February 1997, was a 50-50 joint venture between Erin Ventures Inc. of Kelowna, British Columbia, Canada, and Elektroprivreda, which is the national power company of Serbia. A drilling program was planned to raise the status of a 7-Mt block of reserves that graded 35% to 39% ore from indicated to proven. The minerals are primarily colemanite and ulexite. Ras-Borati also held rights in the Pobrđjski Potok borate deposit in the Jarandol basin. Proven and probable reserves of 140,000 t ore averaged 37% boron oxide.

Tajikistan.—A skarn borosilicate deposit at Ak-Arkhar, which is situated at an elevation of 4,400 to 5,000 m, had measured and indicated reserves of danburite ore that exceed 80 Mt.

Turkey.—Turkey's boron operations were under the control of Etibank, which is the Government corporation. The banking arm of Etibank was privatized at the end of 1997, and the name of the minerals and metals producing company was changed to Eti Holding AS. The government, however, had no plans to privatize Eti Bor, which held all the Turkish borate resources since the law of 1979. Borates are considered strategic minerals, and future Governments will probably keep this valuable business under state control (Etienn, 1999). Ulexite was mined at Bigadic; colemanite, at Bigadic, Emet, and Kestelek; and tincal, at Kirka.

Bigadic Colemanite Works, in the Bigadic District, Balikesir Province, had a production capacity of 500,000 t of run-of-mine colemanite and ulexite ores from three open pits and two underground mines. The concentrator had a capacity of 400,000 t/yr of concentrate. This district had the world's largest colemanite and ulexite deposits. All products from Bigadic were for export. A new computerized grinding process that requires only one operator improved the quality of the product has been installed at Bigadic. Ore was sized to less than 25 mm and layered to produce a homogenous boron oxide content. There are two different process flows lines for colemanite and ulexite before and after grinding. Ore in the size range of 25 to 125 mm from the concentrator plant were transferred to the silos by trucks. The ore was fed into a gyratory crusher with a 100-t/hr capacity and crushed to less than 25 mm. The crushed ore was transported by conveyor belt to indoor systems that layer the ore to achieve chemical homogeneity. The ore was taken by conveyor belt to silos and fed into the grinding unit through a controlled weighing system. Magnetic material, such as clay, was separated from the ore. The moist ores were dried in a hot gas furnace and

reground. The ground ore was air classified and filtered. Capacity was 30,000 t/yr with product specifications of 42% boron oxide and 50-ppm arsenic (Anac, Bilek, and Kanali, 1999).

In 1996, Emet Colemanite Works, which was located in the Emet District of Kutahya Province, had a production capacity of 736,000 t/yr of run-of-mine ores, from open-pit and underground mines. Colemanite concentrate production from a 500,000 t/yr concentrator was 357,000 t/yr and supplied domestic and international markets. Most of the colemanite concentrates were exported. The remaining production was used in the boric acid plant in Bandirma. A new 100,000-t/yr boric acid plant was being added.

Kestelek Boron Mine is located in Mustafakemalpa District, Bursa Province. The underground mine was closed at the end of 1994 because of high cost and low sales. Since then, production has been from the open pit. In 1996, 33,000 t of colemanite concentrate was produced.

The Kirka Borax Works near the Seyitgazi District of Eskisehir Province produced tincal concentrate, borax pentahydrate, and anhydrous borax. During 1996, the facility produced 950,000 t of run-of-mine material. The concentrator had a capacity of 660,000 t/yr of tincal concentrates. A derivatives facility produced 184,000 t/yr of borax decahydrate, 60,000 t/yr of anhydrous borax, and 320,000 t/yr pentahydrate borax. Expansion of a further 160,000 t/yr borax pentahydrate facility to the existing plant would bring total production to 480,000 t/yr.

The storage and loading facility at Degirmenozu had a railway connection to the port at Bandirma. At Bandirma, the facilities have the capacity to produce 100,000 t/yr of boric acid, 55,000 t/yr of borax, and 20,000 t/yr of sodium perborate.

Uzbekistan.—An oil and gas condensate deposit at Dzhartchi has the potential to produce 377 t/yr of boron oxide at a pumping rate of 4,000 cubic meters per day for more than 20 years.

Current Research and Technology

Owens Corning Fiberglas developed and published a mathematical model that enables researchers to predict the likelihood of disease from fiber types by determining the dissolution rate of the fiber. Insulation products of durable special application glass fiber were studied for risk to human health. Glass fibers are one type of the family of fibers known as mineral wool or insulation wool. Although asbestos and durable glass fibers are often found in the lungs of workers, glass wool fibers are generally not present. Glass wool fibers are capable of being inhaled into the lung, then effectively removed by natural body functions. The potential for dust particles and fibers to have an adverse health effects are related to dimension, dose, and durability. Durable fibers can induce disease. The primary difference between the chemical composition of mineral wool and refractory or durable special purpose fibers is the quantity of alkali and alkali earth oxides in the formulation. Mineral wool products manufactured in the United Kingdom are not classified as carcinogens (Houghton, 1999).

Albemarle Corp. and Borax Flame Retardant Group reached an agreement to develop joint applications for zinc borate in flame retardants. The goal is to increase the availability of halogen and halogen-free flame retardants to the polymer industry. Zinc borates are currently used in polyvinylchloride, polyamide, and epoxy compounds, but there are potential opportunities in styrenics, engineering plastics, and other resins (Chemical & Engineering News, 2000).

Boron-bearing antioxidant used in refractory bricks increases the resistance of the brick to oxidation and slag corrosion. The best results were achieved with combinations of aluminum boride with boron carbide and calcium boride when compared to zirconium boride additives (Hunold, 2000).

A substance that can selectively deliver large amounts of B^{10} to cell nuclei has been developed by a team of researchers at the University of California, Los Angeles. Such agents would be useful in neutron capture therapy, which is a form of cancer treatment. In this process, the boron nuclide is selectively delivered to cancer cells, which are irradiated with neutrons to cause fission of B^{10} into highly energetic particles that destroy the targeted cells (Rawls, 1999).

Studies of the changes in the grindability of ulexite and colemanite determined that it was related to different structural modifications created by heat treatment. Heat treatment significantly affected the grindability of ulexite when heated at 200 to 280 °C for 60 minutes, but had no appreciable change on colemanite. Thermally assisted comminution can be used to improve the grindability characteristics of ulexite and used for its separation. An artificial mixture of ulexite and colemanite was separated with 90% recovery by using thermal treatment and semiautogenous grinding and screening (Sener and Özbayoglu, 1999).

Colemanite and borax are the least and most soluble boron minerals of commercial importance, respectively. Boron minerals, such as colemanite and borax, which use primary amine collectors exhibit collector precipitation above a critical pH, determined by a mine content. The collector precipitation was attributed to the formation of amine hydroborate. Current studies indicate that the precipitate is dodecylamine and may enhance the floatability of colemanite (Akin, and others, 2000).

Researchers at the DOE's Ames Laboratory created the second hardest substance after diamond by using an alloy of silicon, aluminum, magnesium, and boron. The material is slightly harder than cubic boron-nitride. The aluminum-magnesium-boron compound could be the least expensive of the three materials (Journal of Metals, 1999).

Chemists in Italy discovered a new aspect of the chemistry of borazine, which is a boron-nitrogen analog of benzene, that is of interest for its fundamental properties and its use as a precursor for boron-nitride ceramics (Chemical & Engineering News, 1999a).

Researchers at the University of Washington, Seattle, used an organic borate to insert oxygen to form hydroperoxo platinum species. The reaction is notable because compounds like the reactant are believed to be intermediates in alkane oxidation. The use of an inexpensive, clean oxidant, such as oxygen, would be ideal for these oxidations and would yield valuable compounds (Chemical & Engineering News, 1999b).

Studies of the use of a supplemental treatment with soluble boron compounds as a wood preservative improved the ability of the boron compound to remain insoluble under humid conditions. Vinyl monomers, such as styrene and methyl methacrylate, were applied to extend the service life of boron-treated wood (Yalinkilie, and others, 1999).

Research groups at Syracuse University, Syracuse, NY, the University of California, Riverside, CA, Washington University, St. Louis, MI, and North Carolina State University, Raleigh, NC, have designed and synthesized light-harvesting arrays that comprise a central porphyrin and one, two, or eight boron-dipyrrin accessory pigments. The array with eight boron-dipyrrin units clustered around the porphyrin is an example of synthetic design that affords extremely close packing of light-harvesting elements around a central energy trap. The array also supports controlled, highly efficient energy transfer, such as the energy flows between the light-harvesting pigments and the trap, without deleterious side reactions. The need to reduce dependence on fossil fuels and to develop technologies to produce clean fuels, such as hydrogen, is one of the major forces driving artificial photosynthesis research. The prospect of developing artificial chemical systems to harness the energy from the sun, such as nature's system, photosynthesis, is complicated. The result of photosynthesis is a separation of electrical charge and therefore a redox potential. Both reduction and oxidation processes require the assistance of enzymes and some advanced chemistry. The ramifications for solar energy conversion would be significant for optoelectronic devices and materials science (Freemantle, 1998).

In work by a researcher at Eastman Chemical Inc., treatment of a dihydrofuran with trimethyl orthoformate catalyzed by boron trifluoride forms methoxytetrahydrofuran. Processing with a platinum catalyst splits out methanol to form a methyl dihydrofuran. The methyl dihydrofuran is used as a solvent or vinyl monomer (Stinson, 1998).

Outlook

The demand for boron in the United States is expected to remain strong. New areas of use in gypsum board and strong demand in the glass industry are expected to increase consumption. Boron compounds and chemicals can reduce the energy use in many products. This may become an important sector if energy costs continue to rise. Although South America has large reserves of boron minerals, location, infrastructure, and processing problems have delayed significant production onto the world market. The world production number for Turkey does not accurately reflect production because some ore once exported is now being consumed as boron products for sale to Asia and Europe. World demand is expected to grow, primarily in the glass industry.

References Cited

- Akin, Y., Hancer, M., Celik, M.S. and Miller, J. D. 2000, Interaction of a mine with borate species in boron flotation pulps: Society for Mining, Metallurgy, and Exploration Annual Meeting, Salt Lake City, UT, February 28-March 1, 2000, Reprint 00-38, 6 p.

- Anac, S., Bilek, C. and Kanali, H., 1999, Processing boron—Eti Aholding upgrades Bigadic: *Industrial Minerals*, no. 376, January, p. 45-49.
- Beale, S.M., 1998b, Borates are an important ingredient in glassfibre manufacture: *Glass*, v. 75, no. 12, December, p. 420.
- Borax Pioneer, 1999a, Body work—Borates go below the surface: *Borax Pioneer*, no. 17, p. 8, 9.
- 1999b, High rollers: *Borax Pioneer*, no. 17, p. 4, 5.
- 1999c, Pioneers at large—Borax acquires Lake Minerals trona mine: *Borax Pioneer*, no. 17, p. 23.
- 1999d, Pioneers at large—Borax celebrates anniversaries with “K” Line and Rhodia: *Borax Pioneer*, no. 16, p. 22.
- 1999e, Soy what?: *Borax Pioneer*, no. 17, p. 7.
- Chemical & Engineering News, 1999a, Borazine undergoes electrophilic substitution: *Chemical & Engineering News*, v. 77, no. 12, March 22, p. 25.
- 1999b, Science/technology concentrates—Oxygen inserts into platinum hydride bond: *Chemical & Engineering News*, v. 77, no. 51, December 20, p. 24.
- 2000, Business concentrates—Albemarle, Borax to collaborate on flame retardants: *Chemical & Engineering News*, v. 78, no. 2, January 10, p. 17.
- Etienn, Charles, 1999, Talking Turkey—An update on the Turkish minerals industry: *Industrial Minerals*, no. 379, April, p. 21-48.
- Freemantle, Michael, 1998, Mimicking natural photosynthesis: *Chemical & Engineering News*, v. 76, no. 43, October 26, p. 37-46.
- Green Markets 1999, IMC Global sell soda ash and boron chemicals businesses: *Green Markets*, v. 23, no. 1, January 4, p. 1 and 12.
- Houghton, Charles, 1999, Mineral wool insulation—No significant risk to health: *Glass*, v. 76, no. 7, July, p. 226-227.
- Hunold, Klaus, 2000, Resistant refractories: *Ceramic industry*, v. 150, no. 2, February, p. 34-42.
- Industrial Minerals, 1999, Borax Argentina: *Industrial Minerals*, no. 381, June, p. 79-81.
- International Trade Administration, 1999, Preliminary determination of sales at less than fair value-hot-rolled flat-rolled carbon-quality steel products from the Russian Federation: *Federal Register*, v. 64, no. 37, February 23, p. 9312-9319.
- Journal of Metals, 1999, Ames researchers create second-hardest known substance: *Journal of Metals*, v. 51, no. 112, December, p. 7.
- Kendall, Tom, 1999, Borax Argentina: *Industrial Minerals*, no. 381, June, p. 55-80.
- McBroom, Bob, 1999, All aboard with Optibor TG boric acid: *Borax Pioneer*, no. 17, p. 11, 12.
- Miranda-Gasca, M.A., Gomez-Caballero, J.A., and Eastone, C.J., 1998, Borate deposits of Northern Sonora, Mexico—Stratigraphy, tectonics, stable isotopes, and fluid inclusions: *Economic Geology*, v. 93, June-July, p. 510-523.
- Rawls, R.L., 1999, Bringing boron to bear on cancer: *Chemical & Engineering News*, v. 77, no. 12, March 22, p. 26-29.
- Review, 1999, Breaking new ground with borax: *Review*, no. 52, December, p. 4-6.
- Sener, S., and Özbayoglu, G., 1999, Effect of structural changes on grindability of some boron minerals: *Society of Mining, Metallurgy, and Exploration, Denver, CO*, March 1-3, 1999, Reprint 99-13, 3 p.
- Simon, J.M., 1999, The role of borate materials in glass production: *Glass*, v. 76, no. 11, November, 1999, p. 351-352.
- Stinson, S.C., 1998, Prosperity for fine chemicals: *Chemical & Engineering News*, v. 77, no. 29, July 19, p. 65-87.
- Yalinkilie, M.K., Imamura, Yuji, Takahashi, Munezoh, and Yalinkilie, A.C., 1999, In situ polymerization of vinyl monomers during compressive deformation of wood treated with boric acid to delay boron leaching: *Forest Products Journal*, v. 49, no. 2, February, p. 43-51.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Boron. Ch. in *Mineral Commodity Summaries*, annual.¹
 Evaporites and brines. Ch. in *United States mineral resources*, U.S. Geological Survey Professional Paper 820, 1973.

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

TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS 1/

(Thousand metric tons and thousand dollars)

	1995	1996	1997	1998	1999
United States:					
Sold or used by producers:					
Quantity:					
Gross weight 2/	1,190	1,150	1,190	1,170	1,220
Boron oxide (B ₂ O ₃) content	728	581	604	587	618
Value	\$560,000	\$519,000	\$580,000	\$486,000	\$630,000
Exports: 3/					
Boric acid: 4/					
Quantity	75	42	92	106	107
Value	\$68,100	\$35,300	\$60,500	\$54,600	\$56,700
Sodium borates:					
Quantity	588	381	473	453	370
Value	\$227,000	\$133,000	\$169,000	\$146,000	\$180,000
Imports for consumption:					
Borax:					
Quantity	9	11 5/	54 5/	14 3/	8 3/
Value	\$936	\$3,470	\$17,000	\$5,160	\$2,840
Boric acid:					
Quantity	16	25 5/	26 5/	23 3/	30 3/
Value	\$10,100	\$10,800 e/	\$11,800 e/	\$12,500	\$14,000
Colemanite:					
Quantity	45	44 5/	44 5/	47 5/	42 5/
Value	\$8,600	\$13,000 e/	\$13,000 e/	\$13,900	\$13,100
Ulexite:					
Quantity	153	136 5/	157 5/	170 5/	178 5/
Value	\$39,300	\$27,200	\$31,400	\$34,000	\$35,700
Consumption: Boron oxide (B ₂ O ₃) content	NA	367	403	NA	416
World: Production	4,170 r/	4,330	4,570 r/	4,670 r/	4,370 e/

e/ Estimated. r/ Revised. NA Not available.

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

2/ Minerals and compounds sold or used by producers, including actual mine production, and marketable products.

3/ Source: Bureau of the Census.

4/ Includes orthoboric and anhydrous boric acid. Harmonized Tariffs Codes (HTS) 2840.19.0000, 2840.30.0000, and 2840.20.0000.

5/ Source: Journal of Commerce Port Import/Export Reporting Service.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE 1/

Mineral	Chemical composition	Boron oxide (B ₂ O ₃) weight percent
Boracite (stassfurite)	Mg ₆ B ₁₄ O ₂₆ C ₁₂	62.2
Colemanite	Ca ₂ B ₆ O ₁₁ •5H ₂ O	50.8
Datolite	CaBSiO ₄ (OH)	24.9
Hydroboracite	CaMgB ₆ O ₁₁ •6H ₂ O	50.5
Kernite (rasortie)	Na ₂ B ₄ O ₇ •4H ₂ O	51.0
Priceite (pandermite)	CaB ₁₀ O ₁₉ •7H ₂ O	49.8
Probertite (kramerite)	NaCaB ₃ O ₉ •5H ₂ O	49.6
Sassolite (natural boric acid)	H ₃ BO ₃	56.3
Szaibelyite (ascharite)	MgBO ₂ (OH)	41.4
Tincal (natural borax)	Na ₂ B ₄ O ₇ •10H ₂ O	36.5
Tincalconite (mohavite)	Na ₂ B ₄ O ₇ •5H ₂ O	47.8
Ulexite (boronatrocaltite)	NaCaB ₅ O ₉ •8H ₂ O	43.0

1/ Parentheses include common names.

TABLE 3
U.S. CONSUMPTION OF BORON MINERALS AND
COMPOUNDS, BY END USE 1/ 2/

(Metric tons of boron oxide content)

End use	1999
Agriculture	14,000
Borosilicate glasses	25,900
Enamels, frits, glazes	14,400
Fire retardants:	
Cellulosic insulation	13,700
Other	1,610
Insulation-grade glass fibers	193,000
Metallurgy	552
Miscellaneous uses	22,800
Nuclear applications	454
Soaps and detergents	23,200
Sold to distributors, end use unknown	35,400
Textile-grade glass fibers	71,100
Total	416,000

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4
YEAREND 1999 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON 1/

Product	Price, December 31, 1998 (rounded dollars)	Price, December 31, 1999 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works 2/	742	637
Borax, technical, anhydrous, 99%, bags, carload, works 2/	802	846
Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/	346	378
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works 2/	286	374
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works 2/	402	426
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works 2/	340	376
Boric acid, technical, granular, 99.9%, bags, carload, works 2/	801	834
Boric acid, technical, granular, 99.9%, bulk, carload, works 2/	743	788
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B ₂ O ₃ , 100-pound-bags, carlots	2,210	1,972
Colemanite, Turkish, 42% B ₂ O ₃ , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC 3/	295	290
Ulexite, Chilen, 38% B ₂ O ₃ , ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA e/	200	200

e/ Estimated.

1/ U.S. f.o.b. plant or port prices per metric ton of product. Other conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiation and/or somewhat different price quotations.

2/ Chemical Marketing Reporter, v. 257, no. 1, January 2000, p. 19.

3/ Industrial Minerals, no. 387, December 1999, p. 70.

TABLE 5
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY 1/

Country	1998			1999		
	Boric acid 2/		Sodium borates 3/ (metric tons)	Boric acid 2/		Sodium borates 3/ (metric tons)
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	4,730	\$2,250	4,810	3,550	\$1,700	7,010
Belgium	--	--	1	--	--	8
Brazil	4,310	1,850	2,270	3,540	1,470	1,210
Canada	4,530	3,010	36,000	4,610	3,040	42,900
Colombia	157	164	1,830	143	140	2,140
France	40	14	2	--	--	(4/)
Germany	41	65	39	360	216	15
Hong Kong	818	443	2,230	209	117	378
India	--	--	602	258	109	2,860
Indonesia	366	230	7,690	1,990	1,320	11,300
Israel	19	16	--	19	16	(4/)
Japan	12,000	9,650	26,000	11,900	10,100	23,300
Korea, Republic of	9,360	6,080	14,100	11,600	7,240	14,900
Malaysia	385	423	4,340	1,350	899	7,690
Mexico	4,270	2,780	24,400	3,580	2,290	20,400
Netherlands	41,200	15,900	240,000	34,100	13,200	149,000
New Zealand	424	214	2,440	376	191	2,200
Philippines	46	33	1,820	151	93	1,800
Singapore	81	62	871	165	114	732
South Africa	--	--	161	--	--	82
Spain	8,610	2,950	58,700	8,790	3,050	49,000
Taiwan	8,610	4,990	7,640	8,730	4,990	10,400
Thailand	1,340	876	5,330	1,730	1,110	6,800
United Kingdom	101	116	108	84	98	96
Venezuela	194	188	430	222	253	640
Other	4,160	2,330	11,500	9,540	4,990	15,000
Total	106,000	54,600	453,000	107,000	56,700	370,000

-- Zero.

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Harmonized Tariffs Code (HTS) 2810.00.0000.

3/ HTS 2840.19.0000, 2840.30.0000, and 2840.20.0000.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY 1/

Country	1998		1999	
	Quantity (metric tons)	Value 2/ (thousands)	Quantity (metric tons)	Value 2/ (thousands)
Argentina	37	\$50	112	\$46
Austria	16	33	--	--
Belgium	--	--	2	6
Bolivia	4,170	1,990	5,750	2,340
Canada	22	60	--	--
Chile	9,090	4,580	12,400	5,330
France	7	39	2	6
Georgia	34	69	53	35
Germany	16	35	123	103
Italy	877	1,110	1,770	1,680
Japan	130	185	26	50
Peru	751	446	1,680	771
Spain	25	25	380	222
Russia	336	323	--	323
Tokelau	58	35	--	35
Turkey	7,800	3,490	7,870	3,410
United Kingdom	8	28	3	12
Total	23,400	12,500	30,200	14,000

-- Zero.

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ U.S. Customs declared values.

Source: Bureau of the Census.

TABLE 7
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Thousand metric tons)

Country	1995	1996	1997	1998	1999 e/
Argentina	245	342	423 r/	350 r/	350
Bolivia (ulexite)	7	9	12	16 r/	10
Chile (ulexite)	211	149	171	280 r/	200
China 3/	295 r/	157 e/	136 e/	137 r/	110
Germany (borax) e/	2	2	1	1	1
Iran (borax) e/ 4/	1	1	1	1	1
Kazakhstan e/	30	30	30	30	30
Peru	41	39	40 e/	40 e/	40
Russia e/ 5/	1,000	1,000	1,000	1,000	1,000
Turkey 6/	1,144	1,447	1,569 r/	1,650 r/ e/	1,410
United States 7/	1,190	1,150	1,190	1,170	1,220 8/
Total	4,170 r/	4,330	4,570 r/	4,670 r/	4,370

e/ Estimated. r/ Revised.

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

2/ Table includes data available through May 19, 2000.

3/ Boron oxide (B₂O₃) equivalent.

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

5/ Blended Russian datolite ore that reportedly grades 8.6% B₂O₃.

6/ Concentrates from ore.

7/ Minerals and compounds sold or used by producers, including both actual mine production and marketable products.

8/ Reported figure.