

BORON

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Boron produced domestically during 2000 totaled 546,000 metric tons (t) of boron oxide valued at \$557 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 were produced by surface and underground mining, in situ, and from brine. U.S. consumption of minerals and compounds amounted to 360,000 t of boron oxide (table 3). Boron products are priced and sold based on the boron oxide content, which varies by ore and compound, and on the absence or presence of sodium and calcium (table 4). Boron exports totaled 532,000 t (table 5). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 6). The United States and Turkey were the world's largest producers of boron (table 7).

The glass industry, which remained the largest domestic market for boron production in 2000, accounted for 76% of boron consumption. Insulation-grade glass fibers accounted for an estimated 47% of domestic consumption; textile-grade glass fibers, 18%; boron sold to distributors, 9%; borosilicate glasses, 7%; soaps and detergents, 7%; enamels, frits, and glazes, 4%; and other uses, 8%.

Legislation and Government Programs

The U.S. Department of Energy (DOE) plans to store spent natural fuel encased in a boron-containing glass inside stainless

steel containers underground at Yucca Mountain, NV, beginning in 2009. As a result of the DOE's delay in building a facility to accept spent nuclear fuel, PECO Energy Co. and the DOE had an agreement to reimburse costs incurred as a result of the delay. The DOE was required by law to begin accepting spent fuel by January 31, 1998 (Chemical & Engineering News, 2000a).

The U.S. Department of Justice, acting on behalf of the DOE, appealed to the district court in Las Vegas, NV, to overturn the Nevada State engineer's decision to deny water permits requested for the DOE's Yucca Mountain high-level nuclear waste project. In February, the Nevada State engineer denied the DOE's application to appropriate 530,000 cubic meters per year of water for use by the Yucca Mountain project beginning in 2002. These five permit applications for water rights were submitted by DOE in 1997 to perform activities mandated by the Nuclear Waste Policy Act (Mining Engineering, 2000a).

In 1990, the desert tortoise was listed by the Fish and Wildlife Service, U.S. Department of the Interior, as threatened. The tortoise is a major environmental issue in the Sonoran Desert, which extends from Utah to Mexico. The tortoise's habitat also includes boron areas being surface-mined and solution-mined. Since 1993, U.S. Borax Inc. has purchased and transferred more than 4,047 hectares (10,000 acres) of tortoise habitat to the Federal and State Governments at a cost of more than \$5

Boron in the 20th Century

Production of borates began in California in 1864 in Lake County and in Death Valley and Armagosa Valley in 1882. In 1901, production was reported in California, Nevada, and Oregon as 16,227 metric tons of borax valued at \$314,811 and 4,848 tons of refined borax valued at \$697,307 for a total value of \$1 million. Historical uses have included detergents, fire retardants, fluxes in glass and metals, and food preservatives. The major producing company was a California company, Pacific Coast Borax Company, which was consolidated under Borax Consolidated Ltd. (London) in 1903. In 1907, colemanite was mined in Inyo, Los Angeles, and Ventura Counties, CA. In 1914, the California borax company was liquidated, and a new Pacific Coast Borax Company was formed under Nevada law. Production from brine at Seales Lake, CA, began in 1919. Total production in 1920 was reported to be 109,153 tons valued at \$2.2 million.

In 1927, large scale production of sodium borates began by Pacific Coast Borax from underground mines in Boron, CA. U.S. production in 1930 was 177,360 tons valued at \$5.4 million. In 1956, the U.S. assets of Borax Consolidated were transferred to Pacific Coast Borax. In 1957, the existing three

underground mines became one large surface mine. By 1960, U.S. production was reported to be 581,053 tons valued at \$47.6 million, all from California.

In 1968, London-based RTZ Corp., the world's largest mining company and owner of Borax Consolidated and Pacific Coast Borax, merged with U.S. Borax. By 1970, U.S. production in California was 907,185 tons valued at \$86.8 million from brines and underground and surface mines. American Borate Co., a wholly owned subsidiary of Owens-Corning, purchased the holding of Tenneco, Inc., in 1976, and development of the Billie Mine was completed in California in 1981. American Borate Co. was sold to a private firm in 1992. Mountain States Mineral Enterprises Inc. began an in situ pilot project near Newberry Spring, CA, which was sold to Fort Cady Minerals Corp., and production started at Fort Cady in 1995. Production at Searles Lake began in 1919 and continued into 2000.

In 2000, total borate production from four producers in California was reported to be 1.1 million metric tons valued at \$557 million. Uses included glass (76%), sales to distributors (9%), soaps (7%), and other (8%).

million. The company also created an endowment of nearly \$240,000 for the California Department of Fish and Game to maintain and enhance the tortoise habitat (Rio Tinto Borax, 2001). During the past 10 years, as many as four tortoises each year are killed at Fort Irwin, CA, at the Army training center's grounds (Washington Times, 2000).

The Federal Railroad Administration of the U.S. Department of Transportation solicited proposals for the construction of a magnetic levitation (maglev) train to be built with funds approved by the Transportation Equity Act for the 21st Century. Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guide way. Boron is used in the superconducting and other high-intensity magnets in this system. By using state-of-the-art electric power and control systems, maglev would reduce the need for many mechanical parts, thereby minimizing resistance and permitting excellent acceleration and cruising speeds of about 386 kilometers per hour (240 miles per hour) or more. Since passage of the High-Speed Ground Transportation Act of 1965, a number of maglev system concepts had undergone research and development in the United States. The Federal Government had appropriated \$1 billion to explore and construct a maglev segment of rail in various locations in the United States. The Federal Government declared the Pittsburgh and the Baltimore-Washington areas the finalists in a nationwide competition to build what could be the first commercial high-speed magnetic levitation train in the world (Federal Railroad Administration, January 18, 2001, U.S. Secretary of Transportation Slater selects two high speed maglev projects, accessed June 14, 2001, at URL <http://www.fra.dot.gov/o/hsgt/hot.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: the sodium borates borax and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite. These minerals were extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru.

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. Reported employment was 110 employees (Business.com, [undated], American Borate Co., accessed June 12, 2001, via URL <http://www.business.com>).

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 the consistency of its chemical composition, namely, 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 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 2000, IMC Global Inc. announced the opening of new corporate headquarters in Lake Forest, IL. IMC Chemicals, headquartered in Overland Park, KS, operated 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 circulated 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. IMC Global continued to divest a controlling share of IMC Chemicals, and another group of investors were considering purchasing the Searles Valley facilities at yearend.

U.S. Borax Inc., which was a member of Rio Tinto Borax Group, mined borate ores at Boron, CA, by open pit methods and transported the ores to the surface via a conveyor. At Boron, reserves containing the minerals kernite and tincal were reportedly in excess of 100 million metric tons (Mt) (Baele, 2000). Production was reported to be 570,000 t during 2000 compared with 543,000 t in 1999 (Rio Tinto, 2000). The stripping ratio was more than 36:1, and the quality of stripped overburden was projected to reach 100 Mt in 2000. During 2000, it was necessary to remove a layer of overburden between 107 m and 198 m thick to access the ore. As the mine advanced to the east and southeast, that overburden layer was projected to gradually increase to 366 m in thickness. A 32 t landslide on the north slope of the pit in 1999 was the initiative for construction of less steep benches, starting at the top of the existing 17 benches. The 91-m thick ore contains four zones. The upper layer is borax, overlaying three layers of borax and kernite (Garrett, 2000). Ore was processed into sodium borate or boric acid products in the refinery complex adjacent to the mine. An onsite 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, CA, facility at the port of Los Angeles for international distribution. California employees include 1,100 people working at the principal mine and refinery in Boron, a refinery and shipping terminal in Wilmington, the global headquarters in Valencia, and a trona mine at Owens Lake that supplies raw material to the Boron refinery (Rio Tinto Borax, 2001).

Cogeneration plants, which are part of the boron-processing facilities at Boron, produced 100 megawatts (MW) of electricity, 85 MW of which were sold to Southern California Edison. One-third of the electricity used at the site goes to operate pollution control equipment (Rio Tinto Borax, 2001). Another cost saving practice was a daily tire pressure check, which would increase tire life by 40%. An environmentally sound practice blended engine oil with diesel fuel to dispose oil and increase engine life by 20% (Garrett, 2000).

A new \$10 million plant at Boron was projected to be able to process more than 1,400 metric tons per day of dry pond material containing 300,000 metric tons per year (t/yr) of high

quality feed (25% boron oxide) for the sodium borate process. Before 1985, thickened clays and muds were sent to storage ponds along with plant liquid effluents containing low levels of borax. The clays contain low levels of pyrrhotite, a paramagnetic iron sulfide mineral, that is attracted to powerful rare-earth magnets (Mining Engineering, 2000b).

On May 1, 1999, U.S. Borax purchased the assets of Lake Minerals Corp., a trona mining operation on Owens Lake near Lone Pine in the central California mountains. Designated as U.S. Borax Inc., Owens Lake Operations, the facility would 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. Owens Lake was the third largest trona deposit in the United States.

The 116-year-old Borax 20-mule team wagons were used in the 110th Tournament of Roses in Pasadena, CA, in 1999, and were placed on permanent display at the Borax visitors center on the edge of the Boron Mine. The visitors center had been open 7 days a week since October 1997, marking the company's 125 anniversary of doing business in California. It was set up as an educational center for modern mining and the impact on minerals on daily life (U.S. Borax Inc., December 21, 1998, Twenty-mule team takes its final ride, accessed October 17, 2000, at URL http://www.borax.com/nonflashsite/company/news_20mule.html). The founder of the 20-mule team, Francis Marion "Borax" Smith, was buried in Mountain View Cemetery, Oakland, CA, in "Millionaire's Row" (Find a Grave, [undated], Frances Marion Smith "Borax", accessed April 7, 2000, at URL <http://www.findagrave.com/pictures/3258.html>).

The 849 employees at the Boron Mine processed about 3 million metric tons per year (Mt/yr) of ore (Rio Tinto Borax, 2001). Two new safety programs were instituted. A safety management audit training program trained employees to observe work practices and encouraged feedback. It transitioned from top-down model enforcement to bottom-up participation. A second program installed video cameras on the trucks to eliminate drivers' blind spots. The primary goal was to improve safety (Craig, 2000).

The Gerstley Borate Mine near Boron, CA, was closed because of the cost of meeting regulatory requirements, including fireproofing and replacing support timber. The run-of-mine ore was used in glazes as a secondary flux at midrange temperatures and a primary glaze at low temperature firing. The ore was popular in middle temperature glazes because its high melt fluidity produced a textured and variegated visual effect. The Gerstley ore was an aggregate of colemanite, ulexite, and hectorite. It also contained some limestone. Gerstley was named after a former president of the company (Gerstleyborate.com, [undated], What was Gerstley borate?, accessed May 24, 2001, at URL <http://digitalfire.com/gerstleyborate/description.shtml>).

Consumption

Total annual world consumption of borates was as follows: insulation, fiberglass, textile fiberglass, and heat-resistant glass (41%); ceramic and enamel frits and glazes (13%); detergents, soaps, and personal car products (12%); and agricultural micronutrients (6%).

Borate applications for glass consumption included the following five categories: borosilicate glass, ceramic frits and glazes, glass fiber insulation, porcelain enamels for steel and aluminum, and textile glass fiber. These five categories of glass have significantly different thermal, chemical, and mechanical properties, although their compositions contain chemicals drawn from the same list of about 10 oxides. Boron oxide allows the formulated glass to have high chemical durability, low thermal expansion, and low electrical conductivity. By using a computer simulation model, it is possible to predict glass properties from the oxide composition. Using models can lessen laboratory research time spent in product development by calculating new glass compositions that have the desired properties (Cook, 2000).

Glass fiber thermal insulation, primarily used in new construction, was a large area of demand for borates and was the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, fiberglass traps and holds 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 were 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-micrometer (μm) to 20- μm diameter filaments. Calcium aluminoborosilicate, e-glass, or textile fiberglass typically contains between 6% and 10% boron oxide.

The minerals colemanite and ulexite were used mainly for the production of ceramic frit on glazed tile, fiberglass, and glass wool. 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 were usually 75% to 85% pure and contained gangue in the associated minerals calcite, clays, and gypsum, and minerals that contain the elements aluminum, arsenic, iron, magnesium, silicon, strontium, and sulfur. Contained water in boron minerals can cause higher energy usage, increase stack emissions, decrease glass quality, and lower production rates. The water in calcium borate minerals is expelled at around 400° C accompanied by vigorous decrepitation of the ore, which can contribute to dust, causing greater refractory corrosion rates and increased particle emissions (Carr, 2000).

Slag is the waste steelmaking produces when unwanted impurities, such as silica, phosphorus, and manganese, are removed from the iron ore. A specialized borate was added to slag to allow the slag to cool slowly and prevent dust and mud. The fist-sized slag rocks formed were suitable for construction material (Borax Pioneer, 2000b).

Triphenylboron (TPB) and triisopropyl borate (TIPB) have been used by E.I. du Pont de Nemours and Co. (DuPont) to make nylon 6,6. For this process, adiponitrile is converted into hexamethylenediamine (HMD). HMD and adipic acid are the building blocks of nylon 6,6. The boron chemicals promote higher yields, but unlike catalysts, they are not reused, nor are they incorporated in the final product. Instead, they are hydrolyzed into boric acid before leaving the plant. The chemicals can be used as an agrochemical, catalyst, flame retardant, and fuel additive. DuPont would also be willing to

sell the boron chemicals for use in nylon intermediates manufacturing in an arrangement under which DuPont would license the adiponitrile technology and supply TPB and TIPB (Tullo, 2001b).

Boric acid was used in wallboard, also known as drywall or gypsum board or plasterboard, to increase the production line speeds, to save raw material, to reduce energy and shipping costs, and to improve the overall board quality. No new wallboard plant had been constructed in North America in the past 10 years. With the rise in residential and commercial building in North America, there was increased demand for wallboard.

Boron is 1 of 16 nutrients essential to all plants. Boron is essential to plant growth and can be applied as a spray and incorporated in fertilizer, herbicides, and irrigation water. Boron applied in May and June can be combined with calcium. For early season apples, boron can be applied post-harvest to provide adequate nutrition as buds begin to develop. During 2000, 18,628 t of boron micronutrients were applied on crops compared with 20,398 t in 1999. The largest region of use was in the west north-central, which used 8,297 t (Terry and Kirby, 2001).

In solution, borates form negative ions that can link with certain organic substances containing alcohol groups. This is an important role of boron in regulating metabolism. Too much borate concentration will turn the regulation into inhibition and stop cells from growing. Stopping cell growth rather than killing the cell makes borate a biostat rather than a biocide. It explains how and why borate compounds can be used to control so many different pests and why acquired resistance to borates is unlikely. The mild biostatic effect also makes borates not harmful to humans. Natural borate compounds have been shown to work against and to control algae, bacteria, fungi, and many insects like ants, beetles, cockroaches, fleas, flies, moths, termites, and wasps. Examples of widespread commercial use of the bacteriostatic properties of borates include additives in air conditioning systems, caviar, cooling fluids, cooling water, cosmetics, eye drops, in-can preservatives for paints, and metal lubrication (Lloyd, 2000).

Advanced Ceramics Corp. opened a \$30 million world headquarters in Strongsville, OH, on February 29. The transfer of equipment and people was scheduled to be completed by the end of 2003. The company produced boron nitride and other nonoxide advanced ceramic powders, hot-pressed shapes, and chemical vapor deposition shapes and coatings (Advanced Materials & Processes, 2000).

U.S. Borax teamed with Osmose Inc., which was the leading chemical supplier to the wood preservation industry, and L-P Corp., which was the world's largest producer of oriented strand board. Osmose would provide borate-treated lumber through its many licenses, and L-P Corp. would incorporate borates into some structural panel products. U.S. Borax would supply Timbor® Industrial (disodium octaborate tetrahydrate) for lumber and plywood, and Composibor® (zinc borate) for engineered wood products (Bhatia, 2001).

Transportation

In 2000, U.S. Borax products from the mine were transported primarily by rail, although trucks were also used. The company ranked as the primary 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 had the only remaining privately owned berth in the harbor. It ranked as the largest exporter of high-value dry bulk products and among the top 10 shippers of ocean containers out of the ports of Los Angeles and Long Beach, CA. About 10 ships per year, with a capacity of 40,000 deadweight tons each, were loaded for locations around the world.

Antwerp, Belgium, which had 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 through the industrialized areas of Belgium, France, Germany, and the Netherlands for destinations in Central Europe, such as Austria, the Czech Republic, and 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 Rotterdam in the Netherlands to customers in Belgium, Eastern Europe, France, Germany, and countries even farther away. For small consignments, 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 could be reached by barge on waterways linking 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.

The Trona Railway connects to the Southern Pacific Railroad between Trona and Searles Stations.

Prices

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

World Review

Argentina.—Borax Argentina S.A., which was a subsidiary of Rio Tinto plc., was the country's leading producer of borates (table 6). Borax Argentina mined borates at three deposits in Salta and Jujuy Provinces. Tincalayu Mine, originally developed in 1976, was Argentina's largest open pit operation and measured 1.5 km long, 800 m wide, and 100 m deep. The clay overburden averages 50 m and typically overlies 30 to 40 m of ore. 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 Quijano plant was ISO 9002 certified. Consumption of boron products was in agriculture, glass, fiberglass, frits, and other applications (Baele, 2000).

The newest producer was Procesadora de Boratos Argéninos S.A., owned by Ferro Corp. and Canadian JEM Resources & Engineering, Inc. The project was purchased in 1999 from S.R. Minerals Ltd., which was an affiliate of Smokey River Coal Ltd., a Canadian coal producer. Tincal and ulexite mined at Loma Blanca were processed with magnetic separation and then calcining at Palpalá. A range of calcined and noncalcined products were produced containing 35% to 60% boron oxide.

Production was about 3,000 metric tons per month (O'Driscoll, 2001).

Norquímica S.A. 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, where it is reacted with sulfuric acid.

Asia.—Albemarle was planning to offer zinc borate flame- and smoke-suppressing products in Asia under a commercial agreement with Borax Polymer Additive Group. The new zinc borate products broaden the company's range of halogen and halogen-free flame retardant systems. Albemarle's flame retardants fall under the umbrella of its polymer chemicals division, which generates about \$450 million per year in sales (Chemical Market Reporter, 2000).

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. Reserves were in the order of 5.5 Mt of boron oxide. In addition to ulexite, Tierra produced boric acid and in 1999 exported 12,500 t worldwide. The operation employed 250 in Bolivia and 45 in Chile.

On August 28, Bolivian (FELCN), Chilean (OS7), and U.S. (DEA) antidrug authorities descended on Tierra and its Chilean sulfuric acid supplier, Alco Ltda. Thirteen executive staff and employees were arrested. In December, the Bolivian executives were released, but the seven Chilean employees were detained. The charge was based on 7,000 to 15,000 t of sulfuric acid allegedly being deviated from the production of boric acid to the illegal cocaine processing plants in the Chapare district of Bolivia. The volume of sulfuric acid in question represented about 35% of Tierra's consumption in the production of boric acid. Judgement on the case in Bolivia was expected to begin in March 2001 (O'Driscoll, 2001).

The case, the first of its kind, highlighted potential problems that could arise with industrial minerals companies that need to consume or process predetermined "precursors," such as soda ash or sulfuric acid. These commodities were recognized by antidrug agencies as being the same level as "controlled substances" in narcotics culture (O'Driscoll, 2001).

The Pampa borax deposit, which was owned by Champagne Miner Rio Grande S.A., had 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 was located in Nor Lapis Province, south of the Salar de Uyuni.

Chile.—Borax Argentina, S.A., had 198 employees working at the Tincalayu, the Sijes, and the Porvenir Mines and the Campo Quijano refinery. The mine at Tincalayu, Salta, is Argentina's largest open pit mine, measuring 1,500 m wide, 500 m long, and 100 m deep. The main minerals mined are tincal, ulexite, colemanite, hydroboracite, and kernite. The mine operates at a rate of 100,000 t/yr. Energy is supplied by two generation plants, which produce 146,000 kilowatts per month (Rio Tinto Borax, 2001).

Química e Industrial del Borax Ltda. (Quiborax) mined ulexite from Salar de Surire, which was the largest ulexite deposit in the world. Reserves were estimated to be 1,500 t. The deposit was located at an altitude of 4,250 m in Monumento

Natural de Surire, a national park. Production in 2000 was 380,000 t of crude ulexite. The ore was trucked to the 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 36,000 t of 98% to 99.9% boric acid. The majority of production was exported through the port of Arica.

Quiborax's other plants included a new granulated ulexite plant, which produced agricultural ulexite ranging between 10% to 13% boron oxide, and another special ulexite plant, which produced different types of boron ranging product between 30% to 45% boron oxide for specific market requirements (O'Driscoll, 2001).

Champagne Minera Salar de Atacama was 100% owned by Sociedad Química y Minera de Chile S.A. (SQM). A large integrated facility was scheduled to begin production of 16,000 t/yr of boric acid as a byproduct of potassium sulfate production. SQM was reported to be purchasing boric acid for resale until the plant could begin boric acid production. SQM also produced ulexite from reserves in excess of 7 Mt boron oxide content at Salar de Ascotán and Salar de Carcote (O'Driscoll, 2001).

China.—Over 80% of the country's borates resources were in Liaoning and Jilin Provinces. The ores were primarily metamorphic deposits containing primarily ascharite, a magnesium borate. Other production was from playa lakes in Qinghai, where borate minerals, such as ulexite, hydroboracite, and borax, were produced from brines near the Qinghai-Tibet plateau (O'Driscoll, 2001).

China announced Shanghai's plans to be the world's first city to build a commercial maglev train (Denver Post Newspaper in Education, 2001, Magnetic levitation train, accessed March 22, 2000, at URL <http://www.colokids.com/indexd4.htm>).

India.—Submarginal borax reserves occur in the Puga Valley Districts of Jammu and Kashmir. In Rajasthan State, the bitterns from Lake Sambhar were reported to contain about 0.5% borax.

Italy.—Rio Tinto Borax appointed Milan-based Novaria Chemicals as its exclusive distributor of its Firebrake range of fire retardant polymer additives in the Italian market. Novaria provided expertise in the storage, handling, and distribution of plastic additives (Chemical Market Reporter, 2001).

Kazakhstan.—More than 100 boron deposits have been discovered in northern Prekaspiy. Boron deposits of the Inder groups were 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 water level. Borate ore reserves were reportedly estimated to be 2 Mt, but the undiscovered resources could reach 120 Mt of 9% boron oxide.

Peru.—Inkabor S.A., 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.

Russia.—In August, 1999, Russia's sole borates producer, JSC Bor, was reorganized and renamed JSC Energomash-Bor in response to a move by Russian power equipment supplier JSC Energomash to become more involved in the borates business. In mid-2000, Energomash-Bor was preparing its second boric acid production line for commissioning, following a 9 month closure. The company also tested a nitrate method of processing datolite ore, which may permit a savings in power consumption. The refurbished plant was expected to double boric acid production and increase output of other boron products to between 100,000 to 140,000 t/yr (O'Driscoll, 2001).

Serbia and Montenegro.—Ras-Borati Ltd. began drilling the Piskanja boron deposit in the Jarandol Basin located near Baljevac in southern Serbia. Ras-Borati, which was established in February 1997, was a 50-50 joint venture between Erin Ventures Inc. of Kelowna, Canada, and Electroprivreda, 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 were 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 of ore reportedly averaged 37% boron oxide.

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

Turkey.—Turkey's boron operations were under the control of Eti Holding AS, formerly Etibank, through its subsidiary Eti Boron Inc. Co. Boron production was managed by five operations, four of which were integrated mine and plant facilities and one, at Bandirman port, was a plant facility. Additional capacity was planned for startup in 2002 with a 160,000-t/yr plant for borax pentahydrate at Kirka and in 2003 with a 100,000-t/yr boric acid facility at Emet (O'Driscoll, 2001).

United Kingdom.—Rio Tinto Borax, a wholly owned subsidiary of Rio Tinto, was dedicated to the mining, refining, and marketing of borates. Borax produced more than 1 Mt/yr of product from ore bodies in the United States and Argentina, employing 1,700 people worldwide. As a miner and refiner, Borax managed the environmental, social, and economic impact of its operations, applying the same standards at each location. These activities were classified under the headings of safety and stewardship. Borax believed its contribution to sustainable development to be that its operations have low environmental impact and make a positive social contribution, that its borate products enhance standards of living and contribute to economic development, and that borates measure up favorably in terms to most substitute products. To aid the mining industry in achieving sustainable development, the Industrial Minerals Association was formed as an industry association. In addition, a number of the world's largest mining companies established the Global Mining Initiative as a case for mining as a positive factor towards sustainable development. This was projected to lead to a major conference on mining and sustainable development in 2001 (Edbrooke, 2000; Mining Minerals Sustainable Development Project, [undated], Stainable development raises as many questions as it answers, accessed June 12, 2001, at URL <http://www.globalmining.com/index.asp>).

Borax Europe Ltd., a subsidiary of Rio Tinto Borax, was involved in a court case against one of its former employees over an alleged breach of confidentiality. The case involved a graph that was placed on the private website of the former employee. The company claimed that the graph disclosed information that was confidential to the company. At the August hearing, the employee voluntarily agreed not to disclose any confidential information and to return the material used to Borax (Industrial Minerals, 2001).

Uzbekistan.—An oil and gas condensate deposit at Dzhartchi had 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

Millennium Cell plc of Eatontown, NJ, is developing a chemical storage technology based on sodium borohydride. A clear aqueous solution of about 30% sodium borohydride is exposed to a proprietary catalyst to yield hydrogen and sodium borate byproducts, resulting in a milky solution of spent fuel. Millennium is forming a joint development with Rohm and Haas Co., a major sodium borohydride supplier, to come up with a better process by closing the loop in the stream and recycling the sodium borate back to sodium borohydride. Millennium stated its storage density rivals liquid hydrogen at about 63 grams per liter (Tullo, 2001a).

A graduate student in chemical engineering at several universities has designed copolymers that can be applied to cells or tissues to prevent adhesion of antibodies or to block the body's response to its own tissues during wound healing. These copolymers could be used to coat organs prior to transplantation to prevent rejection. The backbone of these copolymers is a poly (l-lysine), and grafted onto the backbone are phenylboronic acid and poly ethylene glycol (Rouhi, 2000).

Sodium perborate bleaches stains extremely well at above 60° C temperatures as hydrogen peroxide releases oxygen into the wash. At temperatures of about 40° C, such activators as tetraacetythylenediamine and nanayoyloxybenzenesulfonate can be used to release peracids that are effective oxygen sources. A new catalyst can release oxygen below 40° C that works like a biological enzyme, while suppressing any unwanted chemical reactions (Borax Pioneer, 2000a).

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 epoxy, plyamide, and polyvinylchloride compounds, but there are potential opportunities in engineering plastics, styrenics, and other resins (Industrial Minerals, 2000).

Boron-bearing antioxidants used in refractory bricks increase 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 with zirconium boride additives (Hunold, 2000).

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 amine content. The collector precipitation

was attributed to the formation of amine hydroborate. Studies indicate that the precipitate is dodecylamine and may enhance the floatability of colemanite (Akin and others, 2000).

A new family of weakly coordinating anions could greatly improve the activity of metalloen catalysts used in industrial olefin polymerizations according to researchers at Dow Chemical Co. Aluminum or boron is used in the anions (Chemical & Engineering News, 2000d).

Scientists at Osaka University, Japan, have developed a new catalytic reaction that adds multiple alkyl groups to aromatic rings using a norbornyl group on the phenyl ring. The process repeats itself, proceeding around the ring until steric factors interfere. The reaction of phenylboronic acid and 2-norborene in the presence of a rhodium catalyst yield primarily the tetranorbornylbenzene ring. The method provides a method for the synthesis of a unique class of sterically encumbered aromatic molecules (Chemical & Engineering News, 2000c).

Chemists at Emory University, Atlanta, GA, discovered a palladium-catalyzed coupling of thiol esters with boronic acids to produce ketones under mild conditions. Because the reaction proceeds even at a pH of 4.5, the conditions are very mild and will tolerate functional groups that would not survive standard cross-coupling systems. The reaction is mechanistically distinct from other processes where a base is normally used. The coupling of boronic acids to thiol esters expands boronic acid coupling into completely new fields (Zurer, 2000).

Chemists at the University of California, Irvine, CA, copolymerized two olefin monomers into an ethylene-polyene copolymer. Dimethylsulfonium methylide can be polymerized by triethylborane to make linear polymethylene, more commonly known as polyethylene. The research opens the door to designer polymers not obtainable through conventional polymerization of olefin monomers (Chemical & Engineering News, 2000e).

A new superacid powerful enough to protonate C_{60} to give HC_{60}^+ as a stable ion in both solution and solid state was developed by the University of California, Riverside, CA. The superacid is based on the hexahalocarborane anion $[H(CB_{10}H_6X_6)]$, where $X = Cl$ or Br . The new superacid and oxidant may allow the investigation of processes and reactive species previously difficult or impossible to study (Chemical & Engineering News, 2000b).

Physicists at Aoyama-Gakuin University, Japan, announced that magnesium diboride became superconductive when cooled to or below 39 K. This range of superconductivity is 16 K higher than any other simple metallic compound. The possibility is that magnesium-diboride-based material may be able to carry more current than the copper oxide superconductors. Furthermore, magnesium diboride may not need to be cooled with liquid helium as conventional superconductors are, but rather by electrical refrigeration (Dagani, 2001).

The world's fine chemicals industry displayed its wares and expertise in Milan, Italy, for the Conference on Pharmaceutical Ingredients. Companies introduced new intermediates in their catalogs and unveiled new technologies for producing chemicals to special order. Digital Specialty Chemicals, Dublin, NH, offered oxazaphospholidines that were made by reaction of phenylphosphine-borane with either ephedrine or pseudoephedrine, which are opposites and thus may induce opposite configurations in products (Stinson, 2000).

A senior scientist at Haldor Topsoe Research Laboratories, Lyngby, Denmark, prepared a barium-promoted boron nitride catalyst to synthesize ammonia. The catalyst was prepared from boron nitride crystals and aqueous solutions of ruthenium nitroso nitrate and barium hydroxide (Chemical & Engineering News, 2001).

Boriding, the diffusion of boron into the surface of metals, increases the wear and corrosion resistance of the metals. Boron is an element of relatively small atomic radius, which allows it to diffuse into a variety of metals, such as ferrous metals, metal-bonded carbides, and nickel alloys. Boron reacts with ferrous alloys to form Fe_2B with Knoop hardness in the range of 1,500 to 1,700. The significant increase in case hardness results in substantial reduction of wear and galling (Cataldo and others, 2000).

Laser surface engineering (LSE) is a surface modification process in which a high power laser beam melts a ceramic powder precursor along with a thin layer of substrate to produce a laser melt zone. LSE of titanium diboride coating is a two stage process. In stage 1, a precursor layer of titanium diboride in a water-based organic solvent is deposited on an AISI 1010 steel substrate. In stage 2, an industrial grade laser melts a thin layer of the steel substrate. The titanium diboride powder becomes embedded in the molten steel creating a composite coating. The most significant properties of the coating are its corrosion resistance, modulus of elasticity, hardness, oxidation resistance, smoothness, strong interface, and wear resistance (Agarwal and Dahotre, 2000).

Room-temperature ionic liquids, formerly called molten salts, typically consisting of nitrogen-containing organic cations and inorganic anions are potential "green" [environmentally friendly] designer solvents because they have no detectable vapor pressure and can make synthetic processes more efficient, resulting in a lower usage of raw materials. The organic cations are mated with inorganic anions, such as boron tetrafluoride. Ionic liquids are inherently ionically conductive, can mitigate self-discharge, and are virtually nonvolatile, nonflammable, and less toxic than conventional electrolytes. The electrochemical potential is usually much greater than for aqueous electrolytes. There is substantial interest in using ionic liquids as battery electrolytes. Researchers at the U.S. Air Force Academy are studying a dual intercalating molten electrolyte (DIME) battery. Research has shown that boron tetrafluoride works in the DIME battery (Freemantle, 2000).

Outlook

The demand for boron in the United States is expected to remain strong. New applications in gypsum board and strong demand in the glass industry are expected to increase consumption. Boron compounds and chemicals can reduce energy use in the creation process of 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. The world production amounts for Turkey in table 7 do not accurately reflect production because some ore that was 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.

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TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS 1/

(Thousand metric tons and thousand dollars)

| | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|-------------|-------------|-----------|-----------|-----------|
| United States: | | | | | |
| Sold or used by producers: | | | | | |
| Quantity: | | | | | |
| Gross weight 2/ | 1,150 | 1,190 | 1,170 | 1,220 | 1,070 |
| Boron oxide (B ₂ O ₃) content | 581 | 604 | 587 | 618 | 546 |
| Value | \$519,000 | \$580,000 | \$486,000 | \$630,000 | \$557,000 |
| Exports: 3/ | | | | | |
| Boric acid: 4/ | | | | | |
| Quantity | 42 | 92 | 106 | 107 | 119 |
| Value | \$35,300 | \$60,500 | \$54,600 | \$56,700 | \$64,400 |
| Sodium borates: | | | | | |
| Quantity | 381 | 473 | 453 | 370 | 413 |
| Value | \$133,000 | \$169,000 | \$146,000 | \$180,000 | \$136,000 |
| Imports for consumption: | | | | | |
| Borax: | | | | | |
| Quantity | 11 5/ | 54 5/ | 14 3/ | 8 3/ | 1 3/ |
| Value | \$3,470 | \$17,000 | \$5,160 | \$2,840 | \$716 |
| Boric acid: | | | | | |
| Quantity | 25 5/ | 26 5/ | 23 3/ | 30 3/ | 39 3/ |
| Value | \$10,800 e/ | \$11,800 e/ | \$12,500 | \$14,000 | \$17,500 |
| Colemanite: | | | | | |
| Quantity | 44 5/ | 44 5/ | 47 5/ | 42 5/ | 26 5/ |
| Value | \$13,000 e/ | \$13,000 e/ | \$13,900 | \$13,100 | \$7,410 |
| Ulexite: | | | | | |
| Quantity | 136 5/ | 157 5/ | 170 5/ | 178 5/ | 127 5/ |
| Value | \$27,200 | \$31,400 | \$34,000 | \$35,700 | \$31,800 |
| Consumption, boron oxide (B ₂ O ₃) content | 367 | 403 | NA | 416 | 360 |
| World production | 4,330 | 4,570 | 4,660 r/ | 4,380 r/ | 4,220 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: U.S. Census Bureau.

4/ Includes orthoboric and anhydrous boric acid. Harmonized Tariff Schedule (HTS) codes 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 •20H | 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 (boronatocalcite) | 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 | 2000 |
|---------------------------------------|---------|
| Agriculture | 13,900 |
| Borosilicate glasses | 24,400 |
| Enamels, frits, glazes | 13,800 |
| Fire retardants: | |
| Cellulosic insulation | 10,900 |
| Other | 1,980 |
| Insulation-grade glass fibers | 170,000 |
| Metallurgy | 488 |
| Miscellaneous uses | 5,430 |
| Nuclear applications | 454 |
| Soaps and detergents | 23,600 |
| Sold to distributors, end use unknown | 30,900 |
| Textile-grade glass fibers | 64,500 |
| Total | 360,000 |

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, 1999 (rounded dollars) | Price, December 31, 2000 (rounded dollars) |
|--|--|--|
| Borax, technical, anhydrous, 99%, bulk, carload, works 2/ | 637 | 637 |
| Borax, technical, anhydrous, 99%, bags, carload, works 2/ | 846 | 846 |
| Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/ | 378 | 378 |
| Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works 2/ | 374 | 374 |
| Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works 2/ | 426 | 426 |
| Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works 2/ | 376 | 376 |
| Boric acid, technical, granular, 99.9%, bags, carload, works 2/ | 834 | 834 |
| Boric acid, technical, granular, 99.9%, bulk, carload, works 2/ | 788 | 788 |
| Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B ₂ O ₃ , 100-pound-bags, carlots | 1,972 | 1,996 |
| Colemanite, Turkish, 42% B ₂ O ₃ , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC 3/ | 290 | 270-290 |
| Ulexite, Chilean, 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. free on board (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. 259, no. 1, January 2001, p. 18.

3/ Industrial Minerals, no. 399, December 2000, p. 70.

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

| Country | 1999 | | | 2000 | | |
|-----------|---------------------------|----------------------|----------------------|---------------------------|----------------------|----------------------|
| | Boric acid 2/ | | Sodium borates 3/ | Boric acid 2/ | | Sodium borates 3/ |
| | Quantity (metric tons) | Value (thousands) | | Quantity (metric tons) | Value (thousands) | |
| Australia | 3,550 | \$1,700 | 7,010 | 2,290 | \$1,090 | 5,600 |
| Belgium | -- | -- | 8 | -- | -- | (4/) |
| Brazil | 3,540 | 1,470 | 1,210 | 5,140 | 1,930 | 1,070 |
| Canada | 4,610 | 3,040 | 42,900 | 4,410 | 2,930 | 42,100 |
| Colombia | 143 | 140 | 2,140 | 195 | 184 | 2,940 |
| France | -- | -- | (4/) | -- | -- | 1 |
| Germany | 360 | 216 | 15 | 1,020 | 731 | 3 |

See footnotes at end of table.

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

| Country | 1999 | | | 2000 | | |
|--------------------|------------------------|-------------------|-------------------|------------------------|-------------------|-------------------|
| | Boric acid 2/ | | Sodium borates 3/ | Boric acid 2/ | | Sodium borates 3/ |
| | Quantity (metric tons) | Value (thousands) | | Quantity (metric tons) | Value (thousands) | |
| Hong Kong | 209 | \$117 | 378 | 121 | \$66 | 181 |
| India | 258 | 109 | 2,860 | 19 | 13 | 337 |
| Indonesia | 1,990 | 1,320 | 11,300 | 577 | 315 | 5,190 |
| Israel | 19 | 16 | (4/) | 5 | 4 | (4/) |
| Japan | 11,900 | 10,100 | 23,300 | 15,600 | 11,800 | 26,400 |
| Korea, Republic of | 11,600 | 7,240 | 14,900 | 9,810 | 5,740 | 17,900 |
| Malaysia | 1,350 | 899 | 7,690 | 2,210 | 1,290 | 7,730 |
| Mexico | 3,580 | 2,290 | 20,400 | 3,670 | 2,300 | 28,000 |
| Netherlands | 34,100 | 13,200 | 149,000 | 36,800 | 19,100 | 194,000 |
| New Zealand | 376 | 191 | 2,200 | 342 | 151 | 2,300 |
| Philippines | 151 | 93 | 1,800 | 19 | 15 | 2,010 |
| Singapore | 165 | 114 | 732 | 506 | 289 | 559 |
| South Africa | -- | -- | 82 | -- | -- | 39 |
| Spain | 8,790 | 3,050 | 49,000 | 11,700 | 3,790 | 43,400 |
| Taiwan | 8,730 | 4,990 | 10,400 | 11,700 | 6,150 | 8,880 |
| Thailand | 1,730 | 1,110 | 6,800 | 1,840 | 1,010 | 6,010 |
| United Kingdom | 84 | 98 | 96 | 188 | 162 | 109 |
| Venezuela | 222 | 253 | 640 | 213 | 205 | 362 |
| Other | 9,540 | 4,990 | 15,000 | 11,100 | 5,180 | 18,300 |
| Total | 107,000 | 56,700 | 370,000 | 119,000 | 64,400 | 413,000 |

-- Zero.

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

2/ Harmonized Tariff Schedule (HTS) code 2810.00.0000.

3/ HTS codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.

4/ Less than 1/2 unit.

Source: U.S. Census Bureau.

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

| Country | 1999 | | 2000 | |
|----------------|------------------------|----------------------|------------------------|----------------------|
| | Quantity (metric tons) | Value 2/ (thousands) | Quantity (metric tons) | Value 2/ (thousands) |
| Argentina | 112 | \$46 | 59 | \$40 |
| Belgium | 2 | 6 | 2 | 5 |
| Bolivia | 5,750 | 2,340 | 2,530 | 982 |
| Canada | 23 r/ | 16 r/ | -- | -- |
| Chile | 12,400 | 5,330 | 14,900 | 6,140 |
| France | 2 | 6 | 20 | 63 |
| Georgia | 53 | 35 | -- | -- |
| Germany | 123 | 103 | 21 | 37 |
| Italy | 1,770 | 1,680 | 5,010 | 3,210 |
| Japan | 26 | 50 | 8 | 14 |
| Peru | 1,680 | 771 | 1,500 | 618 |
| Russia | 380 r/ | 222 r/ | 839 | 368 |
| Turkey | 7,870 | 3,410 | 14,300 | 6,000 |
| United Kingdom | 3 | 12 | -- | -- |
| Total | 30,200 | 14,000 | 39,200 | 17,500 |

r/ Revised. -- 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: U.S. Census Bureau.

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

(Thousand metric tons)

| Country | 1996 | 1997 | 1998 | 1999 | 2000 e/ |
|--------------------|-------|---------|----------|-----------|----------|
| Argentina | 342 | 423 | 350 | 360 r/ e/ | 360 |
| Bolivia (ulexite) | 9 | 12 | 7 r/ | 7 r/ | 7 |
| Chile (ulexite) | 149 | 171 | 280 | 200 | 200 |
| China e/ 3/ | 157 | 136 4/ | 137 4/ | 110 | 105 |
| Germany (borax) e/ | 2 | 1 | 1 | 1 | 1 |
| Iran (borax) e/ 5/ | 1 | (6/) r/ | 2 r/ 4/ | 4 r/ 4/ | 4 |
| Kazakhstan e/ | 30 | 30 | 30 | 30 | 30 |
| Peru e/ | 39 4/ | 40 | 40 | 40 | 40 |
| Russia e/ 7/ | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| Turkey 8/ | 1,447 | 1,569 | 1,650 e/ | 1,410 e/ | 1,400 |
| United States 9/ | 1,150 | 1,190 | 1,170 | 1,220 | 1,070 4/ |
| Total | 4,330 | 4,570 | 4,660 r/ | 4,380 r/ | 4,220 |

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 18, 2001.

3/ Boron oxide (B₂O₃) equivalent.

4/ Reported figure.

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

6/ Less than 1/2 unit.

7/ Russian borate ore reportedly grades 8.6% B₂O₃.

8/ Concentrates from ore.

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