BORON

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Boron is produced domestically only in the State of California. Boron products sold on the market are produced from a surface mine, underground mines, in situ, and from brine. The United States and Turkey are the world's largest producers of boron, changing positions from year to year. Boron is priced and sold on the boron oxide basis, which varies by ore and compound and on the absence or presence of sodium and calcium. Boron exports are about one-half of the domestic production.

Legislation and Government Programs

The Smithsonian Institution opened the Janet Annenberg Hooker Hall of Geology Gems & Minerals in September 1997 with the Hope Diamond in the spotlight. The Hope's deep blue color is a result of impurities of boron atoms in place of carbon. What visitors do not see is the unique trait of the dark blue diamond that phosphoresces orange-red in the dark after exposure to ultraviolet light. At 45.52 carats, the Hope is the world's largest deep blue diamond (Ember, 1997).

The U.S. Department of Energy (DOE) began using boron and lithium to dispose of radioactive waste using a vitrification process in 1996. DOE planned in 1997 to unveil the first draft of its plan to cleanup the toxic wastes of its former weapon production sites.

The Environmental Protection Agency issued a notice of an open meeting in the announcing that the National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances was to meet September 23-25 to develop Acute Exposure Guideline Levels for boron trichloride and other chemicals (U.S. Environmental Protection Agency, 1997).

In May, a working draft of the 2000 International Building code (IBC) was presented to the building professionals for public review, discussion, and formal comment. Publication of the final code is scheduled for the year 2000. Boron is used in products that cover fire resistance, insulation, roofing, glass, and other home construction products. The IBC is one of several international codes in the review process or already published from the International Code Council (ICC), a nonprofit organization jointly staffed and funded by the three existing code organizations—BOCA National Building Code from Building Official and Code Administrators International, Inc. (BOCA), the Uniform Building Code from the International Conference of Building Officials, and the Standard Building Code from Southern Building Code Congress International, Inc. Currently ICC's offices are in Birmingham, AL, however, information on the code can be obtained from any of the three model code groups (Engineer News Record, 1997).

Production

Domestic data for boron were developed 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, four responded, representing 100% of the total boron produced. *(See table 1.)*

American Borate Co. mined small amounts of colemanite and ulexite/probertite from the Billie Mine. Colemanite was processed at Lathrop Well, NV. Storage and grinding facilities were at Dunn, CA. (*See table 2.*)

Fort Cady Minerals Corp. produced a salable product named CADYCAL 100. The product was 43% boron oxide that screens 81% less than 325 mesh. Because CADYCAL is a chemically precipitated product, it has advantages in consistency of the chemical composition; i.e., high boron oxide content, low impurities, and consistent physical size. The production process involves injecting a dilute acid 427 meters (1,400 feet) into the borate ore and then precipitating the borate rich ore to obtain a pure calcium borate product. The design of a larger facility was initiated with Flour-Daniel, Inc., which was awarded the design contract. Production of 30,000 tons per year with expansion to 90,000 tons per year was planned.

North American Chemical Co. (NACC), owned by the Harris Chemical North America, Inc., is headquartered in New York and has operating headquarters in Overland Park, KS. NACC operated the Trona and Westend plants at Searles Lake, in San Bernardino County. On December 12, IMC Global Inc. stated that it had reached a definitive agreement to acquire privately held Harris Chemical Group Inc. for $450 million in cash and assume approximately $950 million in debt. Included in the sale are Harris Chemical North American, Inc., which operates North American Salt Co., NACC, and Great Salt Lake Minerals Corp. (Green Markets, 1997). NACC produced refined sodium borate compounds and boric acid from the mineral-rich lake brines from Searles Lake, a playa with three major subsurface evaporite horizons. NACC owns 3,964 hectares (9,197 acres). NACC implemented technical changes in its production operation that took effect April 1996. A 243-hectare (600-acre) area was selected that contains the highest concentration of borax reserves in the lake, about 8,000 tons per 0.40 hectares (1 acre) or reserves of 4.8 million tons. A series of closed systems will circulate brines in the upper unit salt layer of the lake to increase the borax grade to a theoretical 1.45%. The brine will be processed at the Westend plant and circulated through a heat exchanger back to the upper salt layer. The Trona Railway operated between Trona and Searles Station and connected to the Southern Pacific Railroad was included in the IMC sale agreement. The boron products transported were used in ceramics, high-temperature glassware, and insulation.

NACC announced the completion of the sale and leaseback of its Argus electric- and steam-generating facility in Searles Valley, CA, during July 1996. Steam and electricity from the Argus Utilities facility serve NACC's production facilities at its Searles Valley complex. Net proceeds from the sale of $70 million were used to reduce debt under its existing revolving credit agreement. Under terms of the agreement, NACC will lease back the Argus facility for a term of 15 years, including a 2-year bargain renewal period. The lease provides for three renewal periods of up to 5 years each throughout the operating life of the facility.

U.S. Borax, Inc. (Borax) celebrated its 125th anniversary of continuous business October 12, making it one of the United States longest surviving mining firms. The chairman and CEO, was honored by being named "Manufacturer of the Year" by the California Manufacturers Association. There were 1,022 people employed by Borax in California during 1997 in the following locations: Boron, 685; Valencia, 174; and Wilmington, 163. The two gas-turbine cogeneration plants with a thermal efficiency rating of plus 70% supply a significant amount of steam for the processing and electric power. Excess electricity is sold to the local utility (Marcus, 1997). A 557-square-kilometer (6,000-square-feet) visitor center opened at Boron as part of the anniversary that featured exhibits illustrating the mining, processing, and uses of borax (North American Minerals News, 1997a).

Borax is a wholly owned subsidiary of RTZ-CRA. On December 21, 1995, the RTZ Corp. PLC. and CRA Ltd. merged to form The RTZ Corp. PLC., CRA Ltd., and Group Companies (RTZ-CRA). In 1997, RTZ and CRA gained shareholder approval to change their names to Rio Tinto. CRA changed to Rio Tinto Ltd. and RTZ changed to Rio Tinto PLC. Under the Rio Tinto name, individual group operations will continue to trade under the existing business names. The combined Group will continue to retain separate legal entities, stock exchange listings, and share registers and are separate and independently managed (PNG Resources, 1997).

Borax was investing $40 to $50 million capital expenditure over a 5-year period that included a new plant to developed a magnetic separation process for reclaiming the borate content of tailings. After solar drying and crushing to minus one quarter inch, the tailings will pass through a 100-ton-per-day high-intensity rare-earth magnetic separation circuit that will segregate the 10% sodium borate minerals from the mildly magnetic clay gangue. The recovered borates will be pelletized and added to the mined material. The processing of the tailings will allow Borax to recover the maximum borates and allow the company to gradually reclaim 350 hectares of land for restoration to natural desert habitat (North American Minerals News, 1997b).

Borax has the largest mine and the largest railcar fleet in California and is state of the art in providing quality control techniques for its customers. These high-tech quality control techniques include the following: ion chromatography for sulfate analysis; ion selection electrode for chloride analysis; laser technology for particle size analysis; microwave for moisture assessment; atomic absorption for arsenic and calcium detection; and computerized coulometry for carbon dioxide scrutiny (Review, 1997).

Cogeneration plants, part of boron processing facilities at both California cities, Boron and Trona, produce electricity for plant needs and sell excess power to Southern California Edison.

California will begin phasing in a plan to allow selected utility customers to shop for their electricity from suppliers both inside and outside the State. California's electric power market planned to open competition on March 31, 1998, after computer problems forced a delay from the original start date of January 1, 1998. Under the deregulation, California's power transmission grid will be taken over by a State-operated Independent System Operator, and electricity will be traded through a centralized power exchange.

Consumption

Glass accounts for three major borate applications, as follows: glass fiber insulation, borosilicate glass, and textile glass fiber. The use of borates in glass fiber thermal insulation, primarily used in new construction, was a large area of demand for borates and the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, its purpose is to trap and hold air. Typically, between 4% and 5% boron oxide is incorporated in the formulation to aid melting, inhibit devitrification, and improve the aqueous durability of the finished product.

Borates also were used in manufacturing high-tensile-strength glass fiber materials used in a range of products. The process of producing glass fiber uses a borosilicate E-glass formulation that is continuously drawn through platinum alloy bushings into continuous filaments of between 9 and 20 microns in diameter. E-glass, or textile fiberglass, typically contains between 6% and 8% boron oxide. Originally these glasses were used for electrical purposes, and low sodium levels were important. Major applications were reinforcements for plastics, but the low sodium tolerance still applies to the requirements for the production of the reinforced glass. The nonconductive and low dielectric properties of high-strength glass-reinforced materials make them transparent to radar and thus valuable for "stealth" applications. E-glass, a calcium aluminoborosilicate glass that has a balance of mechanical, chemical, and electrical properties is widely applied in composites because of the moderate cost.

In 1997, Owens Corning introduced Advantex, a boron-free glass formulations that exhibits properties that combine the acid corrosion resistance of E-CR glass with the electrical and mechanical performance of traditional E-glasses. Advantex is currently being used as a muffler filling system. The boron-free glass eliminates the need for conventional production aftertreatment with pollution control devices such as scrubbers, but does require higher batch temperatures, so energy consumption is greater (Glass, 1998).

Borosilicate glass is being crafted by Nikon, the leader in camera lens optics, for sunglasses that provide maximum protection from ultraviolet light and feature an anti-reflective scratch resistant coating. Two types of sunglass lenses, LX and

LE, are photochromic, which means they automatically adjust to all light levels, down to as little as 123% light transmittance (Borax Pioneer, 1997a).

Boron is important to many speciality glasses, such as in liquid crystal displays (LCDs). The liquid crystal itself is an organic compound in an intermediate state between solid and liquid. By interaction with an electrical or thermal potential, it will change from being an unstructured to a structured material, as in the change from a liquid to a crystal. All this takes place between two layers of borosilicate glass. Boric oxide is a key constituent of the alkali-free LCD glass. It acts as a network former in the glass structure, it improves optical properties, and it reduces the melting temperature (Funahashi, 1997).

PPG Industries Inc. is increasing the production of fiberglass chopped strand for reinforcing polyethylene terephalate, or PET, polyester to meet growing demand in automotive composite applications. The company is also expanding production of a chopped strand fiber glass reinforcement for nylon resin in auto applications. The company dedicated its newest fiberglass manufacturing plant in Chester, SC. This is the first new fiberglass facility in the United States in more than 15 years (Glass Industry, 1997b).

Fiberglass insulation represents the largest secondary market for recycled glass containers in the United States. A recent survey reported that more than 425 million kilograms (936 million pounds) of recycled glass was used in the manufacture of fiberglass insulation in 1995. This resulted in a savings of 708,000 cubic meters (25 million cubic feet) of landfill space. Estimated figures for 1996 are calculated at more than 454,000 tons (1 billion pounds). According to officials of the North American Insulation Manufacturers Association, the industry average is about 30% recycled glass. Some manufacturing facilities are averaging up to 40%, depending on availability of the recycled glass (Glass Industry, 1997a).

Boron compounds continued to find application in the manufacture of biological growth control chemicals for use in water treatments, algicide, fertilizers, herbicides, and insecticides. Wood preservation using borates can pretreat wood construction products to end biodeterioration by exposure to fungal decay and insect attack. Where pretreatment was not accomplished prior to construction, remedial treatment can be carried out to prevent termites and other wood-destroying organisms (Ford, 1997).

Boron is one of seven micronutrients, three secondary nutrients, and three major nutrients that are essential for plant growth. Lack of boron can lead to deformed and inefficient leaves, poor root development, poor photosynthesis, poor fruiting, or poor seed production. There are specially formulated nutrients for different applications stages and methods (Ford, 1997).

In cellulose materials such as timber, particle board, paper, wood fiber, and cotton products, sodium borates and boric acid are used as fire retardants. Anhydrous borax is used in the manufacture of flame-retardant fiberboard.

Boron compounds can reduced flammability by melting and preventing oxygen from contact with the burning surface. Although not as effective as other intumescent retardants, they are less expensive. Borate flame retardants generate a glass char, similar to the function of intumescent flame retardants. The glassy coating serves as a fairly impermeable barrier between the flame and the combustible substrate, unless the glassy film is rendered foamed by the action of another agent. The heat insulation effect is in general less than that for the intumescent (Mureinik, 1997).

Most of the materials used for furnishings, such as wood and polymers, are potential fuels. Polymer manufacturers pay strict attention to fire safety. A range of zinc borate products offer unique properties which enable these products to significantly reduce fumes and smoke (Ford, 1997).

Ammonium borates are used as key components of electrolyte systems in high voltage electrolytic capacitors. The borates provide a very stable electrolyte with the required conductivity at low costs, while also bestowing fire retardancy. In addition, ammonium pentaborate is used with boric acid in the anodizing process which deposits a dielectric oxide film on the aluminum (or tantalum) components of capacitors. Capacitors are used to store and distribute energy in computers, automobiles, televisions, stereo equipment, CD players, flashlights and strobe lights, and other electronic equipment (Borax Pioneer, 1997b).

The alloys of the nonmetal boron and neodymium and iron metals produce the strongest magnetic material known. The permanent magnets are used in automotive direct-current motors, computer disk drives, portable power tools, and home appliances.

Metallic borides have high hardness up to 2,100 micro hardness in kilograms per cubic meter. Boron is diffused on the surface of metal pierces as a metallic boride layer from 0.0254 to 0.127 millimeters (0.001 to 0.005 inch) in depth. Using a processing temperature between 1,500° F and 1,800° F and cycle times ranging from 1 to 8 hours, a wide range of ferrous and nonferrous alloys can be boronized. The boride layer is diffused into the base metal (Ceramic Industry, 1997).

Sodium perborate has been the principal bleach in European laundry powders and has been introduced into “all-in-one” detergents in the United States. Studies have shown that perborate is a gentler bleaching agent than chlorine. Perborate acts as a stain-removing agent in advanced dish washing powders. Other borates are used to stabilize enzymes in liquid laundry detergents (Ford, 1997).

Transportation

Union Pacific Corp., the largest railroad company in the United States, has been causing delays for glass raw materials suppliers since its acquisition of Southern Pacific Rail Corp. in 1996. The delays are caused by a shortage of rail equipment from Texas to California and by booming agriculture crops. Some of the shipment delays have taken products 6 weeks to arrive at their destinations rather than the previous 5 days. A Union Pacific spokesman reported that the company was hiring and it had ordered more locomotives, but training new hires and getting the engines would take some time (Glass, 1997).

Transport of borax products from Boron is accomplished primarily by rail, although trucks are also employed. Borax ranks as the number one bulk shipper in California on the Burlington Northern Santa Fe Railroad. The company maintains a fleet of more than 700 rail cars.

Ocean transport is from the port of Wilmington, CA, where Borax owns the only remaining privately owned berth in the harbor. Borax ranks as the largest exporter of high value dry bulk product out of the ports of Los Angeles and Long Beach. Furthermore, the company ranks in the top 10 shippers of ocean containers through the same ports. About 10 ships per year with a capacity of 40,000 dead weight tons are loaded for locations around the world. Borax has a long association with the "K" line, a Japanese fleet of semidedicated bulk carriers. After a naming ceremony at the Tsuneishi Dockyard, the merchant ship, Boron Explorer, left on her maiden voyage on February 21 (Marcus, 1997).

An incident aboard a ship in the Pacific Ocean on September 22, 1996, demonstrated how crucial it is to have a contingency plan to cover customer's needs in an emergency. The new vessel, one of a bulk carrier fleet semidedicated to Borax, was bound for Wilmington, CA, to take on 40,000 tons of borate for supply in the Netherlands and Spain. Borax policy is to reconcile economy of distribution with dependability of supply. Transportation from Wilmington to Valencia, Spain, averages 24 to 25 days. By organizing another vessel to carry supplemental product to Spain, product was transferred from Borax Rotterdam to Borax Espana. A full ship arrived in November to alleviate the supply disruption, which no borax customer ever realized took place. Widespread warehousing keeps Borax products near the customer. Warehouses are located as follows: Krems, Austria; Mannheim, Germany; St. Petersburg; Russia; and Tianjin and Guanghau, China. A warehouse in Runcorn, Cheshire, services England and warehouses in Memphis, TN, and Chicago, IL, provide emergency stock points for the midwest and eastern United States (Industrial Minerals, 1997a).

IMC owns a spur to connect to the Southern Pacific Railroad between Trona and Searles Station.

Prices

An Industrial Minerals Prices & Data 1996 was published that included information on Turkish, British, Argentinean, and United States prices of boron minerals and compounds (Industrial Minerals Information Ltd., 1997). (*See table 3.*)

Foreign Trade

The General Agreement on Tariffs & Trade (GATT) was signed into law in December 1994 and took effect January 1, 1995, lowered chemical tariffs by an average of 30%. Chemicals, including bromine, are the nations' largest export commodities, as more than 10 cents out of every export dollar is a product of the chemical industry. The agreement's intellectual property provisions include greater patent protection for products developed by U.S. firms. GATT changes patent enforcement from 17 years from the date of issue to 20 years from the date of application. Patents issued on applications filed before June 8, 1995, will be enforceable for either 17 years from the issue date or 20 years from the filing date, whichever is longer. *(See tables 4 and 5.)*

World Review

Argentina.—Mineral resources, including several active borate mines, are one of Argentina's great assets. The Argentine Infrastructure Development Trust has been conceived to develop the natural resource base with technology that allows for the efficient, profitable, and environmentally safe extraction of minerals resources. The formation of the Trust was inspired by the vision and the work of the office of the secretary of mines. It is the intention of the Trust to coordinate and seek common users so that these efficiencies and benefits can be delivered to the community in a manner that will make the mining industry in the region more competitive (Burns, 1997).

Borax Argentina S.A., a subsidiary of Rio Tinto Borax, was the country's leading producer of borates. Borax mines tincal at Tincalayu, hydroboracite at Sijes, and ulexite from two dry lake beds, Salar Cauchari and Salar Diablillos, all in the Salta Province at elevations more than 4,000 meters (14,000 feet). The tincal and ulexite are processed at Camp Quijano, near Salta. Most of the production is shipped to South American customers through Campo Quijano (Kendall, 1997).

Sucursal Argentina division of S.R. Minerals (Barbados) Ltd. developed the Loma Blanca mine in Jujuy Province in 1996. The mines has tincal, ulexite, and inyoite with average ore grades around 16% boron oxide. The concentrator uses magnetic separation and mechanical processing to produce concentrates of over 30% boron oxide. The concentrate is trucked to a processing plant at Palpala, near San Salvador de Jujuy where the ore is further magnetically separated and calcined. The products are primarily shipped to ceramics customers, but sales to glass and fiberglass customers are increasing (Kendall, 1997).

The third producer in Argentina is Ulex S.A. Ulex produces colemanite and hydroborcite from its mine in the Pastos Grandes area of Salta Province. Ulexite, found in veins, is hand mined for resale to two boric acid producers. The processing involved crushing, washing, milling, and drying to produce a concentrate. Production was reported to be around 10,000 tons per year of each of the minerals, with the majority being exported (Kendall, 1997).

Bolivia.—Borate production is from small companies mining ulexite from government concessions around Salar de Uyuni in the Bolivian Altiplano. Some of the crude mineral production is sold to Corban SA, La Paz. Corban produces dried and calcined ulexite at its Oruro plant and small volumes of borate decahydrate. Cia Minera Tierra has large concessions covering ulexite near the Chilean border and produces dried and washed grades for export (Kendall, 1997).

Boron Chemical International and Teck Corp., both Vancouver-based companies, were exploring and evaluating a number of ulexite deposits. One feasibility study was completed on a deposit close to the Chilean border. A 75,000-ton-per-year operation was expected to cost $28 million. There were no immediate plans to begin development.

Canada.—Kobitex Inc. distributes Etibank's refined boron minerals in North America. Included is granular and powdered boric acid, borax penta and decahydrate from Bandirma, and Etibor-48 and anhydrous borax from Kirka. The products are shipped from Bandirma and Izmir. Kobitex is presently actively supplying products to cellulose insulation, gypsum board, and large chemical distributors (Ovi Gulersen, Kobitex Inc., written commun., 1996).

Chile.—Boron Chemicals International Ltd. continued plans to develop the Aguas Blancas boron project in Northern Chile (Industrial Minerals, 1997d).

Quimica e Industrial del Borax Ltda. (Quiborax) mined from Salar de Surire, the largest ulexite deposit in the world. The salar is located at a 4,250-meter altitude within the border of the Monumento Natural de Surire, a national park in Chile. Production was around 200,000 tons of crude ulexite. The ore is trucked to the El Aguila production facility north of Arica. Some of the ulexite is dried and sold and the balance is reacted with sulfuric acid to produce 25,000 to 30,000 tons per year of boric acid. The majority of production is exported through the ports at Arica, Iquiqui, and Antofogasta. The National Boraxx Corp. (Cleveland, OH) packages and distributes boric acid in the United States for Quiborax (Kendall, 1997).

There are other small mines such as Sdad Boroquimica Ltda., that mine ulexite from salars in regions I and II in the north (Kendall, 1997).

Compania Minera Salar de Atacama, better known as Minsal, is 100% owned by Sociedad Quimica y Minera de Chile SA, better known as SQM. A large integrated facility is planned to begin production of 16,000 tons per year of boric acid in 1998 (Kendall, 1997).

China.—There are numerous producers of borates in the Liaodong peninsula in Liaoning province. The ores are primarily magnesium borates such as szaibelyite. Other production is from the playa lakes in Qinghai, where borate minerals such as ulexite, pinnoite, hydroboracite, and borax have been produced from brines. Total Chinese production is estimated around 100,000 tons per year, with an additional 20,000 tons per year of boric acid (Kendall, 1997).

Europe.—The industrial minerals market in Europe is 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. Three elements impact the decisionmaking process: the geographic location, the range of service needed, and prices. Antwerp is the most central port in Europe, with access to 188 major European cities (Szuflak, 1997).

Barges are the most efficient and reliable method of transporting goods in Europe, which has a 25,000-kilometers network of navigable canals and rivers. Most of the large industrial areas can be reached by barge by waterways that link parts of the North Sea, the Baltic, the Black Sea, the Mediterranean, and the Atlantic Ocean. In 1992, the 170-kilometer canal linking the River Main to the Danube was opened in Germany. Borax uses barges to ship borates from 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 (Review, 1996).

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

Kazakstan.—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 the gypsum include asharite, hydroboracite, inyoite, and ulexite. At two sites, dredging takes place at a depth of 15 to 20 meters below the water level using drag lines. Borate ore reserves do not exceed 2 million tons, but the potential could reach 120 million tons of 9% boron oxide (Alexeev and Chernyshov, 1997).

Mexico.—Vitro SA de CV sold its raw material subsidiary, Materias Primas y Mineria to Unimin Corp., the U.S. silica sand giant. The $131 million cash deal is subject to the signing of a definitive agreement and government-regulatory approval. Materias Primas's primary customer is the Vitro Group, and this relationship will be maintained under a 10-year feldspar and silica sand supply arrangement (Industrial Minerals, 1997c). Materias Primas was formerly in a joint venture with Borax for the development of the Magdelina colemanite property, until 1993, when the venture was dissolved.

Peru.—Cia Minera Ubinas SA and Quimica Oquendo SA, linked under the Inkabor name and owned by the Italian Colorobbia Group, mined ulexite. Ubinas mines at Laguna Salinas, 80 kilometers east of Arequipa. The open pit operation produces some 150,000 to 180,000 tons per year of ulexite ore during 6 or 7 months of mining. Large stocks are maintained for sales during the winter season. The crude ulexite is washed to produce an ulexite concentrate or supplied to Oquendo for boric acid production. Oquendo's plant near Lima produces around 12,000 tons per year of boric acid and 15,000 tons per year of concentrated ulexite. Small volumes of calcined ulexite is sold for fertilizer and the rest of the Inkabor's output is exported (Kendall, 1997).

Russia.—Boron ore reserves are concentrated in deposits of magnesia-skarn and lime-skarn formations found in Southern Yakutiya (Tayozhnoye), in Buryatiya (Solongo) and in the northeast (Titovskoye and Nalyodnoye). The boron-iron deposit at Tayozhnoye is of Archean age. Here skarn ore bodies lie among dolomite, marble, shale, and gneiss. The ore bodies are formed from magnetite and sometimes from ludwigite and ashanite. The reserves exceed 100 million tons of 34% boron. Presently there are no known processing technologies to make the production profitable (Alexeev and Chernyshov, 1997).

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 is mined by Joint Stock Company Bor (JSC), for the datolite and limestone. At the sulfuric acid plant in Komsonolsk (Khabarovsk), datolite is treated to produce boric acid and calcium borate. JSC produces 90% of the Russian output of 220,000 tons of boric acid (Alexeev and Chernyshov, 1997).

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

Sodium perborate is produced by the interaction of solutions of sodium metaborate and hydrogen peroxide. Sodium perborate is produced by a chemical method using hydrogen peroxide, and by an electrochemical method, using electrolysis of solutions containing sodium metaborate and sodium carbonate. The waste chalk is used to produce construction materials, silicate paints, and as a soil additive. Technical grade borax is synthesized from solution of boric acid and soda (Alexeev and Chernyshov, 1997).

***Serbia.*—**A joint-venture company Ras-Borati Ltd., began drilling the Piskanja boron deposit in the Jarandol basin, located near Baljevac in southern Serbia. Ras-Borati Ltd., established February 1997, is a 50-50 joint venture between Erin Ventures Inc. of Kelowna, British Columbia, Canada, and Electroprivreda, the national power company of Serbia. The drilling program is planned to raise the status of a 7-million-ton block of reserves grading 35% to 39% from indicated to proven. The minerals are primarily colemanite and ulexite. Ras-Borati also holds rights to a borate deposit in the Jarandol basin named the Pobrdjski Potok deposit. Proven and probable reserves of 140,000 tons ore averaging 37% boron oxide were identified (Industrial Minerals, 1997b).

***Tajikistan.*—**A skarn borosilicate deposit at Ak-Arkhar, situated at an elevation of 4,400 to 5,000 meters, has measured and indicated reserves of danburite ore that exceed 80 million tons (Alexeev and Chernyshov, 1997).

***Turkey.*—**Turkey's boron operations are under the control of the Government corporation, Etibank. Ulexite is mined at Bigadic; colemanite at Bigadic, Emet, and Kestelek; and tincal at Kirka.

Bigadic Colemanite Works, in Bigadic District of Balikesir Province, has a production capacity of 500,000 tons of run-of-mine colemanite and ulexite ores from three open pits and two underground mines. The concentrator has a capacity of 400,000 tons per year. The Bigadic borate district was reported to be the world's largest colemanite and ulexite deposits. All products at Bigadic are for export.

Emet Colemanite Works, located in Emet District of Kutahya Province, had a production capacity of 700,000 tons per year of run-of-mine ores, both open pit and underground mines. Colemanite ores are processed in a 500,000-ton-per-year concentrator and supplied to domestic and international markets. Most of the colemanite concentrates are exported. The remaining production is used in the boric acid plant in Bandirma.

Kestelek Boron Mine is located in Mustafakemalpa, a district of Bursa Province. The underground mine was closed at the end of 1994 because of high cost and low sales. Production is now from the open pit. Kestelek Boron is now a subsidiary of Bigadic.

The Kirka Borax Works is near Seyitgazi District of Eskisehir produces tincal concentrate, borax pentahydrate, and anhydrous borax. The concentrator has a capacity of 600,000 tons per year of tincal concentrates. A derivatives facility was begun in 1984 for the production of 160,000 tons per year of borax decahydrate and 60,000 tons per year of anhydrous borax. Technical problems regarding the anhydrous production are being studied. An expansion project was under way to increase pentahydrate production capacity to 320,000 tons per year. There is a storage and loading facility 20 kilometers away at Degirmenozu with a railway connection to the port at Bandirma.

In addition to the Government operations, private processing of boron reserves from stockpiles and dumps have occurred for the past decade.

***Uzbekistan.*—**An oil and gas condensate deposit at Dzhartchi, has the potential to produce 377 tons per year of boron oxide at a pumping rate of 4,000 cubic meters per day for over 20 years (Alexeev and Chernyshov, 1997).

Current Research and Technology

The biennial review of the commission on Atomic Weights and Isotopic Abundances reviewed the published literature for atomic weight determinations. This has resulted in changes for the standard atomic weight of 21 elements, including boron. Boron's atomic weight has been changed from 10.811 plus or minus 0.005 to 10.811 plus or minus 0.007 (Coplen, 1997).

A new, longer lasting, higher powered lithium-ion battery may soon boost the usefulness of laptop computers and other electronic equipments that rely on rechargeable batteries. The Fuji Group has designed an alternative material that substitutes tin oxide as the active, lithium-absorbing center. Other oxides of metals such as boron, phosphorus, and aluminum act as part of the materials frameworks but do not participate in the electrochemical actions (Wilson, 1997b).

Researchers are exploring diverse technologies to manage and remedy the legacy of nuclear weapons production. The current strategy is to separate the liquid nuclear waste portion from the solids. The liquid can be disposed of as low-level waste after removal of fission products, such as strontium and cesium. The solid portions, which contains long-lived actinides, are washed and removed as salts. The solid waste will be vitrified to form glass logs and collected at a few nuclear waste sites around the country. Another process uses a commercially available product to remove cesium and strontium. The cesium is then vitrified and converted to an immobile glass that can be stored at designated nuclear waste sites (Wilson, 1997a).

A workshop on the future of nanotubes was held at Rice University to discussed the electronic properties of nanotubes and nanotube junctions. The properties of carbon nanotubes can be bimetallic or semiconducting depending on tube diameter. Such structures allow the formation of various metal-semiconductor, semiconductor-semiconductor, and metal-metal junctions, raising the possibility of producing molecular-level electronic devices by bonding together different types of nanotubes. The electrical properties of nanotubes made from boron nitride are always wideband semiconductors. It might be possible to wrap a metallic carbon nanotube with a boron nitride nanotube to produce an insulated nanoware (Baum, 1997).

A fluoroborate can be used in the development of carbohydrate drugs. Fluorosugars are compounds of emerging importance as enzyme inhibitors and competitive binding ligands. A new process using a mild borated fluorinating agent that is commercially available simplifies a previous complex process (Chemical and Engineering News, 1997).

Using boron and bismuth, the tableware industry is preparing lead-free glazes. The advanced borosilicate (ABS) process involves eliminating lead from compositions, increasing the boric oxide content, and adjusting the remaining oxides (silica, alumina, soda, and lime). Low-melting ABS glazes have been shown to give consistent performance, and color fluxes are promising. More recent work has shown that ABS can be improved by the addition of small amounts of bismuth (Jackson, 1997).

A conference was held at Abington, United Kingdom, on borate glasses. When sodium oxide is added to a glass composition, some of the units link to four oxygen atoms, forming tetrahedrons that bond in three dimensions. The resulting glass is harder and more resistant to water attack. But, the formation of nonbridging oxygens, that bond only to one boron, disrupts the boron-oxygen linking and weakens the glass. The addition of sodium oxide is used exclusively for the formation of tetrahedron until it exceeds a certain threshold value, which varies according to the glass's silicon content. The various chemical groupings influence glass properties in different ways, and the amounts of the groupings can be controlled to some extent by the rapidity of quenching of the glass from the liquid melt and/or the time and temperature of the annealing of the glass (Borax Pioneer, 1997d).

Borax Europe established a scholarship for postgraduate students in the glass and ceramics department of London's Royal College of Art. The recipient of the 1997 award is studying the relationship of a range of glazes and fritz. Boric oxide is an essential part of this study (Borax Pioneer, 1997e).

Outlook

Production of boron minerals and compounds has increased between 1993 and 1997. Production and imports reported in 1 year may be stockpiled and utilized over a period of years. In addition, environmental concerns may change the demand for boron significantly in a short period. The regulation of fire retardants in products has resulted in changes in boron usage as a fire retardant.

Agriculture.—Farming exports are showing increased strength and demand for boron usage in agriculture is expected to increase slightly.

Ceramics and Glass.—Fiberglass, closely related to construction and transportation, was expected to increase. Fiberglass insulation is used primarily in houses, and during times of low-interest rates, housing starts increase, thereby increasing demand for fiberglass.

Coatings and Plating.—Boron usage as a protective coating for steel products and as a glazing on ceramic tiles is expected to increase.

Fire Retardants.—Demand for borated flame retardants has grown 15% per year. Zinc borate is often used with, or in place of, antimony trioxide. Zinc borate serves as a synergist with chlorine- or bromine-based fire-retardant systems.

Fabricated Metal Products.—Boron usage in specialized metal was expected to increase.

Soaps and Detergents.—Usage in soaps and detergents was expected to increase 4% per year during the next 5 years.

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[1]Prior 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)

	1993	1994	1995	1996	1997
United States:					
Sold or used by producers:					
Quantity:					
Gross weight 2/	1,060	1,110	1,190	1,150	1,190
Boron oxide (B2O3) content	574	550	728	581	604
Value	$373,000	$443,000	$560,000	$519,000	$580,000
Exports:					
Boric acid: 3/					
Quantity	75	87	75	42	92
Value	$50,500	$53,300	$68,100	$35,300	$60,500
Sodium borates:					
Quantity	481 4/	498 4/	588	381 4/	473 4/
Value	$181,000 4/	$165,000	$227,000	$133,000 4/	$169,000 4/
Imports for consumption: 4/					
Borax:					
Quantity	40	9	9	11 5/	54 5/
Value	$1,230	$2,700	$936	$3,470	$17,010
Boric acid:					
Quantity	17	20	16	25 5/	26 5/
Value	$11,900	$12,900	$10,100	$10,800 e/	$11,800 e/
Colemanite:					
Quantity	90	27	45	44 5/	44 5/
Value	$48,600	$10,800	$8,600	$13,000 e/	$13,000 e/
Ulexite:					
Quantity	149	120	153	136 5/	157 5/
Value	$40,700	$24,000	$39,300	$27,200	$31,400
Consumption: Boron oxide (B2O3) content	321	296	NA	367	403
World: Production	2,640 r/	2,800 r/	3,000 r/	3,160 r/	3,070 e/

e/ Estimated. r/ Revised. NA Not available.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Minerals and compounds sold or used by producers, including both actual mine production and marketable products.
3/ Includes orthoboric and anhydrous boric acid. HTS code Nos. 2840.19.0000, 2840.30.0000, and 2840.20.0000.
4/ Source: Bureau of the Census.
5/ Source: The Journal of Commerce Port Import/Export Reporting Service.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE 1/

Mineral	Chemical composition	B2O3 weight percent
Boracite (stassfurite)	Mg6B14O26Cl2	62.2
Colemanite	Ca2B6O11 • 5H2O	50.8
Hydroboracite	CaMgB6O11 • 6H2O	50.5
Kernite (rasortie)	Na2B4O7 • 4H2O	51.0
Priceite (pandermite)	CaB10O19 • 7H2O	49.8
Probertite (kramerite)	NaCaB3O9 • 5H2O	49.6
Sassolite (natural boric acid)	H3BO3	56.3
Szaibelyite (ascharite)	MgBO2(OH)	41.4
Tincal (natural borax)	Na2B4O7 • 10H2O	36.5
Tincalconite (mohavite)	Na2B4O7 • 5H2O	47.8
Ulexite (boronatrocalcite)	NaCaB5O9 • 8H2O	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	1996	1997
Agriculture	15,800	14,900
Borosilicate glasses	29,300	46,900
Enamels, frits, glazes	14,600	14,000
Fire retardants:		
Cellulosic insulation	12,800	14,700
Other	1,060	1,720
Insulation-grade glass fibers	162,000	160,000
Metallurgy	2,210	2,020
Miscellaneous uses	25,900	20,300
Nuclear applications	291	291
Soaps and detergents	21,200	21,200
Sold to distributors, end use unknown	42,300	41,500
Textile-grade glass fibers	59,700	66,000
Total	387,000	403,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4
U.S. CONSUMPTION OF ORTHOBORIC ACID, BY END USE 1/ 2/

(Metric tons of boron oxide content)

End use	1996	1997
Agriculture	453	439
Borosilicate glasses	7,250	4,620
Enamels, frits, glazes	1,620	1,600
Fire retardants:		
Cellulosic insulation	3,310	4,730
Other	816	1,480
Metallurgy	170	164
Miscellaneous uses	18,100	14,000
Nuclear applications	290	290
Soaps and detergents	93	93
Sold to distributors, end use unknown	16,500	16,000
Textile-grade glass fibers	25,200	32,000
Total	73,800	75,400

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

TABLE 5
YEAREND 1997 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON 1/

Product	Price, Dec. 31, 1996 (rounded dollars)	Price, Dec. 31, 1997 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works 2/	818	818
Borax, technical, anhydrous, 99%, bags, carload, works 2/	884	884
Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/	381	381
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works 2/	315	315
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works 2/	443	443
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works 2/	375	375
Boric acid, technical, granular, 99.9%, bags, carload, works 2/	883	883
Boric acid, technical, granular, 99.9%, bulk, carload, works 2/	819	819
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B2O3, 100-pound-bags, carlots	1,420	2,210
Colemanite, Turkish, 42% B2O3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC 3/	295	295
Ulexite, Chilien, 38% B2O3, 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. 250, no. 27, December 1996; v. 251, no. 1, January 1998, p. 23.
3/ Industrial Minerals, no. 363, December 1997.

TABLE 6
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY 1/

	1996			1997		
	Boric acid 2/		Sodium borates 3/	Boric acid 2/		Sodium borates 3/
Country	Quantity (metric tons)	Value (thousands)	(metric tons)	Quantity (metric tons)	Value (thousands)	(metric tons)
Australia	1,190	$633	5,040	3,400	$2,220	7,140
Belgium	--	--	53	2	14	71
Brazil	2,590	1,080	1,070	4,550	1,890	3,500
Canada	4,970	3,440	38,300	5,110	3,640	37,200
Colombia	78	85	596	157	165	1,100
France	53	34	29	128	284	1
Germany	141	3,470	13	258	1,860	6
Hong Kong	136	135	3,470	294	262	4,400
India	--	--	63	2	5	138
Indonesia	371	222	8,100	984	615	15,900
Israel	43	32	124	10	7	114
Japan	8,830	8,050	22,300	12,600	10,900	30,700
Korea, Republic of	2,300	1,940	14,600	6,730	4,450	24,300
Malaysia	222	209	6,660	303	350	6,270
Mexico	4,210	2,620	15,100	4,430	2,870	18,500
Netherlands	6,630	7,690	198,000	33,200	17,300	224,000
New Zealand	225	116	1,620	676	343	43
Philippines	9	11	1,390	27	34	2,860
Singapore	557	338	983	394	264	1,040
South Africa	293	162	677	118	60	323
Spain	3,560	1,400	35,900	5,320	2,240	58,500
Taiwan	3,530	2,110	8,350	8,280	4,830	12,200
Thailand	801	637	5,650	1,020	824	6,210
United Kingdom	146	141	149	100	139	1
Venezuela	330	233	941	680	505	1,350
Other	836	535	11,900	3,490	4,370	17,600
Total	42,100	35,300	381,000	92,300	60,500	473,000

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ HTS code No. 2810.00.0000.
3/ HTS code Nos. 2840.19.0000, 2840.30.0000, and 2840.20.0000.

Source: Bureau of the Census.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY 1/

	1996		1997	
Country	Quantity (metric tons)	Value 2/ (thousands)	Quantity (metric tons)	Value 2/ (thousands)
Austria	--	--	8	$5
Bolivia	3,460	$1,730	4,000	2,080
Canada	6	5	51	46
Czech Republic	--	--	17	36
Chile	631	3,500	5,890	3,260
France	8	35	5	22
Germany	13	35	46	38
Italy	1,050	1,130	1,610	1,580
Japan	110	204	280	287
Mexico	--	--	1	4
New Zealand	40	25	--	--
Peru	842	510	1,720	1,010
Russia	218	186	407	355
South Africa	20	28	--	--
Switzerland	2	1	--	--
Turkey	5,830	3,420	6,170	3,020
United Kingdom	2	3	3	15
Total	17,900	10,800	20,200	11,800

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ U.S. Customs declared values.

Source: Bureau of the Census.

TABLE 8

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

(Thousand metric tons)

Country	1993	1994	1995	1996	1997 e/
Argentina	146	215	245	342 r/	270
Bolivia (ulexite)	12	10	7	4 r/	5
Chile (ulexite)	117	86	211 r/	149 r/	150
China e/ 3/	155	188	140	157 r/	140
Germany (borax) e/	2	2	2	2	2
Iran (borax) e/ 4/	1	1	1	1	1
Kazakstan	8 r/	7 r/	7 r/ e/	7 r/ e/	7
Peru	37	30	41 r/	39 r/	40
Russia	33	13	13 e/	13 e/	13
Turkey 5/	1,079	1,140	1,144 r/	1,300 r/ e/	1,250
United States 6/	1,060	1,110	1,190	1,150	1,190 7/
Total	2,640 r/	2,800 r/	3,000 r/	3,160 r/	3,070

e/ Estimated. r/ Revised.

1/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through May 20, 1998.

3/ B_2O_3 equivalent.

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

5/ Concentrates from ore.

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

7/ Reported figure.