

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, and in situ and from brine. The United States and Turkey are the world's largest producers of boron. 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 total about one-half of the domestic production.

Legislation and Government Programs

Vitrification using borosilicate glass is the standard method for the immobilization of high active-nuclear waste. The presence of boron decreases the melt temperature and increases the glass's tolerance to molybdenum digestion (Scales, 1998). Storage of glass-filled cylinders was to begin at Yucca Mountain, NV, in 2002. Studies based on signals from Global Positioning System satellites suggest that the Yucca Mountain area may be undergoing a period of abnormally high strain (Suplee, 1998).

The Hanford Advisory Board is an independent, nonpartisan, and broadly representative body consisting of a balanced mix of the diverse interests set forth in its charter (Hanford Advisory Board, accessed on August 24, 1999, at URL <http://www.hanford.gov/boards/hab/charter/charter.htm#I>). The primary mission of the Board is to provide informed recommendations and advice to the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency, and the Washington Department of Ecology on selected major policy issues related to the cleanup of the Hanford site. The Board consists of representatives from local governments, businesses, the Hanford workforce, local environmental groups, regional citizens, environmental, and public interest organizations, local and regional public health concerns, the three tribes that have treaty rights that are affected by Hanford cleanup decisions, citizens of the State of Oregon that might not otherwise be covered by the categories listed above, and at-large individuals who have expressed a general interest in Hanford cleanup issues and who might otherwise contribute to ethnic, racial, or gender diversity. The Board approved a \$6.9 billion contract with BNFL, Inc., to design and build a facility that will verify the waste (Chemical & Engineering News, 1998b).

In 1982, Congress established a national policy to solve the problem of nuclear waste disposal. This policy is a federal law called the Nuclear Waste Policy Act. Congress based this policy on what most worldwide agreed is the best way to dispose of nuclear waste. In 1987, Congress amended the Nuclear Waste Policy Act and directed DOE to study only

Yucca Mountain. The Act stressed that if, at any time, Yucca Mountain is found unsuitable, studies will be stopped immediately. DOE was required by law to begin accepting nuclear waste by January 1998. As a result of delays in the construction of a permanent storage facility at Yucca Mountain, which was expected to have been completed by 2010, 10 utilities were seeking damages. A proposal to build a temporary storage facility at Yucca Mountain was under consideration (Chemical & Engineering News, 1999c).

A settlement of a lawsuit brought by 39 local and national groups will provide \$6.25 million for nonprofit citizens groups and Native American tribes to hire technical experts to review DOE cleanup plans. The agreement also will require that the DOE create and update annually an Internet data base that will contain detailed information on the DOE's contaminated facilities; volume, type, and radioactivity of nuclear wastes; volume and makeup of chemical waste; and transfer and disposition plans for the entire DOE complex. The data base will cover defense, nuclear energy, and science programs, as well as facilities undergoing cleanups (Johnson, 1998).

The Federal Railroad Administration 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 (Federal Railroad Administration, 1998). 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-art electric power and control systems, Maglev will reduce the need for many mechanical parts, thereby minimizing resistance and permitting excellent acceleration and cruising speeds of about 240 miles per hour or more. Since the High-Speed Ground Transportation Act of 1965, a number of Maglev system concepts have undergone research and development in the United States. To date (1998), \$1 billion in Federal funds has been approved to explore and construct a Maglev segment of rail in various location in the United States (Orlando Sentinel, 1998).

Publication of the 2000 International Building Code (IBC) was scheduled for the year 2000. Boron is used in products, such as, 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 Officials and Code Administrators International, Inc., the Uniform Building Code from the International Conference

of Building Officials, and the Standard Building Code from Southern Building Code Congress International, Inc. Currently (1998), ICC's offices are in Birmingham, AL; information on the code, however, can be obtained from any of the three model code groups (Engineering 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 Inyo and San Bernardino Counties, CA. Of the four operations to which a survey request was sent, all responded, representing 100% of the total boron produced (table 1).

American Borate Co. mined small amounts of colemanite and ulexite/probertite from the Billie Mine in Death Valley, CA. The ore was transported for processing at Lathrop Well, NV. Storage and grinding facilities were at Dunn, CA (table 2).

Fort Cady Minerals Corp. used an in situ process near Hector, CA, to produce a salable product called CADYCAL 100. The product was 43% boron oxide that screened 81% less than 325 mesh. Because CADYCAL is a chemically precipitated product, it has advantages in consistency of the chemical composition; that is, high boron oxide content, low impurities, and consistent physical size. The production process involved 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. Flour-Daniel, Inc. was awarded the contract to design a larger facility. Initial production capacity of 30,000 metric tons per year with expansion to 90,000 tons per year was planned.

In May, IMC Global Inc. announced the creation of IMC Chemicals, headquarter in Overland Park, KS, to operate the Trona and the Westend plants at Searles Lake in San Bernardino County. IMC Chemical produced refined sodium borate and boric acid as a coproduct of soda ash, sodium bicarbonate, and sodium sulfate from the mineral-rich lake brines. A series of closed systems circulates brines in the upper unit salt layer of the lake to increase the borax grade to a theoretical 1.45%. The brine is processed at the Westend plant and circulated back to the upper salt layer. At yearend 1998, IMC Global announced that it would divest a controlling share of IMC Chemicals to Mincorp LLC, a division of Citicorp Venture Capital, a unit of New York-based Citigroup Inc. (Green Markets, 1999).

U.S. Borax Inc., a member of the Rio Tinto Borax Group, mined borate ores at Boron, CA, by open pit methods and transported the ores to the surface via a conveyor. Reserves containing the minerals kernite and tincal were in excess of 100 million tons. The ore was processed into sodium borate or boric acid products in the refinery complex adjacent to the mine. An on-site plant also produced anhydrous sodium borate and boric oxide. Refinery products were shipped by railcar or truck to North American customers or to the U.S. Borax Wilmington facility in the port of Los Angeles for international distribution. U.S. Borax produced a range of specialty borate

products at its Wilmington plant (Baele, 1998a). In 1997, the Boron operation was listed as the third leading industrial minerals mining operation in California based on value of output of total material.

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

Consumption

Glass accounts for the following major borate applications: borosilicate glass, glass fiber insulation, and textile glass fiber. Borosilicate glass has a low expansion coefficient and is thermally shock resistant. The family of glasses is diverse varying, from cookware to laboratory glass to photomultiplier tubes. In a number of glasses, boron is substituted for silica. These glasses are designed to be resistant to sodium vapor, melt at about 1,300° C, and are based on a boron-alumina-alkaline earth (barium, calcium, and strontium) system. Low-pressure sodium lights (yellow street and roadway lights) use a layer of barium borate glass on the inside of a soda-lime glass tube (Henderson and Simpson, 1998).

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

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

The top three companies, Owens Corning Fiberglas Corp., PPG Industries, Inc., and Vetrotex America/Fiber Glass Reinforcements accounted for about 80% of the reinforcement glass fiber market. More than 40,000 applications are available for reinforcement fibers worldwide. Different industries use different types of glass fiber. The most commonly used type is

E-glass fiber, which is used in 90% of applications. Composites, which use reinforcement fibers, have several advantages over traditional materials in vehicles—they make the vehicles lighter and, therefore, save on fuel consumption, are noncorrosive and therefore have a longer life cycle, and are flame resistant and nonconductive, and can consolidate a number of separate components into one unit, and therefore, reduce storage, material handling, and fitting costs. One of the most rapidly growing types of glass-reinforced plastic in automotive applications is glass-mat-reinforced thermoplastics (GMT). Uses for GMT include airbag housings, battery supports, bumper beams, dashboard supports, engine supports, front ends, radiator grills, rear seat backs, seat shells, and sunroof frames. Another type of glass-reinforced plastic includes fiber-reinforced polypropylene, which is used as a shield to enclose the underside of engine compartments. Sheet-molding component thermosets are often used in under-the-hood applications because of their heat- and fire-resistant properties. Glass- and mineral-filled phenolic molding thermoset compounds are used for automotive fuel- and air-management systems, heat shields, turbocharger, and the catalytic convertor system (Glass, 1998b).

Owens Corning and Glass Holdings Corporation, the U.S. subsidiary of Groupe Porcher Industries, headquartered in Badinières, Ysère, France, announced September 30 the establishment of a joint venture to own and operate Owens Corning's former glass fiber yarns and specialty materials business for \$140 million. The new enterprise, named Advanced Glassfiber Yarns LLC, serves the industrial, construction and electronics markets with glass fiber yarns and specialty materials. The business, which will operate independently of both Owens Corning and Groupe Porcher, has annual sales of about \$300 and employs 1,500 people globally. Glass Holdings owns 51% of the new enterprise and Owens Corning owns the remaining 49%. Headquartered in Aiken, SC, the new venture has manufacturing facilities: Aiken, SC, manufacturing glass yarns for industrial, construction and electrical markets; Huntingdon, PA, manufacturing fine glass fiber yarns and specialty materials for electrical, industrial and construction markets; and South Hill, VA, manufacturing fine glass fiber yarns for electrical markets (BGF Industries, Owens Corning, Groupe Porcher complete joint venture, accessed November 11, 1999, at URL <http://www.onlinetextilenews.com/news/9072687802764.htm> and <http://www.onlinetextilenews.com/news/90836992316124.htm>).

Degussa Corporation developed an activator for the boron-based detergents that can enhance detergent performance under lower temperature conditions, as well as stabilize peroxide formation. The company pioneered the use of perborates as an active ingredient in laundry powder in 1907. Perborate exhibits excellent storage stability and detergent compatibility. Sodium perborate monohydrate is favored in compact detergents for its high active-oxygen content and high dissolution rate. Anhydrous sodium perborate is used in alkaline cleansing formulations as a source of effervescent oxygen (Degussa Corporation, Peroxygen chemicals, accessed June 4, 1999, at URL <http://www.degussa.com/peroxygen/index.html>). Sodium perborate tetrahydrate is made in a two-stage process. The

starting product, borax pentahydrate, is digested, with aqueous sodium hydroxide forming a concentrate solution. In the second stage, hydrogen peroxide is added, resulting in the tetrahydrate. At wash temperatures below 60° C, the use of an activator, such as tetracetylenediamine, is needed (Degussa Corporation, Sodium perborate/percarbonate, accessed June 3, 1999, at URL [http://www.degussa.com/peroxygen/html/products.html/sodium perborate](http://www.degussa.com/peroxygen/html/products.html/sodium%20perborate)).

Boron, one of seven essential micronutrients for plant growth, is integral to a plant's reproductive cycle by controlling flowering, pollen production, germination, and seed and fruit development. The mineral also acts as a fuel pump to aid the transmission of sugars from older leaves to new growth areas and root systems. Boron makes almost every fruit, nut, and vegetable crop healthier and more marketable (Keefe, 1998).

In the 14 Southern States that make up the Cotton Belt, the soils are deficient in boron. About 1 to 3 kilograms per hectare of boron is necessary for growing and fruiting and resistance to boll weevils and pink boll worms. For cotton, no amount of any other fertilizer is able to produce so significant an increase in productivity (Borax Pioneer, 1998).

Boron compounds continued to find application in the manufacture of biological-growth control chemicals for use in water treatments, algicides, fertilizers, herbicides, and insecticides. Hints from Heloise published an inexpensive roach bait formula using boric acid (Houston Chronicle, 1999).

In cellulose materials, such as timber, particle board, paper, wood fiber, and cotton products, sodium borates and boric acid are used as fire retardants. An anhydrous borax is used in the manufacture of flame-retardant fiberboard. A zinc borate is used in plastics. Consumption of flame retardants is expected to increase to 8.2 million kilograms (18 million pounds) in 2003 from 5.4 million kilograms (12 million pounds) in 1998 (Industrial Minerals, 1998).

The alloys of the nonmetal boron and neodymium and iron metals produce the strongest magnetic material known. METGLAS, a combination of boron, iron, and rare-earth materials, offers utilities energy savings of up to 70%. AlliedSignal Inc. signed an agreement with the General Electric Co. (GE) that will give AlliedSignal exclusive right to patents for GE's advanced electrical distribution transformers that use AlliedSignal's METGLAS amorphous metal. AlliedSignal began production of the amorphous metal ribbon, METGLAS, in 1989 at Conway, SC. (AlliedSignal Inc., 1998, Materials Edge, 1989.) These permanent magnets are used in automotive direct-current motors, computer disk drives, home appliances, and portable power tools.

Boron-neodymium-iron-boron magnets are being used to sort metal from glass by using eddy-current separators. Metal objects are passed through a high-intensity alternating magnetic field, which generates eddy currents by magnetic field induction, even in nonferrous objects. These eddy currents produce such force that the metal objects are forced off the heads of the roller at an angle, and the glass falls downward. Depending on the nature and weight of the glass, fragments of aluminum that are as small as 5 millimeters (mm) can be separated. The maximum size of fragments recommended for

separation is 40 mm (Glass, 1998a).

Boronizing transforms the surface of a piece of metal into a metallic boride layer, typically from 0.0254 to 0.127 mm (0.001-0.005 inch) in depth, at high process temperatures ranging from 900° C to 1,000° C (1,650° F-1,830° F). Metallic borides have high hardness (up to 2,100 Vickers Hardness), which is retained up to subcritical temperatures 649° C (1,200° F). A wide range of ferrous and nonferrous alloys can be boronized, including plain carbon steel, low alloy steel, tool and stainless steels, and nickel- and cobalt-base alloys. Victor Insulators, Inc., a manufacturer of electrical porcelain insulation, put boronized tools into production after tests showed positive results—tooling life was improved by 25% in some cases, and the boronized tools are more wear-resistance than the chrome-plated tools and need to be sharpened once a day instead of twice, and the process was 25% less expensive than chrome-plated tooling (Alwart and Ulrich, 1998, Ceramic Industry, 1998).

Transportation

Glass raw materials suppliers have experienced delays since Union Pacific Corp., the largest railroad company in the United States, acquired Southern Pacific Rail Corp. in 1996. The delays are caused by a shortage of rail equipment from Texas to California and by an increase in agricultural production of crops. The delays have increased some product shipment times to 6 weeks from 5 days. A Union Pacific spokesman reported that the company was hiring and had ordered more locomotives, but training new hires and getting the engines would take some time (Glass Industry, 1997).

Borax products from Boron were transported primarily by rail, although trucks are also used. Borax ranks as the number one bulk shipper in California on the Burlington Northern Santa Fe Railroad, which has a fleet of more than 700 rail cars.

Ocean transport was from the port of Wilmington, CA, where U.S. Borax owned the only remaining privately owned berth in the harbor. U.S. Borax ranked as the largest exporter of high-value dry bulk products and in the top 10 shippers of ocean containers out of the ports of Los Angeles and Long Beach. About 10 ships per year with a capacity of 40,000 deadweight tons each are loaded for locations around the world (Marcus, 1997).

IMC Global owned a spur to connect to the Southern Pacific Railroad between Trona and Searles Station. The Trona Railway, transported boron products that would be used in ceramics, high-temperature glassware, and insulation.

Prices

Prices of boron minerals and compounds produced in Argentina, Brazil, Turkey, and the United States are listed in Industrial Minerals Information Ltd. (1997) (table 3).

World Review

Argentina.—The Argentine Infrastructure Development Trust was created to develop the country's natural resource base

by using technology that allowed for the efficient, profitable, and environmentally safe extraction of mineral resources. The Trust was formed by the vision Office of the Secretary of Mines. It is the intention of the Trust to coordinate and seek common users of minerals that will make the mining industry in the region more competitive with the world economy (Burns, 1997).

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

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

Ulex S.A. produced colemanite and hydroboracite from its mine in the Pastos Grandes area of Salta Province. Ulexite, found in veins, was hand mined for resale to two boric acid producers. Processing involved crushing, washing, milling, and drying to produce a concentrate. Production capacity was reported to be around 10,000 tons per year for each of the minerals; most was exported (Kendall, 1997).

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

Boron Chemical International and Teck Corp., both Vancouver, Canada-based companies, were exploring and evaluating a number of ulexite deposits. One feasibility study was completed on a deposit close to the Chilean border that was expected to cost \$28 million for a 75,000-ton-per-year operation.

A study of the Pampa borax deposit owned by Champagne Miner Rio Grande S.A. showed that the boron oxide content of the ulexite ore grades between 30% and 34% of 1.7 million tons 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 (T.H. Pate, unpub. data, 1998).

Chile.—Quimica e Industrial del Borax Ltda. mined ulexite from Salar de Surire, the largest ulexite deposit in the world. The salar is located at an altitude of 4,250-meters in Monumento Natural de Surire, a national park. Production

capacity was around 200,000 tons of crude ulexite. The ore was trucked to El Aguila production facility north of Arica. Some of the ulexite was dried and sold, and the balance was reacted with sulfuric acid to produce from 25,000 to 30,000 tons per year of boric acid. The majority of production was exported through the ports of Arica, Iquique, and Antofagasta. The National Borax Corp., Cleveland, OH, packaged and distributed boric acid in the United States for Quiborax (Kendall, 1997).

Other small mines, such as Sdad Boroquimica Ltda., mined ulexite from salars in the north (Kendall, 1997).

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

China.—Numerous producers of borates were in the Liaodong peninsula in Liaoning Province. The ores are primarily magnesium borates, such as szaibelyite. Other production was from the playa lakes in Qinghai, where borate minerals, such as ulexite, pinnoite, hydroboracite, and borax, have been produced from brines. Total Chinese production of borate minerals was estimated to be 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 was characterized by high volumes of imported materials, mostly forwarded to the industrialized areas of Belgium, France, Germany, or the Netherlands for destinations in Central Europe, such as Austria, the Czech Republic, or Slovenia. The decision to import material is based on three elements—the geographic location, the range of service needed, and prices. Antwerp has the most central port location in Europe, with access to 188 major European cities (Szufiak, 1997).

Barges were the most efficient and reliable method of transporting goods in Europe, which had a 25,000-kilometer 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, the Baltic, the Black, and the Mediterranean Seas and the Atlantic Ocean. In 1992, the 170-kilometer canal linking the River Main to the Danube was opened in Germany. Borax used 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 than barges (Review, 1996).

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

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

1997).

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

Peru.—Cia Miner Ubinas SA and Quimica Oquendo SA, subsidiaries under the Inkabor name and owned by the Italian Colorobbia Group, mined ulexite. Ubinas mined at Laguna Salinas, 80 kilometers east of Arequipa. The open pit operation produced from 150,000 to 180,000 tons per year of ulexite ore during 6 or 7 months of mining. Large stocks were maintained for sales during the winter season. The crude ulexite is washed to produce a ulexite concentrate. The calcining plant operated 24 hours per day, producing 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 tons per year of boric acid and 15,000 tons per year of concentrated ulexite. Small quantities of calcined ulexite were sold in Peru for fertilizer, and the rest of the Inkabor S.A. output was exported (Inkabor S.A., Mining, accessed May 26, 1999, at URL <http://www.inkabor.com>).

Peru and Ecuador ended a half-century dispute by signing a peace treaty that settled ownership of a slice of Amazonian jungle that caused wars between the neighboring countries in 1981 and 1995. The 77-kilometer (48-mile) section has not been explored fully for its boron mineral potential because the area was left undefined after a 1941 border war (Washington Times, 1998).

Russia.—Boron ore reserves are concentrated in deposits of magnesias-karn and lime-karn formations found in Southern Yakutiya (Tayozhnoye), in Buryatiya (Solongo) and in the northeast (Nalyodnoye and Titovskoye). The boron-iron deposit at Tayozhnoye is of Archean age. Here, skarn ore bodies are found among dolomite, gneiss, marble, and shale. They were formed from magnetite and, sometimes ascharite (szaibelyite) and ludwigite. The reserves exceed 100 million tons of 34% boron. As of 1998, processing technologies to make the production profitable were not available (Alexeev and Chernyshov, 1997).

Reserves of commercial boron that have been in production since 1959 are associated with the Paleogene lime-karn deposit of Dalnegorsk. The deposit consists of calcite, datolite, garnet, hedenbergite, quartz, and wollastonite. Boron oxide content varies from 6% to 16%. The deposit was mined for datolite and limestone by Joint Stock Company Bor (JSC). At the sulfuric acid plant in Komsonolsk (Khabarovsk), datolite was treated to produce boric acid and calcium borate. JSC produced 90% of the Russian output of 220,000 tons of boric acid (Alexeev and Chernyshov, 1997).

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

The gypsum waste is used as a gypsum binding agent or mineral fertilizer.

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

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

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, Etibank Bankacilik A.O., the Government corporation. Ulexite was mined at Bigadic; colemanite, at Bigadic, Emet, and Kestelek; and tincal, at Kirka.

Bigadic Colemanite Works, in the Bigadic District of Balikesir Province, had 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 had a capacity of 400,000 tons per year of concentrate. This district was reported to have the world's largest colemanite and ulexite deposits. All products from Bigadic were for export.

In 1996, Emet Colemanite Works, located in the Emet District of Kutahya Province, had a production capacity of 736,000 tons per year of run-of-mine ores, from open pit and underground mines. Colemanite concentrate was 357,000 tons, 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. Since then, production has been from the open pit. In 1996, 33,000 tons of colemanite concentrate was produced.

The Kirka Borax Works near the Seyitgazi District of Eskisehir Province produced tincal concentrate, borax pentahydrate, and anhydrous borax. During 1996, the facility produced 950,000 tons of run-of-mine material. The concentrator had a capacity of 660,000 tons per year of tincal concentrates. A derivatives facility produced 184,000 tons per

year of borax decahydrate, 60,000 tons per year of anhydrous borax, and 320,000 tons per year pentahydrate borax.

The storage and loading facility at Degirmenozu had a railway connection to the port at Bandirma. At Bandirma, the facilities have the capacity of 100,000 tons per year of boric acid, 55,000 tons per year of borax, and 20,000 tons of sodium perborate (ÜNCÜ, 1998).

In addition to the Government's operations, private companies have processed boron reserves from stockpiles and dumps for the past decade.

Waste materials at colemanite operations in Turkey were studied for possible beneficiation to a usable product for ceramic glazes. By using 3-mm samples from the mine at Hisarcik, the boron oxide content could be raised to 52% from 22% by calcining for 30 minutes at 500° C (Asian Ceramics, 1998).

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 more than 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).

The Second International Symposium on the Health Effect of Boron and Its Compounds was held in Irvine, CA. Sponsors for the event included the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency, and the Food and Drug Administration as well as producers, including U.S. Borax, Etibank, and North American Chemical Co. The director of USDA's Western Human Nutrition Research Center (also the former chair of the National Academy of Science/Institute of Medicine's Food and Nutrition Board) stated that further research was needed prior to formalizing boron's scientific status as an essential element. Researchers have been studying how much boron is in a healthy diet and what role boron plays in maintaining and promoting health. Studies were conducted on boron's specific functions on growth, development, and reproduction performance. New studies on the effects of eliminating dietary boron on embryo development to determine what specific functions boron has on reproduction are underway. The Food and Nutrition Board's recommendations for essential trace elements like boron, should coincide with the third symposium (Coughlin, 1998).

Researchers at Kyoto University, Japan, found that an organic polymer with boron atoms is highly fluorescent with intense blue emissions. The polymer may be useful for light-emitting diodes, energy-storage systems, or nonlinear optical materials (Chemical & Engineering News, 1998c).

A substance that can selectively deliver large amounts of B¹⁰ to cell nuclei has been developed by a team of researchers at the University of California, Los Angeles. Such agents would be useful in neutron capture therapy, a form of cancer treatment.

In this process, the boron nuclide is selectively delivered to cancer cells, which are irradiated with neutrons to cause fission of boron into highly energetic particles that destroy the targeted cells (Chemical & Engineering News, 1998a; Rawls, 1999). Immunomedics, Inc., was granted a patent for a new process to treat cancers with selectively directed boron atoms. A biospecific antibody targets the cancer cells. After nontargeted materials have time to be excreted from the body, a second binder containing a large amount of boron atoms is injected. An imaging radioisotope attached to the boron compound indicates where the boron has localized. In this way, only boron atoms that are deposited in cancers and revealed by the imaging would be irradiated with neutrons, thus sparing normal tissues from being irradiated (Immunomedics, Inc., 1998).

A study was designed to determine if boards could be treated with a borate preservative by using traditional dip-fusion methods for control of wood decay fungi and wood-destroying insects. Various concentrations and storage conditions were tested, and their effects on diffusion were compared. Results indicated that aspen boards can be adequately treated with Tim-Bor, a borate preservative, by using these traditional methods (Puettmann and Schmidt, 1997).

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

Chemists in Germany have synthesized a unique structure among polyhedra of boron-group elements. Synthesis was completed for the unprecedented 12-member polyhedron (Chemical & Engineering News, 1999b). A new self-assembled monolayer comprising polyhedral borane derivatives was produced at the University of California, Los Angeles. The researchers hope that the unique electronic properties of polyhedral boranes will lead to monolayers with unique applications, such as electron-transfer mediators for bioelectrochemistry, monocomposites, or selective cations sensors (Chemical & Engineering News, 1999d).

Two borate compounds are being used for cationic catalysts in a wide variety of reactions. In an effort to prepare a "superweak" anion, the $(B_{12}B_{12})^{-2}$ ion is replaced by $(CB_{11}B_{12})^{-1}$. Carborane anions have enabled the preparation and stabilization of highly reactive cations. The purpose of the research is to produce an anion that is coordinated to the cations as weakly as possible so as not to disrupt the cations' structure or to interfere with its performance of chemical tasks. This appears to be a new realm of chemistry in which metal ions and elemental ions in unusual oxidation states could be produced (Dagani, 1998).

At the American Chemical Society Board of Directors meeting, the first recipient of the new Herbert C. Brown Award for Creative Research in Synthetic Methods was its namesake, who is best known for his Nobel Laureate award for studying the role of boron in organic chemistry for which he won the Nobel prize in 1979 (Chemical & Engineering News, 1998d).

Outlook

Production of boron minerals and compounds increased between 1993 and 1998. Production and imports reported in 1 year may be stockpiled and used during 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 increases in boron usage as a fire retardant.

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

TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS 1/

(Thousand metric tons and thousand dollars)

	1994	1995	1996	1997	1998
United States:					
Sold or used by producers:					
Quantity:					
Gross weight 2/	1,110	1,190	1,150	1,190	1,170
Boron oxide (B ₂ O ₃) content	550	728	581	604	587
Value	\$443,000	\$560,000	\$519,000	\$580,000	\$486,000
Exports: 3/					
Boric acid: 4/					
Quantity	87	75	42	92	106
Value	\$53,300	\$68,100	\$35,300	\$60,500	\$54,600
Sodium borates:					
Quantity	498	588	381	473	453
Value	\$165,000	\$227,000	\$133,000	\$169,000	\$146,000
Imports for consumption:					
Borax:					
Quantity	9	9	11 5/	54 5/	14 3/
Value	\$2,700	\$936	\$3,470	\$17,000	\$5,160
Boric acid:					
Quantity	20	16	25 5/	26 5/	23 3/
Value	\$12,900	\$10,100	\$10,800 e/	\$11,800 e/	\$12,500
Colemanite:					
Quantity	27	45	44 5/	44 5/	47 5/
Value	\$10,800	\$8,600	\$13,000 e/	\$13,000 e/	\$13,900
Ulexite:					
Quantity	120	153	136 5/	157 5/	170 5/
Value	\$24,000	\$39,300	\$27,200	\$31,400	\$34,000
Consumption: Boron oxide (B ₂ O ₃) content	296	NA	367	403	NA
World: Production	3,810 r/	4,020 r/	4,330 r/	4,360 r/	4,370 e/

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

1/ Data are rounded to three significant digits.

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

3/ Source: Bureau of the Census.

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

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

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE 1/

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

1/ Parentheses include common names.

TABLE 3
YEAREND 1998 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON 1/

Product	Price,	Price,
	December 31, 1997 (rounded dollars)	December 31, 1998 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works 2/	818	742
Borax, technical, anhydrous, 99%, bags, carload, works 2/	884	802
Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/	381	346
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works 2/	315	286
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works 2/	443	402
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works 2/	375	340
Boric acid, technical, granular, 99.9%, bags, carload, works 2/	883	801
Boric acid, technical, granular, 99.9%, bulk, carload, works 2/	819	743
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B ₂ O ₃ , 100-pound-bags, carlots	2,210	2,210
Colemanite, Turkish, 42% B ₂ O ₃ , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC 3/	295	295
Ulexite, Chilian, 38% B ₂ O ₃ , ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA e/	200	200

e/ Estimated.

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

2/ Chemical Market Reporter, v. 251, no. 1, January 1998, p. 23.

3/ Industrial Minerals, no. 375, December 1998, p. 78.

TABLE 4
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY 1/

Country	1997			1998		
	Boric acid 2/		Sodium borates 3/	Boric acid 2/		Sodium borates 3/
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	3,400	\$2,220	7,140	4,730	2,250	4,810
Belgium	2	14	71	--	--	1
Brazil	4,550	1,890	3,500	4,310	1,850	2,270
Canada	5,110	3,640	37,200	4,530	3,010	36,000
Colombia	157	165	1,100	157	164	1,830
France	128	284	1	40	14	2
Germany	258	1,860	6	41	65	39
Hong Kong	294	262	4,400	818	443	2,230
India	2	5	138	--	--	602
Indonesia	984	615	15,900	366	230	7,690
Israel	10	7	114	19	16	--
Japan	12,600	10,900	30,700	12,000	9,650	26,000
Korea, Republic of	6,730	4,450	24,300	9,360	6,080	14,100
Malaysia	303	350	6,270	385	423	4,340
Mexico	4,430	2,870	18,500	4,270	2,780	24,400
Netherlands	33,200	17,300	224,000	41,200	15,900	240,000
New Zealand	676	343	43	424	214	2,440
Philippines	27	34	2,860	46	33	1,820
Singapore	394	264	1,040	81	62	871
South Africa	118	60	323	--	--	161
Spain	5,320	2,240	58,500	8,610	2,950	58,700
Taiwan	8,280	4,830	12,200	8,610	4,990	7,640
Thailand	1,020	824	6,210	1,340	876	5,330
United Kingdom	100	139	1	101	116	108
Venezuela	680	505	1,350	194	188	430
Other	3490	4370	17,600	4,160	2,330	11,500
Total	92,300	60,500	473,000	106,000	54,600	453,000

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

2/ Harmonized Tariffs Code (HTS) 2810.00.0000.

3/ Harmonized Tariffs Codes (HTS) 2840.19.0000, 2840.30.0000, and 2840.20.0000.

Source: Bureau of the Census.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY 1/

Country	1997		1998	
	Quantity (metric tons)	Value 2/ (thousands)	Quantity (metric tons)	Value 2/ (thousands)
Argentina	--	--	37	\$50
Austria	8	\$5	16	33
Bolivia	4,000	2,080	4,170	1,990
Canada	51	46	22	60
Czech Republic	17	36	--	--
Chile	5,890	3,260	9,090	4,580
France	5	22	7	39
Georgia	--	--	34	69
Germany	46	38	16	35
Italy	1,610	1,580	877	1,110
Japan	280	287	130	185
Mexico	1	4	--	--
Peru	1,720	1,010	751	446
Russia	407	355	336	323
Spain	--	--	25	25
Tokelau	--	--	58	35
Turkey	6,170	3,020	7,800	3,490
United Kingdom	3	15	8	28
Total	26,000	11,800	23,300	12,500

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 6
BORON MINERALS: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Thousand metric tons)

Country	1994	1995	1996	1997	1998 e/
Argentina	215	245	342	270 e/	270
Bolivia (ulexite)	10	7	9 r/	12 r/	12
Chile (ulexite)	86	211	149	171 r/	160
China e/ 3/	188	140	157	136 r/	140
Germany (borax) e/	2	2	2	1 r/	1
Iran (borax) e/ 4/	1	1	1	1	1
Kazakhstan e/	30 r/	30 r/	30 r/	30 r/	30
Peru	30	41	39	40 e/	40
Russia e/ 5/	1,000 r/	1,000 r/	1,000 r/	1,000 r/	1,000
Turkey 6/	1,140	1,144	1,447 r/	1,510 r/ e/	1,550
United States 7/	1,110	1,190	1,150	1,190	1,170 8/
Total	3,810 r/	4,020 r/	4,330 r/	4,360 r/	4,370

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, 1999.

3/ Boron oxide (B₂O₃) equivalent.

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

5/ Russian borate ore reportedly grades 8.6% B₂O₃.

6/ Concentrates from ore.

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

8/ Reported figure.