

BORON

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Boron is produced domestically only in 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. Boron is priced and sold on an 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 domestic production.

Legislation and Government Programs

The Mineral Land Classification program of the California State Geologist was begun in 1977 under the authority of the California Surface Mining and Reclamation Act. Local government agencies are required by State law to incorporate the information provided by the State Geologist into their general plans and formulate mineral resource management policies that emphasize conservation and development of mineral deposits. Mineral commodities are separated into two categories, metallic and nonmetallic. Boron is included in the nonmetallic, or industrial minerals, category. Mineral land classification studies address the overall mineral potential of a region through the identification of local and regional geologic factors that control or influence the formation of mineral deposits. The California State Geologist provides local governments with maps and information regarding mineral resource occurrences essential in planning wise development of mineral deposits. About 33,000 square miles of land have been classified for mineral potential.¹

Cogeneration plants, part of boron processing facilities at both Boron and Trona, produce electricity for plant needs and sell excess 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. A wholesale power pool would begin by January 1997. The pool would buy power at the lowest rate available from utilities and independent producers and act like a commodities market, with new prices quoted every half hour. The State began deregulation plans when the Federal Government passed the Energy Policy Act in 1992. That law deregulated sales among wholesale power buyers but left end-users deregulation to the states. The plan included provisions that would implement rate-making based on performance factors. It is predicted that companies will comparison shop based on performance of the utility and the subsequent price of energy. The economic effect of selling cogenerated electricity at plants at Boron and Trona has not been determined.²

Officials from the Minnesota Pollution Control Agency and

Minnesota Department of Health are studying the health hazards of private wells along Lake Superior that contain high concentrations of boron. Boron is a natural element that occurs in the rock formations. Studies show that in large doses over long periods may result in male sterility. Thirty-six wells had levels as high as 5,000 parts per billion. The State has set 600 parts per billion as the safety threshold. A water filter has been identified that can effectively remove the boron. Municipal water supplies use surface water and are not at risk for boron contamination.³

Production

Domestic data for boron were developed by the United States Geological Survey (USGS) 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. All the four operations to which a survey request were sent responded, representing 100% of the total boron produced. (*See table 1.*)

American Borate Co. mined small amounts of colemanite and ulixite/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. started production in May of a salable product unique on the market. The product was 43% boron oxide that screened 81% less than 325 mesh. The in situ process offered economic advantages such as low initial capital investment, high production per man hour, as well as environmental advantages. The process used hydrochloric acid to dissolve calcium borate deposits 244 meters (800 feet) to 366 meters (1,200 feet) beneath the surface. Lime added to the boric acid solution precipitates a high-purity calcium borate. The continuous flow production facility averaged 50% boron oxide for the 6-month startup period. Arsenic levels of the product were less than 10 parts per million and iron content was in the 0.06% range. With the exception of the submersible pumps, all standard chemical process equipment was used. The hydrochloric acid was recycled using sulfuric acid to produce gypsum. Because the product is chemically precipitated, it has advantages in consistency of the chemical composition, i.e., high boron oxide content, low impurities, and consistent physical size. The design of a larger facility was initiated in November and Flour-Daniel, Inc., was awarded the design contract. Production of 30,000 tons per year with expansion to 90,000 tons per year was planned.

Fort Cady was chartered in 1989 to commercially develop the property. The first environmental applications were

submitted in April 1990 with the final permit issued in March 1995 for rates of 90,000 tons per year. The process was accepted by all environmental agencies because water usage was low, land disturbance was acceptable, and no organic material was used.⁴

North American Chemical Co. (NACC) operated the Trona and Westend plants at Searles Lake, in San Bernardino County, to produce refined sodium borate compounds and boric acid from the mineral-rich lake brines.⁵ The Trona Railway operated between Trona and Searles Station and connect to the Southern Pacific Railroad. The boron products transported were used in ceramics, high temperature glassware, and insulation.

NACC planned technical changes in its production operation planned to take effect in 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 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 design is the result of a computer based model. The model contains 37 data fields and 207 calculated fields. An actual field test was run against the model and pumping rates were selected to minimize the effect of surface water during the winter and spring.

U.S. Borax, Inc. (Borax), a part of Borax Consolidated Ltd. of the RTZ Corp. PLC of London, United Kingdom, continued to be a primary world supplier of sodium borates. The world-class sodium borate deposit was being developed as a modern open pit operation near Boron, CA. The deposit is a sequence of borax and kernite crystals together with claystone.⁸ Processing at the mine included blasting the overburden and the ore. The overburden is removed by electric shovels and 170-ton electric trucks. The borate ore is mined with a hydraulic shovel and transported by truck to a primary crusher in the pit. A conveyor belt transported crushed ore to stockpiles where a bucket-wheel reclaimer removed ore to a conveyor belt. Conveyor belts carry ore past separators that removed magnetic contaminants. The ore was crushed and screened.

Fine tinal ore was dissolved in hot borate solutions. Solids are removed during this process. The saturated borate solution was pumped into a series of thickeners to separate insoluble matter. Clear borax solution entered the vacuum crystallizers and is cooled to precipitate decahydrate- and pentahydrate-borax. After drying, the products were stored in two 18,000-metric-ton hemispherical storage structures or bagged and palletized.

Kernite ore was dissolved in a mixture of sulfuric acid and hot borax liquor. Classifiers separated insoluble matter with mechanical rakes. Fine insoluble matter was settled in a series of thickeners. The solution was filtered and pumped to tanks that feed the crystallizers where boric acid was formed. The boric acid crystals were washed, centrifuged, and dried. Production was stored in bins for sampling and then to storage silos for shipment.

The waste from the dry beneficiaton process was deposited

with other overburden and mine waste.⁹

The majority of material was shipped to Borax's storage in Wilmington, CA. Products made at Wilmington included ammonium borates, potassium borates, sodium metaborates, and zinc borate. All plants at Wilmington and Boron are registered to ISO 9000 and 9002 standards.

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 the largest 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 4% to 5% boron oxide is incorporated in the formulation to aid melting, inhibit devitrification, and improve the aqueous durability of the finished product.

Borates were also used in manufacturing high-tensile-strength glass fiber materials for use 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 fiber glass, calcium aluminoborosilicate glass typically contains between 6% and 8% boron oxide. Originally these glasses were used for electrical purposes, and low sodium levels were important. By 1995, major applications were reinforcements for plastics, but the low sodium tolerance still applied. 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 has a balance of mechanical, chemical, and electrical properties and at moderate cost, are widely applied in composites for aircraft panels and in filament-wound rocket motor cases. Fiberglass was also used in helicopter rotor blades and pressure vessels. Polymer composites for aerospace are defined as reinforcement fibers supported by a polymer binder known as a matrix. In structural polymer composites, the fiber is stiffer and stronger than the continuous matrix phase. In fiber-reinforced composites, the fibers, provide virtually all of the strength and stiffness.¹⁰

PPG Industries, Inc., planned to build a continuous-strand fiber glass manufacturing plant in Chester, SC. The \$50 million plant will produce reinforced fiberglass for composite applications. PPG planned to purchase the property, building, and infrastructure of Glass Fiber Technologies, which ceased production in 1986. PPG planned to install a furnace that used PPG proprietary manufacturing technology. The Chester plant is near the Shelby and Lexington, NC, PPG facilities. Plans are that the facility will be in operation by spring 1996 and will employ about 100 people with an annual production capacity of about 50 to 60 million pounds per year. The facility can be expanded to two or more furnaces as demand warrants.¹¹

Boron, added to glass in amounts between 10% and 13%

reduced the viscosity of the melt, assisted with fiber formation during processing, allowed for improved specific optical properties, increased resistance to aqueous or chemical attack, enhanced certain mechanical properties, and reduced the thermal expansion coefficient and thermal shock resistance of the borosilicate glass products. Scientific glassware products are usually fabricated in Pyrex borosilicate glass. This type of glass is resistant to heat up to 400 °C and to chemical corrosion from liquids and gases.¹²

Owens-Corning Fiberglas Corp. (OCF), formed on November 1, 1938, as a joint venture between Owens Illinois and Corning Glass, pioneered the production and use of glass fiber.¹³ OCF announced an additional 300 million pounds of fiberglass reinforcement capacity at three domestic sites. The increased capacity would require an investment of \$105 million over 3 years and come on-stream in 1997. A second furnace that would add 140 million pounds, nearly double current production, would be added in Jackson, TN. The other expansions were at Anderson, SC and Amarillo, TX.¹⁴

Construction of the Nation's first facility to produce a borosilicate glass from solid nuclear waste began at Savannah River Site, Aiken, SC. High-level nuclear waste that has accumulated during 35 years will be reprocessed and stored in stainless steel canisters for temporary storage before interment in a geologic repository. Boron and lithium are added to the sludge to improve the viscosity of the glass. If the viscosity is too low, excessive convection currents can occur, increasing corrosion and erosion. After vitrification at 1,150 °C, the glass is pored into the stainless steel canisters for interim storage.¹⁵

Borosilicate glass along with hazardous waste products, such as asbestos, was being turned into delicate glass figures by a partnership with Catholic University's Vitreous State Laboratory. Vitrification of the hazardous material worked on two levels. The furnace consumes organic chemicals and fuses inorganic matter into glass. Second, the glass was extremely durable. The Environmental Protection Agency has no concerns about vitrifying asbestos.¹⁶

Boron compounds continued to find application in the manufacture of biological growth control chemicals for use in water treatments, algicide, fertilizers, herbicides, and insecticides. Boron was applied as a spray and incorporated in herbicides, fertilizers, and irrigation water. Boron is a micronutrient essential to crop growth. Boron controlled and regulated a group of biochemical reactions vital to plants that include sugar synthesis, pollination, disease and frost resistance, and enzyme reactions.¹⁷

Boron compounds were used as flame retardants where they reduce flammability by melting and preventing oxygen from contact with the burning surface. Although not as effective as other flame retardants, they were less expensive. In cellulose materials such as timber, particle board, paper, wood fiber and cotton products, sodium borates and boric acid were used. Anhydrous borax was used in the manufacture of flame retardant fiberboard. In plastics, zinc borate was the most widely used borate compound. Ammonium pentaborate was an efficient intumescent additive for thermoplastic polyurethanes.¹⁸

Wood composites used small trees and maximized useful production of limited resources. Wood products were mixed with resin and wax and hot-pressed to produce waffle board, a stronger product than sawn timber. Disodium octaborate tetrahydrate and zinc borate were good wood preservatives against fungi and insects and fires with low toxicity to mammals and minimal environmental impact. Because of zinc borates' low solubility, it is more resistant to leaching than other borates and may make it suitable for ground contact applications. Powdered borates were easy to incorporate into composites during manufacture.¹⁹ Borates were also used as fire retardants in cellulosic insulation.

The alloys of the nonmetal boron and neodymium and iron metals produced the strongest magnetic material known. The magnets are used in automotive direct-current motors, computer disk drives, portable power tools, and home appliances.²⁰

Boron also was used as a bleaching agent in detergents and cleaning products, such as compact washing powders. Perborates carry active oxygen that form hydrogen peroxide in solution. Perborate tetrahydrate was displaced by perborate monohydrate, which was more soluble in cool laundry wash temperature conditions.

Morton International expanded production of dry sodium borohydride at its plant in Elma, WA, which manufacturers both liquid and dry forms of the product. With the new Elma output, Morton planned to discontinue dry sodium borohydride production at Danvers, MA.²¹

Prices

The price for ultra high-purity boron oxide increased. All other reported prices decreased. (*See table 3.*)

European prices of boron minerals were listed as \$290 to \$295 per ton for Turkish lump colemanite, 40% to 42% boron oxide content, free on board (FOB). Argentinean natural colemanite was listed as \$360 to \$400 per ton at 40% to 42% boron oxide content ground and bagged, FOB.²²

Foreign Trade

The General Agreement on Tariffs & Trade (GATT) that was signed into law in December 1994, and took effect January 1, 1995. GATT will lower chemical tariffs by an average of 30%. Chemicals, including borates, are the nation's 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 American firms. GATT changes patent enforcement 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.

The majority of material from the Borax facility in Boron was shipped to storage, loading, and shipping facilities at Wilmington, CA. A large part of the output was exported to

Western Europe from Wilmington to Botlek, Netherlands. ISO 9000 registration was achieved at distribution center and bulk borate terminal at Rotterdam, the boric acid plant at Coudekerque, France, at warehouses in Valencia, Spain, and Widnes, United Kingdom, and at laboratories at Guildford, United Kingdom. (See table 4 and 5.)

Notice of the competitive need limits and per capita gross national product limits for 1994 of the countries/products that lost generalized system of preferences (GSP) privileges on July 1, 1995, because they exceeded the competitive need limits in 1994, were published in the Federal Register May 30, 1995. The list included refined borax from Turkey.

World Review

Data on world borate deposits were collected between 1988 and 1995 by G. J. Orris for known borate deposits and sorted by county and then site name. Data for each deposit listed included location, mineralogy, host rock and age, associated volcanic rocks and ages, and references that refer to that site. The data were published in the USGS Open-File Report 95-842.

Argentina.—A 5-year plan for the mineral's sector, which runs from 1995 through 1999, was based on four strategic areas as follow: encouraging private investment; ensuring investment protection through a clear legal and fiscal framework; ensuring structural stability between the production of metals, nonmetallic minerals and construction materials; and promoting minerals related activity that is compatible with sustainable development. Argentina's mineral potential remains largely unknown. Until recently, minerals exploration was accorded a relatively low priority.

There is a fundamental relationship between tectonics, magmatism, and mineralization in Argentina. Mineralization resulting from chemical-sedimentary and magmatic processes formed borate-bearing Tertiary evaporite continental basins, such as Tincalayu and Sijes in Salta Province. Borax S.A. is the country's leading producer of borates from operations of salars in the Puna region.²³ 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. The tincal and ulexite are processed at Quijano, near Salta. Most of the production is shipped to South American customers through Campo Quijano.

Ulex S.A. produces colemanite and hydroboracite in Salta Province. Economical ore reserves are estimated to be in excess of 20 years at mining rates of 15,000 tons per year of hydroboracite and 10,000 to 15,000 tons per year of colemanite. The mine is located at about 4,500 meters elevation. At the Sol de Manana Mine, colemanite and hydroboracite ore are mined by open cast methods using bulldozers and front-end loaders and trucked to the El Paso processing facility about 15 kilometers away. Ulexite found in veins is hand mined for resale to two boric acid producers. Colemanite and hydroboracite ore is hand sorted and washed to remove impurities. The final product contains 42% boron oxide suitable for fiberglass or frit manufacture. Bulk and container material

is transported via railroad to the ports of Antofagasta or Tocopilla, Chile, and via railroad or truck to Buenos Aires, Argentina.²⁴

Boroquimica S.A. continued production of tincal from the Salar del Hombre Muerto and boric acid from Tincalayu in Salta Province. Tincal between 16% and 18% boron oxide is concentrated by washing and crystallizing to a 99.9% borax product. At Sijes in Salta Province, hydroboracite and colemanite are produced. Ulexite is produced by Boroquimica at Cauchari in Jujuy Province and at Diablillos in Salta Province.²⁵

The Loma Blanca borate deposit was explored between 1990-95. Reserves of kernite were reported as 20 million tons of 13.5% boron oxide. The deposit is rated as the third largest tincal deposit in the world after the Kirka, Turkey, and Boron, CA, deposits. The mine uses 35-ton trucks and a loader in an open pit mine. The strip ratio of waste to ore should average less than 1.75 to 1 over the first 20 years of the mine. The ore is transported 0.5 kilometers to drying pads adjacent to the preconcentration plant. After drying for 3 to 5 days, the ore is ready for batching to the magnetic separation facility to remove the clays. The resulting preconcentrate averages more than 26% boron oxide. The concentrate is trucked to the processing plant at Palpala. The concentrate is again sized and fed to magnetic separators. The final concentrates grade more than 38% boron oxide. The concentrate is dried to yield a product grading between 54% and 55% boron oxide. Products are shipped from the port at Antofagasta, Chile. The Loma Blanca deposit was owned by S.R. Minerals (Barbados) Ltd., a wholly owned subsidiary of S.R. Minerals Ltd., a private corporation incorporated in Alberta, Canada. S.R. Minerals Ltd. is a sister company of Smoky River Coal Ltd.²⁶

Bolivia.—Corban, S.A., a division of Empresa Minera Industrial, processes ulexite purchased from mines from the Salar de Uyuni. The largest ulexite mining area is the Rio Grande area, where 5,000 tons per month of ulexite is obtained from cooperatives allowed to mine on government reserves. Corban also owns numerous deposits in Potosi Province. Purchased or mined ore contains 20% boron oxide by weight but can reach 27% boron oxide after solar drying. The dried ore is trucked to a plant at Oruro, where the ulexite is dried until it reached between 37% and 40% boron oxide content. Borax decahydrate is produced by reacting the ulexite in hot water with trona minerals obtained from the Salar de Collpa Laguna. After cooling, the product is centrifuged and dried in gas-fired dryers and packaged. Production is currently 90 to 100 tons per month of borax decahydrate and 300 tons per month of 37% ulexite or 200 tons per month of 40% ulexite. Transportation is via truck from Oruro to Santa Cruz where the material is shipped via rail cars to Corumba, Brazil, and then to trucks for delivery. Some product is trucked to the Port of Arica, Chile, or, on rare occasions, to the Port of Iquique for shipping.²⁷

Chile.—Quimica e Industrial del Borax Ltda. (Quiborax) mined from Salar de Surire, the largest ulexite deposit in the world. Ulexite reserves were reported to be 1.5 million tons of 35% boron oxide. The salar is located at 4,250 meters altitude

within the border of the Monumento Natural de Surire, a national park of Chile. The mine shuts down between December and March for the rainy season. About 200,000 tons of crude ulexite are mined in the 6-or 7-month period. The ore is trucked to El Aguila production facility north of Arica. Quiborax operates six diesel units that can generate 2,375 kilowatt hours of capacity. Two steam generators of 6,000 kilograms per hour each produce steam for the boric acid process. The company operates a reverse osmosis treatment facility for water. About 30,000 tons of the ore is air dried, washed and sold as fertilizer and as feed stock for other chemical manufacture, such as fiberglass. The remainder of the 36.5% boron oxide ore is converted to boric acid by the addition of sulfuric acid. The hot solution is filtered and cooled to precipitate boric acid. The boric acid crystals are washed and dried. The waste liquor is reclaimed in solar ponds. From 24,000 to 30,000 tons per year of boric acid between 99.5% and 99.9% purity is produced per year. The products are exported from the ports at Arica, Iquique, and Antafagasta.²⁸ The National Borax Corp. (Cleveland, OH) packages and distributes boric acid in the United States for Quiborax.

Compania Minera Salar de Atacama (Minsal) is a joint-venture project between Sociedad Quimica y Minera de Chile SA (SQM), 75%, and Corporacion de Fomento de la Produccion (CORFO), 25%, at the Salar de Atacama. The first stage of the project is a \$90 million potassium chloride production facility to be constructed by 1996. The second stage involves lithium carbonate production to begin in 1997. The final stages involve potassium sulfate and boric acid production to be constructed at such time that the overall project is yielding a profit.

CORFO distributed detailed information on the planned auction of its 18.8% stake in the Minsal project to foreign investors through the embassies of South Africa and Israel. Production of potassium chloride began in November. In December 1995, SQM purchased the remaining 18.8% stake for \$7 million from CORFO. With this purchase, SQM owns 100% of the project. The European Union will remove generalized system of preferences status for imported Chilean fertilizer on January 1, 1996.²⁹

China.—The borates in the salt lakes of China are mainly found on the Qinghai-Xizang (Tibet) Plateau. The waters contain a mean value 85 milligrams per liter of boron oxide. The maximum value of boron oxide is 1,516 milligrams per liter.³⁰

In Liaoning Province, reserves were reported at 44 million tons of boromagnesite with 8.4% boron oxide content. Production was reported as 77,000 to 110,000 tons per year of borax and 10,000 to 18,000 tons per year of boric acid at the following production sites: Liaoning, Jilin, Qinghai, and Tibet.³¹

A Chinese company was to process 120,000 tons of boron-iron ore following recent success to separate the boron from the ore. The deposits in the Liaoning Province represent 64% of the country's total boron resources and 90% of these deposits are associated with iron.³²

India.—Submarginal borax reserves of 74,200 tons have

been estimated in Leh District of Jammu and Kashmir. Occurrences are also known in Surendra Nagar District of Gujarat and Jaipur and Nagaur Districts of Rajasthan.

Kazakstan.—Boron minerals were reported to be produced in Kazakstan. The Government was actively pursuing foreign investment to increase production capacity by improving efficiency to increase exports. The decision by Kazakstan to invite bids on these properties at this time reflects its keen interest to attract mineral exploration and mining companies as a matter of high national priority.³³

Netherlands.—Morton International Inc. planned to increase capacity by 40% for sodium borohydride solution at its Delfzijl plant. The increase is to keep pace with bleaching demands for production of high gloss papers. The bleaching process uses Borol, a 12% solution of sodium borohydride in 40% caustic soda.³⁴

Peru.—Compania Minera Ubinas S.A. and Quimica Oquendo S.A., owned by the Colorobbia Group of Italy, produces boron products under the Inka Bor trademark. Inka mined about 150,000 to 180,000 tons per year of ulexite at Laguna Salinas, a playa deposit located at 4,100 meters elevation near Arequipa. The brines of the playa are rich in boron, lithium, and alkali and alkaline earth compounds. Reserves of ulexite were reported to be 10 million tons of 32% boron oxide contained. The mining is dependent upon the weather and is usually limited to 6 to 7 months per year. Inka produces electricity and maintains a village to house workers. The mined ulexite is crushed, screened, and dried and passed through a strong magnetic field to remove clays. About 5,000 tons per year of agriculture grade ulexite and 15,000 tons of other ulexite is produced each year. Raw ulexite is also trucked to Quimica Oquendo at Lima, a subsidiary that produces 12,000 tons per year of boric acid. Most production is for export from the ports of Callao and Matarani.³⁵

Russia.—Primorsky Industrial Amalgamation, in Dalnegorsk, produces boron minerals from datolite containing between 6% and 12% boron oxide. Amalgamation is part of the Russian Agricultural Joint Stock Co. known as ROSAGROCHIM. ROSAGROCHIM coordinates the activities of about 100 companies.

Turkey.—Turkey's boron operations are under the control of the Government corporation Etibank. During September and November, large-scale strike action by metal and mining workers affected both boron plants and mines owned and operated by Etibank. When Turkish port workers joined the strike action, imports and exports were affected. In mid-October, the strikes at the port facilities ended. On October 17, workers at the Bandirma boron chemicals plants decided to take strike action. The workers continued to strike until November 10. Etibank was able to continue to deliver some goods, but at lower quantities.³⁶

Ulexite is mined at Bigadic; colemanite at Bigadic, Emet, and Kestelek; and tincal at Kirka. The company also refines tincal and colemanite ores and concentrates in the Kirka and Bandirma plants. Turkish boron minerals are generally processed by similar methods due to similar geochemical properties. Attrition

and scrubbing are usually applied as processing methods, and comminution and classifying methods are also employed for required particle sizes. Direct flotation is a well established physiochemical separation process used to separate boron minerals from clays using chemical reagents, such as collectors and frothers. The most conventional collectors for flotation were sulfonates such as sodium alkyl sulfonate.³⁷

The Bigadic borate district was reported to be the world's largest colemanite and ulexite deposits. Proven borate mineral reserves are 532 million tons and total reserves are estimated at 987 million tons (Etibank State Mining Co.). Several private companies operated mines when the deposits were nationalized in 1978. After nationalizing the borate mines, a detailed exploration of the deposits was undertaken by Etibank. The borates were formed in two zones separated by a volcanic unit. Borates were found in an upper zone up to 30 meters thick beneath sediments between 25 and 410 meters thick. A lower borate zone was found to be up to 65 meters thick at depths between 150 and 950 meters deep. The borate beds and associated sediments are dislocated by normal faults, which occurred after depositions of the upper borates.³⁸

Private processing of boron reserves from stockpiles and dumps have occurred for the past decade. One such company, Rasih ve Ihsan Maden sought capital to expand its processing of 3 million tons of boron reserves.³⁹

Yugoslavia.—A boron deposit estimated to contain 10 million tons of reserves at Raska in southern Serbia was announced. A 5,000 ton-per-year boric acid plant was planned to meet regional demand and for export.⁴⁰

Current Research and Technology

Borates were being tested with chlorine in domestic swimming pools. One problem has been the ability to maintain the correct concentration of chlorine. The chemical combination has reduced the levels of chlorine needed to maintain pool water sanitization. Testing in residential pools reduced algae growth, reduced in eye and skin irritation, and improved maintenance requirements.⁴¹

The U.S. Bureau of Mines conducted a mineral investigation of the 34,310-acre Diablo Mountain study area (OR-001-058), Lake County, OR. Brines within unconsolidated Quaternary and Pleistocene lake and playa sediments had marginally economical occurrences of borate and other evaporite minerals.⁴²

Studies were conducted on the boron isotope composition of 17 samples of boron minerals and the strontium ratio in 13 borate samples from the Kirka borate deposit in western Anatolia, Turkey. The boron isotope date is consistent with colemanite being precipitated from a more acidic brine than ulexite, and with borax being precipitated from a brine that was more basic. Models indicate that during precipitation of the borax, up to 90% of the dissolved boron was incorporated in the borax, whereas during ulexite precipitation 55% was incorporated. During colemanite precipitation only 40% dissolved boron was incorporated. The data indicated that a substantial portion of the boron in solution was either lost from

the basin during hydrologic processes or incorporated into nonborate minerals.⁴³

A convenient and economical process to make borazine was invented by chemists at the University of Pennsylvania, Philadelphia, PA. Borazine is used to make high-temperature, chemically resistant, polymers that are useful as precursors of boron nitride or boron nitride/silicon carbide ceramics. Sodium borohydride and ammonium sulfate were reacted in solvent to yield a 60% borazine.⁴⁴

Commercial production of a titanium diboride material began using the self-propagating, high temperature (SHS) process. In conventional titanium diboride processes, boron carbide and titanium dioxide are heated together leaving some carbide material as contaminants. The SHS process uses powdered metal and boron oxide, producing submicron particles. Once started, the self-sustaining reaction reaches temperatures of more than 2,000° C. Commercial application of the SHS process began for use in wire dies, cutting tools, and other abrasion and wear-resistant parts.⁴⁵ A new class of boron carbide ceramics requires sintering temperature of less than 2,000° C, and produces 99% density. The process enables a major reduction in production costs.⁴⁶

Although boronizing has been commercially available for 25 years, it is now well known. The process can provide a treatment to improve the capabilities of current materials to prolong the service life. Boronizing can be selectively applied to current material as a surface treatment. A boride layer is formed by diffusing boron into a base metal at high temperature. In some instances, boride plain carbon steel can replace tool steels, reducing manufacturing cost while improving performance. The surface hardness of borided tool steels is comparable to titanium nitride coatings. The presence of aluminum and silicon tend to promote a brittle structure and should be limited to 0.5%. Resulfurized and leaded steels promote layer spalling and cracking and are not suitable substrates. Nitride steels retard the diffusion of boron in steel. Although initial cost is higher, service life improvements justify the process.⁴⁷

A wet forming process for neodymium-iron-boron magnets, developed at Hitachi Metals Ltd., Japan, prevents degradation and improves performance. Known as the Hitachi Low Oxygen Process, the process involves application of a special type of oil to the powder during pressing but before sintering. The process uses finer powder enabling higher density and stronger magnetic fields. The magnets are in pilot production.⁴⁸

Outlook

Production of boron minerals and compounds have increased between 1990-95. One reason is that production and imports reported in 1 year may be 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. More recent decreases in domestic consumption have been attributed to decreases in glass consumption because

of less demand resulting from a recession. Moreover, one-half of domestic production is exported. Because of increases in production in other countries, this amount has decreased significantly during the past few years.

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

Ceramics and Glass.—Fiberglass was closely related to construction and transportation and was expected to increase.

Coatings and Plating.—Primarily used as a protective coating for steel products and as a glazing on ceramic tiles, boron usage increased 50% during the year. Future demand for this use is expected to increase during 1996.

Fabricated Metal Products.—Boron usage increased in metal products during the year. Usage in specialized metal was expected to increase.

Soaps and Detergents.—Usage in soaps and detergents increased. Recent concerns for environmental effects of chlorine has reversed the decline. Perborate bleaches have returned to name brand soap products. The usage of boron in soaps and bleaches was expected to increase by 4% per year during the next 5 years.

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TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS 1/

(Thousand metric tons and thousand dollars)

	1991	1992	1993	1994	1995
United States:					
Sold or used by producers:					
Quantity:					
Gross weight 2/	1,240	1,010	1,060	1,110	796
Boron oxide (B2O3) content	626	554	574	550	495
Value	\$443,000	\$339,000	\$373,000	\$443,000	\$372,000
Exports:					
Boric acid: 3/					
Quantity	47	80	75	87	75
Value	\$35,500	\$53,700	\$50,500	\$53,300	\$68,100
Sodium borates:					
Quantity	554 4/	489 4/	481 4/	498 4/	588
Value	\$206,000 e/	\$159,000 4/	\$181,000 4/	\$165,000	\$227,000
Imports for consumption: 4/					
Borax:					
Quantity	10	16	40	9	9
Value	\$3,260	\$5,330	\$1,230	\$2,700	\$936
Boric acid:					
Quantity	5	6	17	20	16
Value	\$3,780	\$4,340	\$11,900	\$12,900	\$10,100
Colemanite:					
Quantity	18	30	90	27	45
Value	\$4,390	\$16,100	\$48,600	\$10,800	\$8,600
Ulexite:					
Quantity	16	42	149	120	153
Value	\$4,060	\$11,300	\$40,700	\$24,000	\$39,300
Consumption: Boron oxide (B2O3) content	262	345	321	296	NA
World: Production	2,960	2,670 r/	2,680 r/	2,710 r/	2,390 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.

4/ Source: Bureau of the Census.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE 1/

Mineral	Chemical composition	B2O3 weight percent
Boracite (stassfurtite)	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 (boronatrocite)	NaCaB5O9 • 8H2O	43.0

1/ Parentheses include common names.

TABLE 3
YEAREND 1995 PRICES FOR BORON MINERALS AND COMPOUNDS PER METRIC TON 1/

Product	Price,	Price,
	Dec. 31, 1994 (rounded dollars)	Dec. 31, 1995 (rounded dollars)
Borax, technical, anhydrous, 99%, bulk, carload, works 2/	794 r/	794
Borax, technical, anhydrous, 99%, bags, carload, works 2/	843 r/	843
Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/	333 r/	333
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works 2/	283 r/	283
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works 2/	374 r/	374
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, works 2/	324 r/	324
Boric acid, technical, granular, 99.9%, bags, carload, works 2/	830 r/	830
Boric acid, technical, granular, 99.9%, bulk, carload, works 2/	780 r/	780
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% B ₂ O ₃ , 100-pound-bags, carlots	1,813	1,951
Colemanite, Turkish, 42% B ₂ O ₃ , ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC 3/	212	191
Ulexite, Chilen, 38% B ₂ O ₃ , ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA 3/	231	257

r/ Revised.

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. 247, No. 1, Dec. 1994, p. 27; V. 249, No. 1, Jan. 1996, p. 27.

3/ Bureau of the Census.

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

Country	1994			1995		
	Boric acid 2/		Sodium borates 3/	Boric acid 2/		Sodium borates 3/
	Quantity (metric tons)	Value (thousands)		Quantity (metric tons)	Value (thousands)	
Australia	1,600	\$895	6,790	1,490	\$754	6,710
Belgium	66	26	1,910	1	9	44
Brazil	2,320	795	488	2,480	982	1,140
Canada	7,250	4,860	39,600	5,150	3,540	35,600
Colombia	182	156	2,930	200	197	1,910
France	4,390	1,020	83	181	92	83
Germany	2,000	1,550	5	114	93	5
Hong Kong	963	559	3,280	585	448	5,060
India	--	--	620	--	--	694
Indonesia	2,720	1,430	11,400	1,800	991	12,500
Israel	89	58	186	105	88	173
Japan	14,500	12,500	27,600	11,400	10,800	27,600
Korea, Republic of	11,900	6,950	15,000	5,590	3,630	25,800
Malaysia	3,440	1,590	6,430	1,380	796	11,000
Mexico	6,740	3,420	22,800	6,700	3,250	18,200
Netherlands	5,950	6,200	263,000	16,400	27,200	329,000
New Zealand	218	118	2,370	504	262	3,010
Philippines	2,050	530	1,500	561	226	2,580
Singapore	884	391	1,950	197	149	1,460
South Africa	375	192	649	695	366	1,180
Spain	5,420	2,100	63,400	9,850	8,750	65,800
Taiwan	10,200	5,320	10,500	5,990	3,510	11,700
Thailand	2,380	1,650	6,810	1,380	1,020	7,310
United Kingdom	125	92	673	77	113	498
Venezuela	403	264	984	241	180	873
Other	1,190	613	6,750	1,450	661	18,500
Total	87,400	53,300	498,000	74,500	68,100	588,000

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

Country	1994		1995	
	Quantity (metric tons)	Value 2/ (thousands)	Quantity (metric tons)	Value 2/ (thousands)
Belgium	--	--	2	\$2
Bolivia	2,120	\$1,030	989	411
Canada	--	--	3	12
Chile	6,170	3,380	7,510	3,520
China	30	29	--	--
France	5	19	12	36
Georgia	--	--	42	27
Germany	20	28	11	13
Italy	5,650	3,990	1,240	1,290
Japan	134	186	180	161
Netherlands	41	26	18	11
Peru	--	--	471	249
Russia	470	484	438	425
Switzerland	1	1	--	--
Turkey	4,980	3,720	4,670	3,920
United Kingdom	25	38	4	5
Total	19,600	12,900	15,600	10,100

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	1991	1992	1993	1994	1995 e/
Argentina	116	125	146	140 e/	140
Bolivia (ulexite)	14	23	12 r/	10	10
Chile (ulexite)	97	203	117	86 r/	90
China e/ 3/	93	127	155 r/	120	140
Germany (borax) e/	3	2	2	2	2
Iran (borax) 4/	1	(5/)	1 e/	1 e/	1
Kazakstan e/	XX	100	90	80	80
Peru	26	27	27 e/	27 e/	27
Turkey 6/	1,210	1,059	1,079 r/	1,140 r/	1,100
U.S.S.R. e/ 7/	160	XX	XX	XX	XX
United States 8/	1,240	1,010	1,060	1,110	796 9/
Total	2,960	2,670	2,680 r/	2,710 r/	2,390

e/ Estimated. r/ Revised. XX Not applicable.

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 June 20, 1996.

3/ B2O3 equivalent.

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

5/ Less than 1/2 unit.

6/ Concentrates from ore.

7/ Dissolved in Dec. 1991.

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

9/ Reported figure.