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Borate deposits: An overview and future forecast with regard to mineral deposits

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ABSTRACT

The element boron does not exist freely by itself in nature, it occurs in combination with oxygen and other elements in salts, commonly called "borates". Over 250 boron-bearing minerals have been identified, the most common being sodium, calcium, or magnesium salts. Boron is a rare element in the nature (average content in the Earth's crust is 10 ppm), but extraordinary concentrations can be found in certain places. The formation of borate deposits can be summarized as follows; (1) a skarn group associated with intrusive and consisting of silicates and iron oxides; (2) a magnesium oxide group hosted by marine evaporitic sediments; (3) a sodium– and calcium–borate hydrates group associated with lacustrine (playa lake) sediments and explosive volcanic activity.

Borate is defined as any compound that contains or supplies boric oxide (B_2O_3). A large number of minerals contain boric oxide, but the four that are most important from a worldwide commercial standpoint which are borax, kernite, ulexite, and colemanite. These are produced in a limited number of countries, and Turkey has largest borax, ulexite and colemanite reserves in the world. All the countries are dependent upon colemanite and ulexite reserves of Turkey.

Borate exploration consists of detailed prospecting of favorable areas followed by drilling, and uses all the tools available to the exploration geologist. Most of the world's commercial borate deposits are mined by open pit methods. Brines from Searles Lake, and presumably the Chinese sources, are recovered by either controlled evaporation or carbonation. Boric acid is one of the final products produced from most of the processes.

Detail mineralogical and advanced chemical data on the individual borate minerals and associated minerals (such as clay and lithium minerals) will increase the knowledge of borate end-products and their incomes as well as creating new gateways to the high technology and research on the borate minerals. These types studies will be extremely important for borate and related mineral industry.

Very few modern industries can get by without borates, and very few people can get by without their products. When you consider the role boron plays in plant life, and by extension, all life, it's hard to imagine our world without it. Therefore, borates and their products could be one of the main topics for sustainable development in whole world.

1. Introduction

Borates are an unusually large grouping of minerals, but the number of commercially important borates is limited, and their chemistry and crystal structure are both unusual and complex. The accounts of the early exploration, mining, and processing of borates are fascinating, because their remote locations often led to unusual difficulties, and hardships in recovering the desired products. Specific conditions are essential for the formation of economically viable borate deposits in playa-lake volcano-sedimentary sediments: (1) formation of playa-lake environment; (2) concentration of boron in the playa lake, sourced from andesitic to rhyolitic volcanic, direct ash fall into the basin, or hydrothermal solutions along faults; (3) thermal springs near the area of volcanism; (4) arid to semi-arid climatic conditions; and (5) lake water with a pH of between 8.5 and 12.

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Boron's chemistry and reactivity are fascinating because they form a wide variety of oxygen compounds that occur in an essentially unending variety of simple to exceedingly complex molecules. The borates are among the most interesting of the world's industrial minerals, having been known and used since the earliest recorded history, first for precious metal working and later in ceramics [1,2].

Borate deposits occur in a limited number of Neogene to Holocene non-marine evaporitic settings [3-5]. In such areas, the subduction-related processes may have played significant role in the formation of borate-rich series [6-8].

Boron is enriched in continental crust, clastic sediments, and seawater- altered oceanic crust. Thus, the initial source and enrichment of boron was probably in a subduction environment via metasomatism of lithosphere by boron-rich fluids released from down-going altered oceanic slabs and possibly boron-rich pelagic sediments [9-12].

Boron is one of the rarer and more unevenly distributed elements in the Earth's crust, but there are extraordinary concentrations of boron on an industrial scale in some localized areas (Figure 1). Borate minerals are formed in various environments and in very different conditions. The most important economic deposits are very closely related to the Tertiary volcanic activity in orogenic belts. They are situated close to converging plate margins; characterized by andesitic-rhyolitic magmas; arid or semiarid climates; and non-marine evaporitic environments. Turkish, United States, South American and many other commercial borate deposits are non-marine evaporites associated with volcanic activity [12-15].

Four main metallogenic borate provinces, with exogenous deposits of continental environments, were recognized in global scale. They are Anatolia (Turkey), California (USA), Central Andes (South America) and Tibet (Central Asia). Generally, the origin of borate deposits is related with Cenozoic volcanism, hydrothermal spring activity, closed basins and arid climate. Borax is the major commercial source of boron, with major supplies coming from Turkey, USA and Argentina whereas kernite is main product from the Kramer deposit in USA. Colemanite, large-scale production of main calcium borate, is restricted to Turkey. Datolite and szaibelyite are confined to Russia and Chinese sources. Tincal (borax) deposits are present in the world: one in Anatolia (Kırka), another one in California (Boron), and two in the Andes (Tincalayu and Loma Blanca). Kırka, Boron and Loma Blanca have similarities in order to the chemical and mineralogical composition of the borate minerals with sequences colemanite and/or inyoite//ulexite//borax or kernite//ulexite//colemanite and/or inyoite. Colemanite deposits with or without probertite and hydroboracite are present in Anatolia (Emet, Bigadiç, Kestelek), Death Valley, California (Furnace Creek Fm.), and Argentina (Sijes). Quaternary borates are present in salars (Andes) and playa-lakes and salt pans (USA and Tibet).

Known borate deposits of Turkey were formed in the lacustrine sediments of Tertiary age during periods of volcanic activity which commenced in the early Tertiary period and continued at least to the beginning of the Quaternary. The lithology of the borate deposits shows some differences from one deposit to another, but they are, generally, interbedded with conglomerate, sandstone, tuff, clay, marl and limestone. Sediments in the borate lakes often show clear evidence of cyclicity. Borate minerals were deposited in separate of possibly interconnected lakes under arid or semi-arid climatic conditions within lake sediments.

Pyroclastic and volcanic rocks of rhyolitic, dacitic, trachytic, andesitic and basaltic composition are intercalated with these lacustrine sediments. The existence of volcanic rocks in every borate district suggests that volcanic activity may have been necessary for the formation of borates.

Figure 1. World major borate mines.

2. Mineralogy

By at least 3.8 Ga (Geologic age), boron had been concentrated sufficiently to form its own minerals, which are thought to have stabilized ribose, an essential component of ribonucleic acid and a precursor to life [16]. Boron is the only light element with two abundant isotopes, B^{10} and B^{11}; the former has a large capture cross-section that makes it an excellent neutron absorber. These two stable isotopes differ significantly in atomic weight so that boron isotopic compositions of minerals and rocks retain signatures from their precursors and the processes by which they formed. Boron compounds comprise a great diversity of crystal structures. Evaporites constitute the richest concentrations of boron on Earth, and thus are the main source of boron for its many applications in medicine, electronics and the nuclear industry.

Boron is a minor element in the Earth with an average concentration of 10 ppm in the upper continental crust. It occurs in many metamorphic and acid plutonic rocks in the mineral tourmaline. In sediments, it is present as detrital tourmaline and as a minor element in illitic clays.

Boron is never found in the elemental form in nature. Boron combines with oxygen and other elements to form borates which contain the BO_3 (triangular) or BO_4 (tetrahedral) structural coordination units [17]. These borate units may be polymerized similarly to the SiO_4 of the silicate minerals. This results in more than 230 naturally occurring borate minerals identified until 1996 [3,4,18,19] but the new analytical techniques allow the continuous identification of new borate minerals. Although borates can be formed with any cation, and form double salts with other anions, the most abundant minerals are formed with calcium, sodium or both elements. Borates are strongly ionic compounds, soluble in hot water, and as the cations are generally alkalis or alkaline earth elements, most of them are transparent and colourless having a glassy luster. Three different chemical formulation systems (structural, empirical, and oxide-like) are used in borate minerals. The main borate minerals present in evaporitic lacustrine deposits. Neogene ore deposits with boron concentrations allowing industrial exploitation are restricted to four groups of major borates: Ca-borates (inyoite, meyerhofferite, colemanite and priceite), Na-Ca-borates (ulexite and probertite), Na-borates (borax, kernite) and Mg-Ca-borates (hydroboracite) (Table 1). Other borates occur as minor phases and do not require the presence of the major ones [14,15,20,21].

Over 250 boron-bearing minerals have been identified, the most common being sodium, calcium, or magnesium salts [22]. Borax is the major commercial source of boron, with major supplies coming from Turkey, USA and Argentina, whereas kernite comes from USA. Colemanite, large-scale production of main calcium borate, is restricted to Turkey. Datolite and szaibelyite are confined to Russia and Chinese sources.

Table 1. Composition of principal boron minerals (Garrett, [3]).

Mineral	Empirical Formula	B_2O_3 Content, Wt %
Sassolite	$B(OH)_3$ or $B_2O_3.3H_2O$	56.4
Borax (Tincal)	$Na_2B_4O_7.10H_2O$	36.5
Tincalconite	$Na_2B_4O_7.5H_2O$	48.8
Kernite	$Na_2B_4O_7.4H_2O$	51.0
Ulexite	$NaCaB_5O_9.8H_2O$	43.0
Probertite	$NaCaB_5O_9.5H_2O$	49.6
Priceite (Pandermite)	$Ca_4B_{10}O_{19}.7H_2O$	49.8
Inyoite	$Ca_2B_6O_{11}.13H_2O$	37.6
Meyerhofferite	$Ca_2B_6O_{11}.7H_2O$	46.7
Colemanite	$Ca_2B_6O_{11}.5H_2O$	50.8
Hydroboracite	$CaMgB_6\ O_{11}.6H_2O$	50.5
Inderborite	$CaMgB_6\ O_{11}.11H_2O$	41.5
Kurnakovite	$Mg_2B_6O_{11}.15H_2O$	37.3
Inderite	$Mg_2B_6O_{11}.15H_2O$	37.3
Szaibelyite (Ascharite)	$Mg_2B_2O_5.H_2O$	41.4*
Suanite	$Mg_2B_2O_5$	46.3
Kotoite	$Mg_3B_2O_6$	36.5
Pinnoite	$MgB_2O_4.3H_2O$	42.5
Boracite (Strassfurite)	$Mg_3B_7O_{13}Cl$	62.2
Datolite	$Ca_2B_2Si_2O_9.H_2O$	21.8
Cahnite	$Ca_2AsBO_6.2H_2O$	11.7
Danburite	$CaB_2Si_2A_8$	28.3
Howlite	$Ca_4Si_2B_{10}O_{23}.5H_2O$	44.5
Vonsenite (Paigeite)	$(Fe,Mg)_2FeBO_5$	10.3
Ludwigite	$(FeMg)_4Fe_2B_2O_7$	17.8
Tunnellite	$Sr\ B_6O_{10}.4H_2O$	52.9

Sassolite, borax, kernite, ulexite, probertite, pandermite, colemanite, hydroboracite and szaibelyite are economically operated boron mines that have commercial importance.

3. Depositional setting and formation of borate deposits

As one of the 92 elements that make up the planet, it's not surprising that boron is all around us - in soil and water, plants and animals. Boron is one of the rarer and more unevenly distributed elements in the Earth's crust, but there are extraordinary concentrations of boron on an industrial scale in some localized areas. Borate minerals are formed in various environments and in very different conditions (Figure 2). The most important economic deposits are very closely related to the Tertiary volcanic activity in orogenic belts. They are situated close to converging plate margins; characterized by andesitic-rhyolotic magmas; arid or semi-arid climates; and non-marine evaporite environments. Turkish, United States, South American and many other commercial borate deposits are non-marine evaporites associated with volcanic activity [6,13,21].

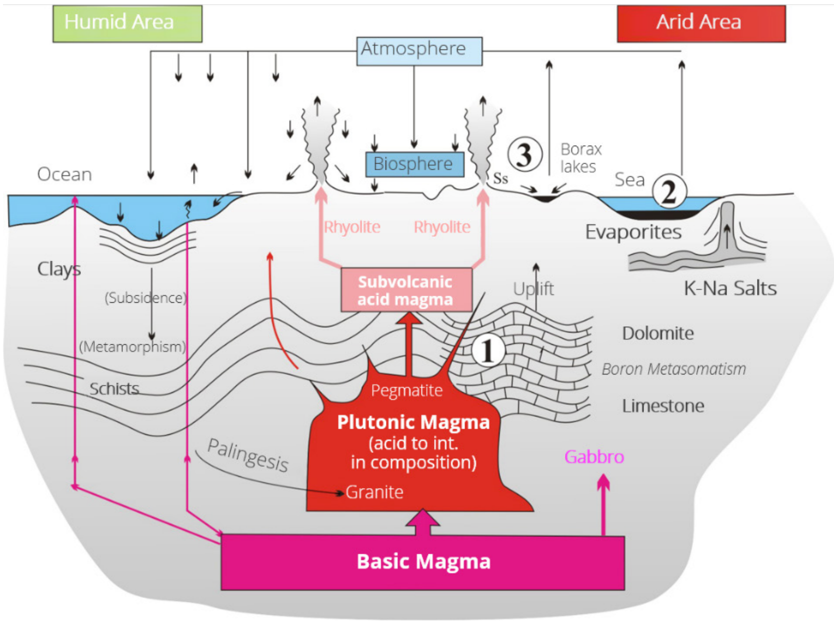

Figure 2. Scheme for the cycle of boron. 1. Skarn Deposits; 2. Marine Deposits; 3. Playa-lake Deposits (Modified after Watanabe, [12]).

Arid to semiarid climatic conditions are required for the deposition of economic amounts of the soluble borates by evaporation. According to Muessig (1966), hydrated borates may accumulate in several ways within a nonmarine basin. They may be deposited in layers in a spring apron around a borate spring, with ulexite, borax, or inyoite as the primary borate mineral [18]. Borates may also form in a pool dominantly fed by a borate spring, with borax crystals formed in bottom muds or at the intermittently-dried margins, as at Clear Lake, CA and at Salar de Surire, Chile [14].

Papke (1976) concluded that if the spring flows are low or intermittent, evaporation develops a surface efflorescence or precipitate, or an accumulation of crystals just below the surface; these are the marsh or playa deposits of early mining in California and Nevada and some of the salar deposits of South America. Finally, there are lake deposits, whose occurrence required much more than seasonal flooding; these are the borax and kernite deposits such as in Boron, California (USA) and Kırka (Turkey), formed by chemical precipitation in a closed basin [14].

Borate minerals may be subdivided, for convenience, into three broad groups with respect to their origin and geological environments. These are: A) Skarn mineral group is associated with intrusives and consists of silicates and iron oxides; B) Magnesium oxide group hosted by marine sediments; C) Hydrates sodium and

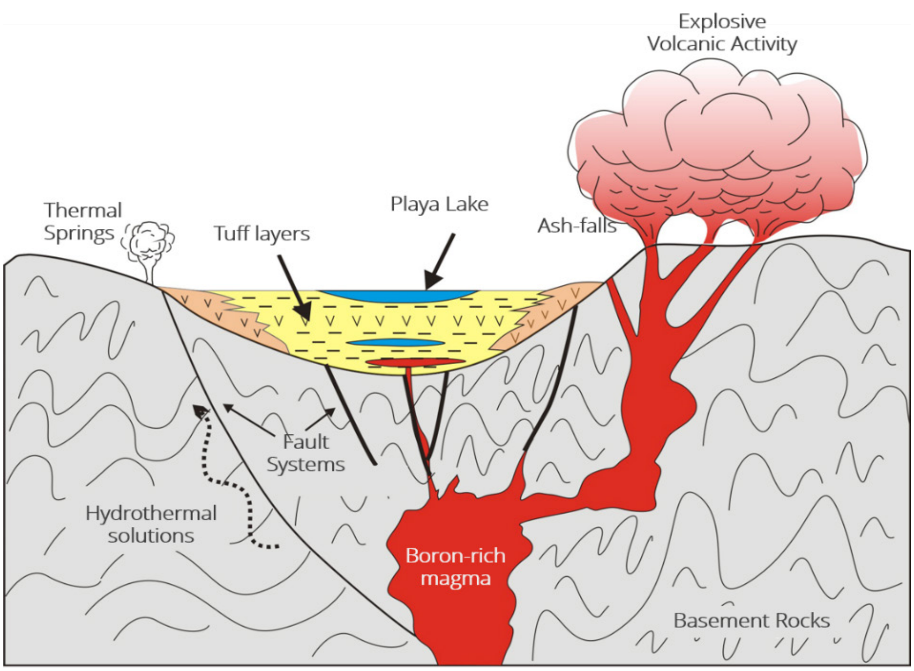

Figure 3. Generalized playa lake depositional model showing the formation of borate deposits in Neogene basins of western Anatolia, Turkey (after Helvacı, [21]).

calcium borate group related to lacustrine sediments and volcanic activity. A large number of minerals contain boric oxide, but the six that are the most significant from a worldwide commercial stanpoint are: colemanite, ulexite, borax, kernite, pandermite and hyroboracite.

Borate deposits of Turkey, as of other countries, originated as chemical precipitates and are found interbedded with clays, mudstone, tuffs, limestones, and similar lacustrine sediments. There is evidence that most of these deposits were closely related in time to active volcanism. Thermal springs and hydrothermal solutions associated with this volcanic activity are therefore regarded as the most likely source of the boron (Figure 3) [14,23-27].

Boron minerals are found in various geological environment:

1. a skarn group associated with intrusives and consisting of silicates and iron oxides;
2. a magnesium oxide group hosted by marine evaporitic sediments;
3. a sodium– and calcium–borate hydrates group associated with lacustrine (playa lake) sediments and explosive volcanic activity.

The following conditions are essential for the formation of economically viable borate deposits in playa-lake volcanosedimentary sediments:

- formation of playa-lake environment;
- concentration of boron in the playa lake,
- sourced from andesitic to rhyolitic volcanics, direct ash fall into the basin, or hydrothermal solutions along graben-margin faults;
- thermal springs near the area of volcanism;
- arid to semi-arid climatic conditions; and
- lake water with a pH of between 8.5 and 12.

4. Borate exploration

There are extraordinary concentrations of boron at an industrial scale in some localized areas (Figure 1). Borate minerals are formed in various environments and in very diverse conditions. The most important economic deposits are very closely associated with the Tertiary volcanic activity in extensional Neogene basins. In some instances they are situated close to converging plate margins, characterised by andesitic-rhyolitic magmas, arid or semi-arid climates and non-marine evaporite environments.

Borate exploration consists of detailed prospecting of favorable areas followed by drilling and utilizes all the tools available to the exploration geologist. The recognition of trends of favorable host rocks and structures is an important guide to areas that are of possible interest. Satellite imagery, both real and false color, and standard photo interpretation can be successfully used under certain conditions.

In most parts of the world, the identification of a Cenozoic suite of non-marine fine-grained sediments and tuffs is the usual starting point for the field geologist, because most commercial borates are found associated with these rocks. Because many borates are associated with volcanic rocks, volcanic centers, flows, ash deposits, and tuffs, particularly if zeolite-bearing, may also be favorable guides to borate prospecting [14,20,28].

The skarn borates of Eastern Europe and Asia were found by careful prospecting in geologically preserved fold belts where limy sediments are in contact with potassic to alkaline volcanics. Datolite and danburite occur in skarns where the limestone was originally rich in calcium and silica; axinite, kotoite, and ludwigite skarns are hosted by dolomitic limestones. The magnesium borates and those associated with iron ores are generally of low grade. Marine borates are sought in tectonically stable areas with shallow to outcropping salt structures, with gypsum caps, where near surface borate deposits are identified by whitish soil cover and scanty vegetation [23].

In arid regions, ulexite often accumulates at, or just beneath, the current surface of salt flats and playas, indicating that boron is moving in the system. These recent crusts may also indicate brine deposits containing boron values of interest. Springs and recent spring deposits containing anomalous borates may also be used as a guide to ore in certain areas.

Geochemical surveys [29] are useful methods of narrowing down prospect areas to a drill target. Both soil and rock chip sampling techniques are utilized in exploration programs with boron, strontium, arsenic, and lithium as a common suite of elements. Beryllium is also used in the search for skarn borates in Russia, as are complex B-Mg-Ca-Cl ratios. Water sampling, both surface and well (subsurface), may be useful. Certain plants are boron sensitive and vegetation surveys might prove interesting, but only the Russians have done much work in this area.

Geophysical surveys, particularly gravity and magnetics, are used to outline target basins or structures beneath sedimentary basin fill. Resistivity and seismic surveys have been used to define basin structures and formations which may be associated with the borates in that area. Various downhole well logging techniques, including natural gamma and neutron probes will indicate the approximate percentage of borates and clay in zones of special interest.

Geologic mapping followed by drilling is still the definitive test in most areas of the world. While rotary drill methods may be used, cores are generally taken of the most prospective zones. Assays of B_2O_3 and other associated elements (arsenic, lithium, strontium) are then run on the horizons that appear favorable for borates. Because the saline borates are water soluble, short core runs are used, but the common borates generally core well with recoveries above 90%.

Under current economic conditions, bedded deposits of borax, colemanite, and ulexite are not generally sought at depths greater than 500 m. Brines with a high borate content, particularly those associated with other salts of value, might be extracted from greater depths under certain circumstances. The skarn and magnesium borates are economical only from surface and near surface excavations at this time.

Borate exploration consists of detailed prospecting of favourable areas followed by drilling, and uses all the tools available to the exploration geologist.

- contribution of Miocene volcanics and volcanoclastics interbedding within sediments;
- to Neogene playa-lake basins;
- formation of capping limestone;
- claystone–limestone–marl intercalations;
- evidence of hot springs or hydrothermal solutions carrying boron into the playa lake;
- and evaporitic horizons or an indication of leaching of them.

When considering its geochemical behavior [3,6] boron shows a very high mobility in the earth crust and therefore, it is rather difficult to find unaltered borate minerals at or close to earth surface. Rapid alteration by the effect of water and CO_2 calcite forms and boric acid is washed away according to the following reaction:

$$\underset{\text{Colemanite}}{2CaO.3B_2O_3.5H_2O} + \underset{\text{Carbonic acid}}{2CO_2 + nH_2O} \rightarrow \underset{\text{Calcite}}{2CaCO_3} + \underset{\text{Boric acid}}{6H_3BO_3} + (n\text{-}4)\,H_2O$$

5. World resources of borates

A large number of minerals contain boric oxide, but the three that are the most important from a worldwide commercial standpoint are: borax, ulexite, and colemanite. These are produced in a limited number of countries, dominated by Turkey, the United States, and South America, which all together furnish about 90-95% of the world's borate supplies [14,30]. Production in the United States originates in the Mojave Desert of California; borax and kernite are mined by US Borax from its large deposit at Boron, and a limited amount of colemanite is probably mined by Newport Mineral Ventures from Death Valley. There are over 40 borate deposits located along and 885 km trend in the high Andes near the common borders of Argentina, Bolivia, Chile, and Peru, of which at least 14 are currently in production.

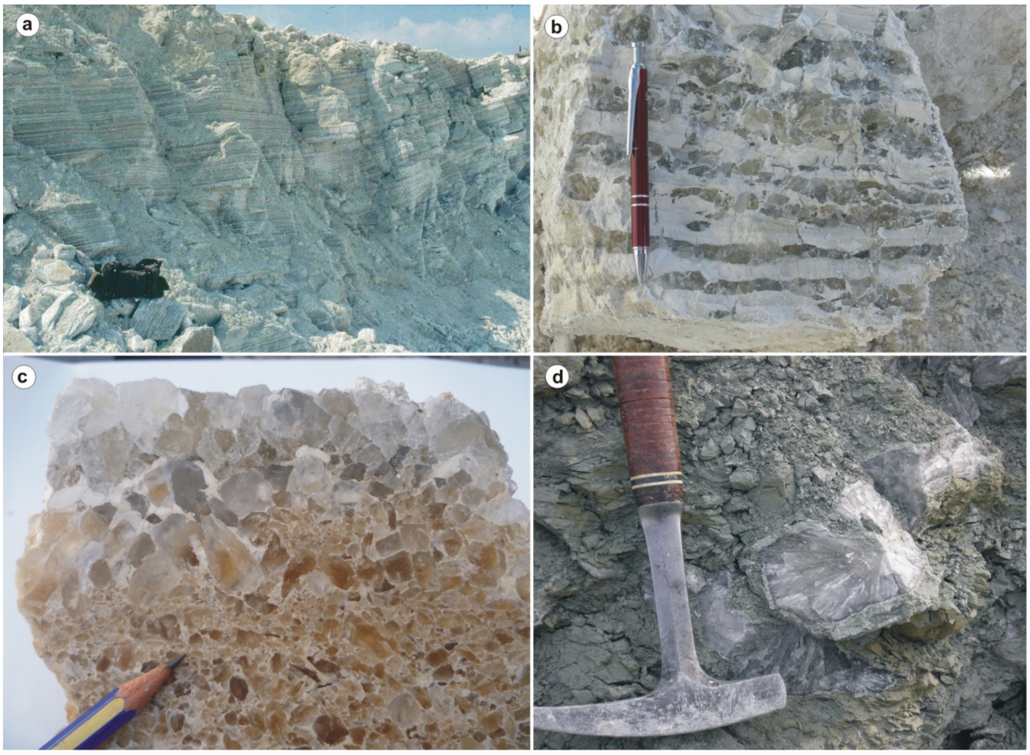

Figure 4. a) Borax and dolomitic clay alternations, Kırka opencast borax mine, Kırka deposit, Eskişehir. b) Borax layers and dolomitic clays alternating in Kırka borate deposit, Turkey. c) Massive crystalline borax lithofacies. The borax crystals show zone growth (matrix inclusions) at the top. Borax crystals are transparent and rectangular to equant. These crystals have variable size and are surrounded by an lutitic matrix. d) Colemanite is principal borate mineral and is interclated with green clay as nodular and lensoidal lenses, Espey open pit mine, Emet, Turkey.

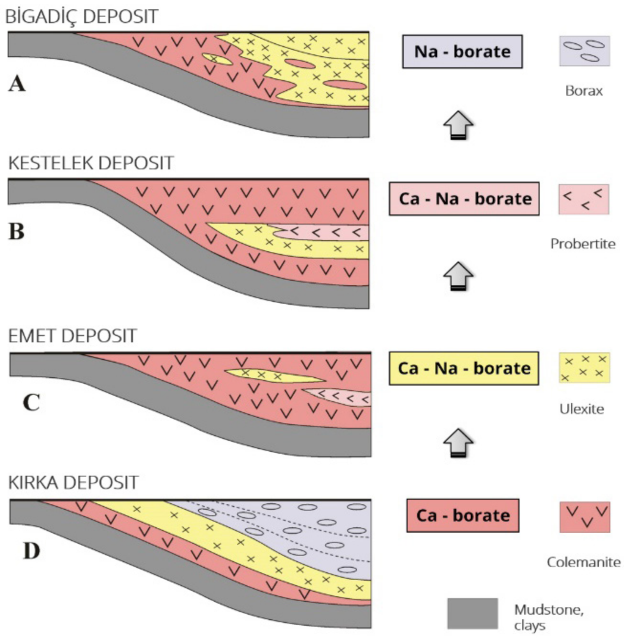

Figure 5. Sequence of boron mineral formations in Turkish borate deposits (Helvacı, [15]).

Neogene basins which spread on a wide scale in west Anatolia, contain lignite, bituminous shale, uranium, borate deposits and several industrial raw materials. Considering that only boron mines of those mentioned above, include 80% of world reserves. The western Anatolia borate district contains five distinct areas. From the west to east they are: Bigadiç, Sultançayır, Kestelek, Emet and Kırka [31,32]. This district contains the largest borate reserves in the world [14].

Turkish borate deposits were formed in the Tertiary lacustrine sediments during periods of volcanic activity, forming in separate or possibly interconnected lake basins under arid or semi-arid climatic conditions [4,14,15,20-23,25,31,33-35]. Sediments in the borate lakes often show clear interconnected lakes, and volcanosedimentary sequences exceed over 1000 m in the deposits, and they are intensively dislocated by NE-SW and NW-SE-trending gravity faults (Figure 4, 5).

Turkey has an important share in the world markets with borax (tincal) production in Kırka; colemanite and ulexite production in Emet, Bigadiç and Kestelek regions. Turkey is the biggest colemanite producer of the world and the visible and potential reserves are greater compared to current production. The most pessimist observers even agree on the fact that these reserves may last longer than a couple of hundred years (Table 2) [36].

Eti Maden Works and the private sector should cooperate in producing end products from boron minerals, thus follow marketing and industry oriented research policies. The country's resources need to be evaluated in a planned and programmed manner.

6. Mining and mineral processing

The sodium borates borax (tincal) and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite make up 90% of the borates used by industry worldwide. Most borates were extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru (Figure 6).

Boron compounds and minerals were produced by surface and underground mining and from brine. Commercial borate deposits in the world are mined by open pit methods. The Kırka mine in Turkey are huge open pit mines utilizing large trucks and shovels and front end loader methods for ore mining and overburden removal similarly to the world's major borate operations (Figure 7). Ores and overburden are drilled and blasted for easier handling. Boron operation uses a belt conveyor to move ore from the in-pit crusher to a coarse ore stockpile form which it is reclaimed by

Table 2. The reserve and life estimates of the world borate deposits (Helvacı, [21]).

Country	Known economic reserve (million tons of B_2O_3)	Total reserve (million tons of B_2O_3)	Estimated life of known reserve (year)	Estimated life of total reserve (year)
Turkey	224.000	563.000	155	389
USA	40.000	80.000	28	55
Russia	40.000	60.000	28	69
China	27.000	36.000	19	25
Chile	8.000	41.000	6	28
Bolivia	4.000	19.000	3	13
Peru	4.000	22.000	3	15
Argentina	2.000	9.000	1	6
Kazakstan	14.000	15.000	10	10
TOTAL	363.000	885.000	253	610

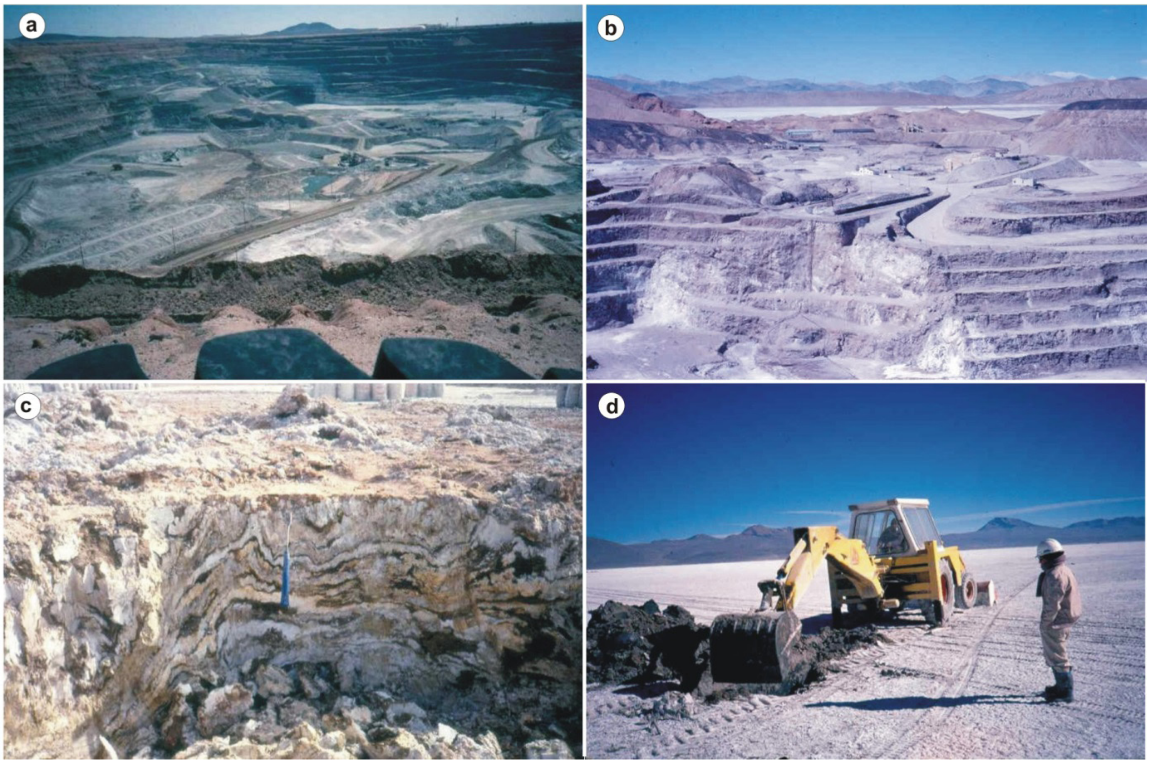

Figure 6. a) Boron open pit mine, California, USA. b) Tincalayu open pit mine, Argentina. c) Salar de Pastos Grandes, Argentina. d) Exploration of borate distribution at Lake Salinas, Laguna Salinas, Peru.

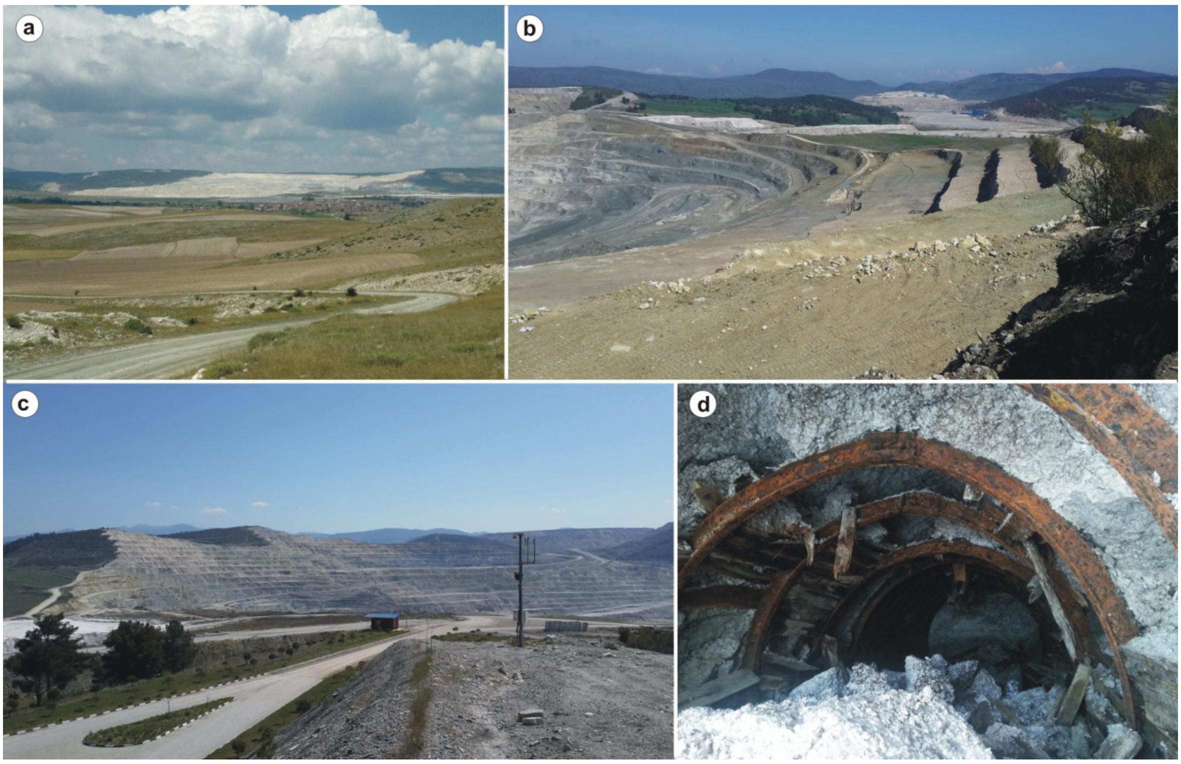

Figure 7. a) Kırka opencast borax mine, Kırka deposit, Eskişehir. b) Simav opencast mine, Bigadiç area, Turkey. c) Tülü opencast mine, Bigadiç area, Turkey. d) Old mine adit, Simav mine, Bigadiç area, Turkey.

a bucketwheel that blends the ore before it is fed to the refinery. Brines from Searles Lake, and presumably the Chinese sources, are recovered by either controlled evaporation or carbonation. Boric acid is one of the final products produced from most of the processes.

In terms of mining, operation of Turkish boron mines are immensely susceptible with respect to geography, transportation, energy, etc. compared to other countries (especially Latin America, USA and China) and suitable for marketing. For instance, boron deposits in South America are at an altitude of 4000 metres and those in North America are located in the middle of the desert, hence it is difficult and problematic to mine the deposits.

Borax decahydrate, borax pentahydrate, anhydrous borax, boric acid, sodium perborate tetrahydrate, sodium perborate monohydrate and anhydrous boric acid are economically significant chemical boron components. Turkey, USA, Russia, China, Kazakhstan, Italy, Argentine, Bolivia, Peru and Chile are prominent countries that produce boron minerals and products (Figure 8). Borax, kernite, colemanite, and ulexite are the main boron minerals, which provide the source for most of the world's production from Turkey, South America, and the United States [3,4,12,14,15,19,21,37,39].

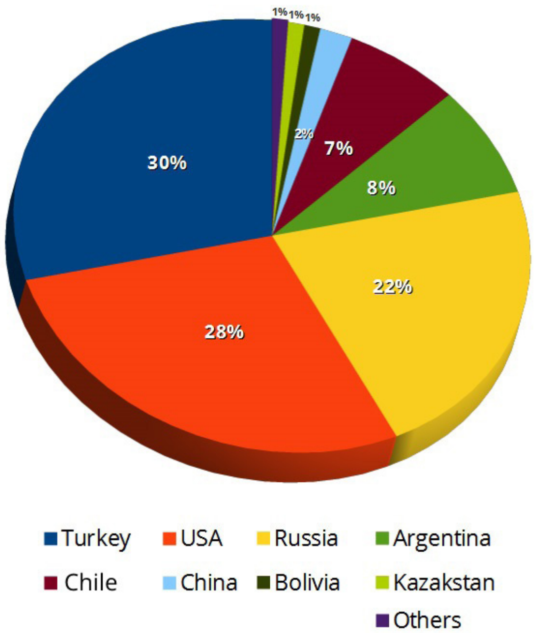

Figure 8. World borate production (Helvacı, [21]).

Processing techniques are related to both the scale of the operation and the ore type, with either the upgraded or refined mineral (borax, colemanite, and ulexite) or boric acid as the final product for most operations (Table 3) [33]. Borax-kernite ores (Boron, Kırka, Tincalayu) are crushed to 2,5 cm and then dissolved in hot water/recycled borate liquor. The resultant strong liquor is clarified and concentrated in large counter-current thickeners, filtered, fed to vacuum crystallizers, centrifuged, and then dried. The final product is refined borax decahydrate or pentahydrate or fused anhydrous borax, or is used as feed for boric acid production. Colemanite concentrates are used directly in specific glass melts or used as a feed for boric acid plants. The ulexite from most of the South American salars is air dried, screened, and bagged. It is then combined with locally available sulfuric acid to produce a relatively low grade boric acid or exported as feed for boric acid plants elsewhere.

Boron mineral and its products are indispensable industrial raw materials of today. They are widely used from hygiene to health, from durable materials to space industry. Boron minerals and products used in different branches of industry, compose of major industrial utility products such as; fibreglass, medical applications and pharmaceutical materials, for safety purposes in nuclear reactors, artificial fertilizers, in photography, glass and enamel. Used in several compound forms like borax and boric acid, boron creates multi-faceted and useful components. The subject compounds provide an advantage especially in strong soldering, in welding, in reducing friction and in processes of metal purification.

Table 3. Commercial refined borate productions.

Product	Formula	% $B_2 0_3$
Borax decahydrate	$Na_2B_4O_7$ $10H_2O$	30,5
Borax pentahydrate	$Na_2B_4O_7$ $5H_2O$	47,8
Boric Acid	H_3BO_3	56,3
Borax anhydrous	B_2O_3	100,0
Sodium perborate	$NaBO_3$ $4H_2O$	22,0
Raw borax anhydrous	$Na_2B_2O_3$	69,2

Borax and boric acid, with their property to diminish bacteria, to dissolve easily in water and to soften the water perfectly; are extensively used in the making of soaps, cleansing agents, detergents, officinal products, textile colouring, protection of different materials, low resistant alloys and agricultural industry. Some of boron products, because of their structure as a perfect melting matter, are irrevocable materials in metal purification and production of steel, atomic reactors, ignition switch fuses, lamps in electronic tools and solar batteries. "Cubic boron nitride" its main raw material a boron compound is used in production of commercially named "borazon", harder than diamond; "Boron nitride" as a termic isolator used in producing durable materials like"boron carbide"; "boron tricloride", "boron triflouride" and boron esters are used in the making of durable industrial products like oil refineries as catalyzers. Boron compounds; diborane (B_2H_6), pentaborane (B_5H_9), decaborane ($B_{10}H_{14}$) and alkali borons are foreseen as the potential jet and rocket fuels of the future [40,41].

The principal uses of borates have not changed much in the past decade and major markets include fiberglass, insulation, textile or continuous-filament glass fibers, glass, detergents and bleaches, enamels and frits, fertilizers, and fire retardants (Figure 9).

In certain organisms, borates can inhibit metabolic processes. One of the key chemical effects is seen in laundry detergents and other cleaning products, where borates are important components in bleaching

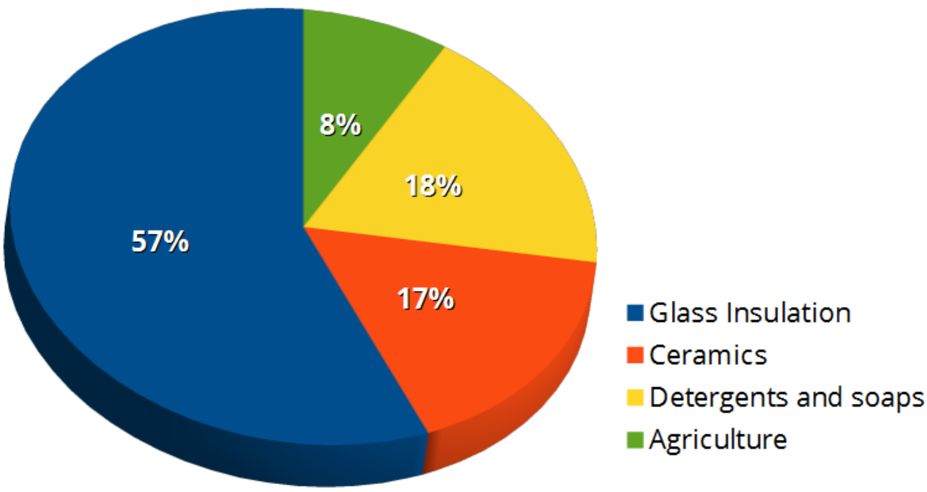

Figure 9. World borate end uses (after Helvacı, [21]).

and stain removal. The chemical properties of borates serve to balance acidity and alkalinity in many applications. Borates are able to bond with other particles to keep different ingredients dispersed evenly and are used to control viscosity in paints, adhesives and cosmetics. Borates modify the structure of glass to make it resistant to heat or chemical attack. Borates interact with surfaces containing iron to form a coating which protects the metal from corrosion. Combined with zinc, borates are used to retard flames and suppress smoke in polymers that coat electrical cables. Borates also act as a flame retardant in cellulose insulation. Borates absorb neutrons in applications ranging from nuclear containment shields to treatments for cancer.

7. Conclusions

Although some reports declare 72-73% in their annual reports, approximately 75-80% of the world's boron reserves are located in Turkey (Table 2) [42]. Turkish borate deposits are the largest and highest grade (respectively 30, 29 and 25% B_2O_3) of colemanite, ulexite and borax (tincal) deposits in the world and have sufficient potential to meet the demand for many years. Turkey's potential of visible and prospective boron mines is greater than its supply. Even the most pessimistic observers are unanimous on the opinion that these reserves might meet demands for a couple of hundred years. All countries in extensively using these minerals are dependent on Turkey's boron supplies.

Standard of living going up rapidly, advancement of scientific and technological discoveries will eventually result in the demand and necessity for perfect boron compounds. Production and marketing of boron minerals should be directed towards end products with a high added-value, instead of raw or semi-finished products, and related investments have to be realized. Boron products have a high added-value and they have a strategic role in the area they are used. Recently, boron products have been utilized in different fields of industry and shown an increase parallel to technological innovations as standard of living going up rapidly, advancement of scientific and technological discoveries will eventually result in the demand and necessity for perfect boron compounds (Figure 10).

Production policy should be grounded on a detailed

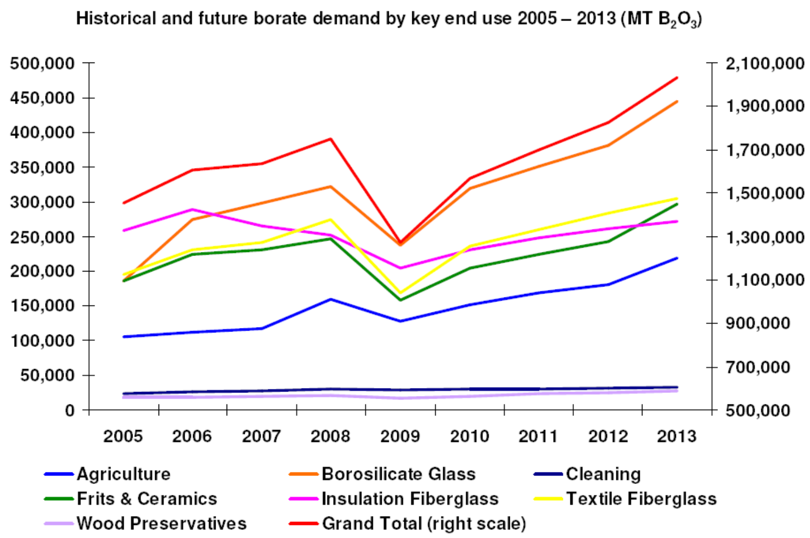

Figure 10. Present and future borate demand by key end use 2005-2013 (MT B_2O_3) (Rio Tinto Inc.,[40]).

and thorough market research. These important underground resources must be restructured and organized to ensure maximum return for the country's economy. Further research on mineralogy and chemistry with regard to borate minerals and associated minerals will increase the knowledge of borate end-products. Research and technological development towards production of end-products with a high added value, should take first place in the fundamental restructuring, rather than the mineral boron raw and semi-manufactured products. Borate and their products could be one of the main topic for sustainable developments of the world.

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