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Boron Minerals: Geological Distribution, Economic Significance, and Applications

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Abstract

Boron (B), a critical micronutrient, plays a vital role in various biological and industrial processes. This study provides a comprehensive review of the main boron minerals, including borax (sodium borate), kernite, colemanite, and ulexite, with a focus on their geological distribution, particularly in the Mojave Desert. These minerals serve as significant sources of boron, with tincal and rasorite emerging as key contributors to global reserves. Notably, the estimated global reserves of boron minerals are approximately 210 million tonnes, with major deposits located in countries such as Turkey, the USA, Argentina, and China. The economic implications of boron mining are explored, highlighting Turkey's substantial contributions to global boron production and its strategic importance in the mineral market. The applications of boron extend to agriculture, medicine, and various industrial sectors, though many health-related claims lack robust scientific validation. Furthermore, this paper discusses the sustainability of boron resources amid increasing demand and technological advancements that may influence their criticality in the future. By analyzing the dynamics of boron mineral resources, this study aims to enhance understanding of their significance in both environmental and economic contexts, thereby informing policy and research directions for sustainable boron management.

Keywords: Environmental, sustainable, natural resource, boron, boron-containing products

INTRODUCTION

Minerals of Boron (B, Atomic Number 5)

Borax, hydrated sodium borate (Na_2O-$2B_2O_3$-$10H_2O$), kernite (rasorite), and hydrated sodium borate (Na_2O-$2B_2O_3$) were the main boron minerals. Tincal (borax ore) and rasorite (kernite) ores are significant sources of boron. The Mojave Desert is home to both ores. Tincal is the main source of boron in Mojaves. Several naturally occurring boron and oxygen compounds are known as borate minerals. While most borate minerals are uncommon, some form sizable deposits that are mined for profit. Perhaps boron has antioxidant effects. Boron is widely used to treat vaginal yeast infections and boron deficiencies.

In addition, it is used to treat osteoarthritis, osteoporosis, menstrual cramps, athletic performance, and a host of other ailments; however, few claims have solid scientific backing. Boron is a trace mineral that plays many important roles in metabolism, making it essential for human, animal, and plant health. A recent study has revealed that boron may have been required for the evolution of life on Earth. In terms of boric oxide, the estimated global reserve of boron minerals is 210 million tons. Among the nations possessing significant resources are the USA, Argentina, Chile, China, Peru, Russia, and Turkey. Borax, also known as $Na_2B_4O_5(OH)_4$-

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$8H_2O$, is a borate mineral that can be found in arid regions as a surface efflorescence and in evaporite deposits of alkaline lacustrine environments. It is the main mineral extracted from deposits in Boron, California, and the surrounding areas, and the main supply of borax for commercial use.

Natural Resource

In this study, boron (B) was studied to review the suggested resources. Boron and borate have historically been extracted primarily by mining boron-containing minerals, such as colemanite, ulexite, tincal, and kernite. Relevant deposits were handled using the usual economic mine ethics. The natural history of non-metallic elemental boron has not yet been studied. From an academic standpoint, boron is considered a nonmetal in Group 13 of the periodic chart. Boron has an empty p-orbital and a low electron count. One of the types of boron examined is amorphous boron, which is a black powder inert to oxygen, water, acids, and alkalis. In contrast to semimetals, which are often appraised in a range of forms and given by substances pertinent to bleach and glass formation, boron is robust and heat-resistant, making it useful in semiconductor manufacturing, fertilizer production, medical science, and other fields. Boron is a mineral found in food, medicine, and everyday environments. It is used to strengthen bones and muscles, treat osteoarthritis, and improve cognitive functions and motor coordination. Pure boron has unknown chemical characteristics and is difficult to prepare. Boron has traditionally been a poor electrical conductor; however, at high temperatures, it transforms into a good conductor. Boron has been shown to yield elements with greater tensile strength than usual. Boron and its derivatives are used to produce both refined and unrefined goods such as acid borique, anhydrous borax, borax pentahydrate, borax decahydrate, and sodium perborate.

The lakes provided mineral tributary feed in this process. To prevent contamination in humans, borate products are being studied worldwide. The presence of borates in the human body and diets found in the sea. Gravity methods have traditionally been used to upgrade boron ore; otherwise, boron minerals are concentrated by scrubbers and then screened and classified to remove clay minerals [1].

Raw to Compromise Socialism

Mining operations are important for a country's wealth and development. They provide a nation's economy with the highest added value. Mineral resources and their effective use are largely due to the prosperity of developed nations. Turkey has extensive mineral reserves, including boron, marble, trona, chromium, and other raw industrial minerals. With 803 million tons [2], it accounts for approximately 72% of the world's total boron deposits. The largest producer, Eti Holding, accounts for 31% of the global production of B_2O_3. The tenor and quality of these boron reserves are very high. Additionally, 60% of the world's boron reserves have been sufficient to meet the demand for 250–500 years. Tincal, colemanite, and ulexite are the three most significant boron in Turkey. After the United States, Turkey is the second-largest producer of boron. 92% of its boron minerals are exported, with 8% used domestically. The opposite pattern is true for the US State of Affairs. The remaining boron reserves are exported, with only 60–65% being used domestically.

Monthly Estimate

No elemental boron exists in the natural world. They are always present in their oxidized states as borate salts. The most economically viable borate deposits come in four mineral forms: two sodium borates (tincal and kernite), one calcium borate (colemanite), and one sodium-calcium borate (ulexite).

Areas with arid climates and active tectonic plates have borate deposits. Large deposits can be found in the Tethyan belt in western Asia, the Andean belt in South America, and the Mojave Desert in the United States, close to Boron, California [3]. The majority of borates are extracted in Turkey and California.

Dynamism of System

There is significant uncertainty regarding the number of years that a relatively high number of minerals will be available, in contrast to some critical minerals that are anticipated to experience impending supply shortages, such as indium. One of these minerals, boron, has been the subject of debate in literature regarding reserve and supply estimation. The rapid invention and pursuit of new boron-consuming technologies and alternatives to boron-consuming products have raised concerns about the long-term viability of minerals. To comprehend how boron minerals might meet future demand given their diffusion and application in important boron-consuming sectors, as well as how diffusion may affect its price and exploration activity intensity as well as important growth indicators such as gross domestic product and population, it is necessary to first determine whether boron minerals will become a critical resource on a global scale. To do this, a model that captures system dynamics and only partially addresses complexity was created to predict how the diffusion of boron-containing products can change on a global scale, and how long boron reserves can be used to satisfy the corresponding demand. When a fast diffusion scenario is achieved, boron minerals may transition from no criticality to a high criticality [4]. According to the slow diffusion scenario, the yearly consumption of borate will increase from 1,800 kilotons in 2017 to 12,200 kilotons in 2117, meeting boron needs for the next 100 years. As boron reserves increase through 2078, the price of boron ore steadily drops to one-third of its present price of $1,620 per Biodate. Competitive history following a brief description of boron's distribution on Earth in rocks, soil, and water, the history of its discovery, early use, and geologic genesis is summarized. Borate mineral concentrates, borax, boric acid, and other refined products have a variety of modern applications, including glass, fiberglass, washing goods, alloys and metals, fertilizers, wood treatments, insects, and micro-biocides. The chemistry of boron has been examined in light of its potential negative effects on health. The study concludes that boron is likely complexed with hydroxylated species in biological systems, that the stimulation and inhibition of enzymes and coenzymes are crucial to the mechanism of action, and that boron is found in all types of rocks, soil, and water. The majority of the Earth's soils contain less than 10 ppm of boron, with areas of the western United States and other locations from the Mediterranean to Kazakhstan having the highest concentrations. The average soil boron content ranges from 10 to 20 ppm, and most of the world suffers from boron deficiency [5]. The average amount of boron in the Earth’s crust is 10 ppm, with basalts having a boron content of 5 ppm and shales having a boron content of 100 ppm. The boron concentrations in the soil varied from 2 to 100 ppm. Boron concentrations in seawater range between 0.5 and 9.6 ppm, with an average of 4.6 ppm. Freshwater concentrations typically vary from less than 0.01 to 1.5 ppm, with higher levels occurring in areas with significant soil boron concentrations. Rare and often found in arid areas with a history of volcanism or hydrothermal activity, highly concentrated deposits of boron minerals, invariably in the form of compounds containing boron linked to oxygen, are economically significant. These deposits are exploited for extraction in Turkey, the United States, and several other countries. Concentrations of borate minerals and refined products are produced and distributed worldwide. They are used in a wide range of applications including glass and related

Vitreous, washing bleach, fire. This context was provided by the International Symposium on the Health Effects of Boron and its Compounds, which also addressed the use of boron as a micronutrient in fertilizers, flame retardants, and other applications. The extensive chemistry and significance of borates are dominated by their capacity to create trigonal and tetrahedral bonding patterns as well as complexes with organic functional groups, many of which are biologically important.

To set the stage for papers that discuss the effects of boron on health, the current review will provide an overview of boron, covering its sources, uses, and chemistry. Distributive evaporite

Naturally occurring borates are the primary economic source of boron. Borates have been used as precious metals for over 4,000 years and are now crucial elements in contemporary industry. Although borates have been extracted from other sources, the main commercial sources of borates today are three minerals from nonmarine evaporites: borax, colemanite, and ulexite. These significant commercial deposits are located in tectonically active extensional regions at the plate boundaries and are linked to Neogene volcanism. The world's largest borate reserves are situated in western Anatolia (Turkey), one of the most important continental borate provinces, along with the United States, Argentina, Chile, Peru, and China [6].

By-Product

One of Turkey's most valuable natural resources is its abundance of boron minerals. In terms of reserves and mineral quality, Turkey has great potential for boron minerals. Boron minerals are used extensively and increasingly in a variety of industries, including the glass and detergent industries, as well as metallurgical, agricultural, and nuclear uses. One of the most crucial elements is boron, which is used most frequently worldwide. Therefore, industry is one of the most significant pillars. Natural structures composed of boron oxide (B_2O_3) in varying ratios are known as boron minerals. More than 200 naturally occurring boron-containing minerals, including tincal, colemanite, kernite, ulexite, pandermite, boracite, szaibelyite, and hydroboracite, are commercially important. Tincal, Colemanite, and ulexite are three readily accessible boron minerals in Turkey. These minerals are composed of sodium, calcium, and sodium with calcium and boron bonds. These minerals can first be physically processed into concentrated boron, which can then be refined and transformed into various boron chemicals [7]. Most of the time, boron is consumed in the form of boron chemicals. In addition, the boron concentration is directly consumable. Products made from borax are used in a variety of industries, including glass, ceramic, and polymeric materials, nanotechnology, aerospace and aviation, nuclear applications, military vehicles, fuel, electronics and communications, agriculture, metallurgy, and construction industries [5–7]. Boron-containing products are used in nearly 75% of these industries, including glass, ceramics, agriculture, and detergents.

Allocative Pursue

The rate of new boron mineral discoveries is higher now than it has been in the previous ten years, suggesting that the diversity of boron minerals in the Earth's crust has no obvious upper limit. Using a finite Zipf-Mandelbrot (fZM) model and Sichel's Generalized Inverse Gauss-Poisson model (GIGP), the large number of rare events (LNRE) models calculated from 295 species of B minerals discovered through 2017 gave a total predicted B mineral endowment in Earth's crust of 459 ± 65.5 and 523 species, indicating a very real limit of no more than 500 species. LNRE modeling assumes no changes in the discovery of minerals between the late 18th century and early 2017.

This is a warning provided by Hazen, Hystad, and their co-authors. However, changes might account for the inconsistent indications, since this condition is not the case [8–10]. The most significant changes include the following: (i) the introduction of the electron microprobe, which began to be widely used in 1978 for the chemical analysis of B minerals, (ii) improvements in single-crystal X-ray diffractometry, (iii) improvements in electron microscopy, including the introduction of electron backscattered diffraction, (iv) improvements in micro-Raman spectroscopy, and (v) modifications to mineralogical nomenclatures, particularly those pertaining to the tourmaline supergroup. The size of the studied able mineral grains is predicted to be reduced by changes (i) through (iv), increasing the number of studied able species. Additionally, if a species' distribution is fractal (i.e., diversity is independent of scale), then the examination of smaller and smaller grains will reveal an even greater variety of species. A descriptive model of the 146 B minerals discovered until 1978 was chosen as the cutoff point because (i) the electron microprobe later played a significant role and (ii) the number of species was half that of today, to assess the effects of these changes on the LNRE modeling. This model generated 306 (fZM) and 359 (GIGP) species in total; hence, whether the fZM or GIGP distribution is chosen, the greater the availability of smaller grains made available by better analytical instrumentation has improved estimates of total endowment by 50% since 1978. Given that we anticipate further technological advancements in the future, we do not believe that the estimate of 500 B species represents the end of the story [8]. The natural limit set by the minimum number of unit cells required for a new mineral to be viable may represent a more realistic conclusion, and LNRE modeling may still demonstrate that the total amount of B minerals present on Earth is finite. According to an examination of the past patterns of new boron mineral discovery, only 19% of B minerals were synthesized before being discovered. This can help us predict what to expect in future discoveries.

Synthetic compounds are not the most promising source of new B minerals. In contrast, 29% of B minerals have unique structures, and 22% of them were discovered before being synthesized, indicating that they do not have synthetic analogs or share an isostructural relationship with any known minerals. As a result, 41% of the B minerals could not be predicted, and we conclude that the universe of B minerals that have not yet been discovered contains a sizable number of surprises.

Trade

Boron is a non-metallic strategic mineral resource that is crucial to the growth of emerging strategic national industries. This study examines the evolution of global trade and anticipated future rivalry for boron ore using a complex network approach, core-periphery model, and link prediction model. The study discovered that: (i) Boron ore trade volume and demand worldwide exhibited a yearly growth trend, with closer trade ties and greater trade effectiveness. (ii) Boron ore export and resource availability are closely related [9]. Turkey, the world's largest nation in terms of reserves and production, currently holds an absolute export initiative in boron ore trade worldwide. The level of economic development has a significant impact on the imports of boron ore. Among the major importers under control are China and the United States, with Europe serving as a key transit region. (iii) International trade in boron ore is experiencing an increase in import competition, which is both intense and concentrated. Turkey is the main source of this competition, and currently, it is essentially a contest between economically developed nations, with "China-US-India-Europe" as its focus point; other import rivalries are affected by geography. (iv) As emerging economies begin to experience potential import competition, the center of the conflict will gradually shift from Europe and Asia to Latin America, Africa, and the Caribbean. Countries with geographical advantages, such as coastal locations, ports, and proximity to boron ore deposits, will have more trade options and higher potential for competitive development.

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