



University of Belgrade  
Technical Faculty in Bor



Chamber of Commerce  
and Industry of Serbia

# XV International Mineral Processing & Recycling Conference



INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

# Proceedings

Editors:  
Jovica Sokolović  
Milan Trumić

17-19 May  
2023

Belgrade  
SERBIA





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# **XV** International Mineral Processing & Recycling Conference

## **PUBLISHER:**

*University of Belgrade, Technical Faculty in Bor*

## **FOR THE PUBLISHER:**

*Dean: Prof. Dr Dejan Tanikić*

## **EDITORS:**

*Prof. Dr Jovica Sokolović*

*Prof. Dr Milan Trumić*

## **PROCEEDINGS COVER DESIGN:**

*Vojislav Jotović*

## **PRINTED BY:**

*Grafomed - Trade Bor d.o.o., Bor, Serbia*

*Printed: 200 copies*

## **PUBLICATION YEAR:**

**2023**

=====  
CIP - Каталогизacija у публикацији  
Народна библиотека Србије, Београд

622.7(082)  
502.131.1:628.477.6(082)  
628.477.6(082)

INTERNATIONAL Mineral Processing and Recycling Conference (15 ; 2023 ; Belgrade)  
Proceedings / XV International Mineral Processing and Recycling Conference, IMPRC, 17-19  
May 2023, Belgrade, Serbia ; editors Jovica Sokolović, Milan Trumić. - Belgrade : University,  
Technical Faculty in Bor, 2023 (Bor : Grafomed Trade). - XII, 634 str. : ilustr. ; 25 cm

Na vrhu nasl. str.: Chamber of Commerce and Industry of Serbia. - Tiraž 200. - Bibliografija uz  
većinu radova.

**ISBN 978-86-6305-133-1**

а) Руде -- Припрема -- Зборници б) Отпадне материје -- Одрживи развој -- Зборници в)  
Отпадне материје -- Рециклажа -- Зборници

COBISS.SR-ID 114566153

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***Conference is financially supported  
by Republic of Serbia,  
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## INVESTIGATION OF THE POSSIBILITY OF VALORIZATION OF TWO BORATE SAMPLES FROM THE DEPOSIT "POBRĐE" – BALJEVAC

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**ABSTRACT** – Boron is a rare element from the group of non-metals and it occurs in nature in over 250 boron-bearing minerals-borates. Turkey has the largest borate reserves and is their largest producer. Serbia has significant borate resources, for now without exploitation and processing. This paper presents the results of investigating two borate samples from the deposit "Pobrđe". The following properties were determined on borate samples: free and hygroscopic moisture, granulometric composition, chemical composition, mineralogical analysis by size classes, and XRD analysis.

**Keywords:** "Pobrđe" Deposit, Boron Minerals, Properties.

### INTRODUCTION

Boron is a rare element from the group of non-metals (concentration of 10 ppm in the upper continental crust) [1,2]. Boron occurs in nature in over 250 boron-bearing minerals-borates, which are defined as any compound containing boric oxide ( $B_2O_3$ ). The most important boron minerals in commercial terms are: borax(tincal), kernite, ulexite, colemanite [3]. Approximately 75% of the world's boron reserves are located in Turkey, which is also the largest producer of borates (Table 1) [2].

**Table 1** World reserves and production of borates [4,5]

Countries	Total Reserve (Thousand ton $B_2O_3$ )	Distribution (%)	Productions of borate concentrates, t (2019.)
Turkey	948,712	73.4	4,000,000
Russia	100,000	7.7	80,000
USA	80,000	6.2	1,300,000
Peru	22,000	1.7	111,108
Argentina	9,000	0.7	80,000
China	36,000	2.8	250,000
Bolivia	19,000	1.5	214,500
Chile	41,000	3.2	352,225
Kazakhstan	15,000	1.2	500,000
Serbia	21,000	1.6	/
<b>TOTAL</b>	<b>1,291,712</b>	<b>100</b>	

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Starting in 2014, Boron was marked as "critical" in the European Commission's assessment study for the E.U. [6,7]. Four main sectors of boron mineral application represent 86% of its world annual consumption: 1. Glass sector -1.17 Mt B<sub>2</sub>O<sub>3</sub>; 2. Ceramics sector -280,000 B<sub>2</sub>O<sub>3</sub> 3. Agriculture sector 240,000 B<sub>2</sub>O<sub>3</sub> 4. Detergents sector -45,000 B<sub>2</sub>O<sub>3</sub> [8,9]. There are several borate deposits in Serbia: Piskanja - 11.8 Mt [10], Pobrđe - about 150,000 t [11] and it is counted on the possible production of boron from the jadarite mineral [9].

Boron ore from the "Pobrđe" deposit was exploited by "Ibar Coal Mines". After mining, the borates ore was crushed and then sieved on a screen with an opening of 30 mm. Commercial borate concentrate was obtained from the size class +30 mm by hand picking. The size class -30+0.00 mm was discarded to the landfill as tailings. "Elixir group", the largest producer of mineral fertilizers in the Balkans, bought 7-8,000 tons of this raw material and transferred it to the "Elixir Zorka" factory in Šabac. Here, after grinding, this raw material is used as an additive for mineral fertilizer. The "Elixir group" wanted to examine the possibility of obtaining boron mineral concentrates both from run-of-mine ore and from the -30+0.00 mm class. The goal of these tests would be to obtain K/B<sub>2</sub>O<sub>3</sub> with a B<sub>2</sub>O<sub>3</sub> content of over 35% and a middling product that would have a B<sub>2</sub>O<sub>3</sub> content of 7-10% for the fertilizer industry. In order to determine the possibility of conducting magnetic separation tests, detailed physical-chemical and mineralogical characterization was performed.

#### **EXPERIMENTAL (MATERIALS AND METHODS)**

Two representative borate samples were taken for these investigations. The run-of-mine borate ore sample had an upper size of limit -280+0.00 mm, mass m=130 kg, and the -30+0.00 mm class sample had a mass of m= 82 kg. On both samples, free moisture was determined. After that, both samples were crushed to a size of -10+0.00 mm, and physico-chemical and mineralogical properties of these samples were determined. The following were determined on the samples: hygroscopic moisture, granulometric composition, chemical composition, mineralogical analysis by size classes, and XRD analysis. Mineralogical analysis by size classes was performed on a polarizing microscope "JENAPOL-U", Carl Zeiss-Jena, with a measuring device. X-ray diffraction (XRD) analysis was performed on a "PHILIPS" X-ray diffractometer, model PW-1710.

##### **Determination of moisture content and granulometric composition of borate ore samples**

The content of free moisture in the run-of-mine sample was 2.39% and hygroscopic 0.21%; in the sample of the size class -30+0.00 mm the content of free moisture was 2.51% and the hygroscopic 0.22%.

The granulometric composition for both samples was determined by sieving on a Tyler series of sieves, with the last sieve having an aperture of 0.1 mm. All the weights of the sieves oversize together with the sieve undersize of the last sieve were measured. Granulometric analysis showed that: - for the run-of-mine sample of the borate ore, after three-stage comminution, the d<sub>95</sub> is 6.895 mm, while the d<sub>50</sub> is 2.323 mm; - for a borate



sample of the size class -30+0.00 mm, after comminution,  $d_{95}$  is 6.773 mm, while  $d_{50}$  is 2.193 mm.

### Chemical analysis of the borate samples

The chemical composition of both borate samples was determined by chemical analysis. In both samples, the content of the  $B_2O_3$ , and secondary components was determined, before all  $Fe_2O_3$ . Loss of ignition at 800 °C is shown. The chemical compositions of borate samples are shown in Tables 3 and 4.

**Table 2** Chemical composition of the run-of-mine borate ore

Comp.	$B_2O_3$	$SiO_2$	$Al_2O_3$	$Fe_2O_3$	CaO	MgO	$Na_2O$	$K_2O$	$TiO_2$	LOI at 800°C
Cont.,%	32.21	15.20	4.05	1.61	20.30	3.75	1.06	0.57	0.168	21.03

**Table 3** Chemical composition of the borate, size class -30.0+0.00 mm

Comp.	$B_2O_3$	$SiO_2$	$Al_2O_3$	$Fe_2O_3$	CaO	MgO	$Na_2O$	$K_2O$	$TiO_2$	LOI at 800°C
Cont.,%	21.05	21.60	6.09	2.38	20.13	4.83	1.16	0.83	0.33	23.26

Chemical analysis showed that these two borate samples are significantly different from each other. Namely, the starting sample of the borate ore has a much higher boron content ( $B_2O_3$  content 32.21%), compared to the -30+0.00 mm size class sample ( $B_2O_3$  content 21.05%). The starting sample also has a lower content of  $Fe_2O_3$  -1.6% and sample of the size class -30+0.00 mm, has content of  $Fe_2O_3$  -2.38%.

### Qualitative-quantitative mineralogical investigation of borate samples

Quantitative-qualitative mineralogical analysis was performed using an optical polarization microscope and X-ray diffraction analysis on several different samples of borate ore. Mineralogical analysis by size class was carried out on crushed borate samples with a size of -10 mm, in order to determine intergrowth and liberations of minerals in each class of the borate samples. These data made it possible to define the size of the class in which boron minerals can be separated from tailings minerals. X-ray diffraction (XRD) analysis was performed on both borate samples after micronization, on the basis of which the mineral composition of the samples was determined.

### Mineralogical analysis by size classes of run-of-mine borate sample and borate sample size class -30+0.00 mm

Both borate samples were sieved into the following narrow size classes: -10.00+9.52 mm; -9.52 +7.93 mm; -7.93 + 6.35 mm; -6.35 + 5.00 mm; -5.00 + 4.00 mm; -4.00 + 3.36 mm; -3.36 + 2.83 mm; -2.83 + 2.38 mm; -2.38 +1.6 mm; -1.6 + 1.19 mm; -1.19+0.00 mm. Mineralogical analysis by size classes for both borate samples was performed by examination with an optical polarization microscope. This analysis, for both borate samples, determined that the liberations of boron minerals of over 80% are achieved in the size class -2.83+0.00 mm. Mineralogical analysis by size class of the borate sample of

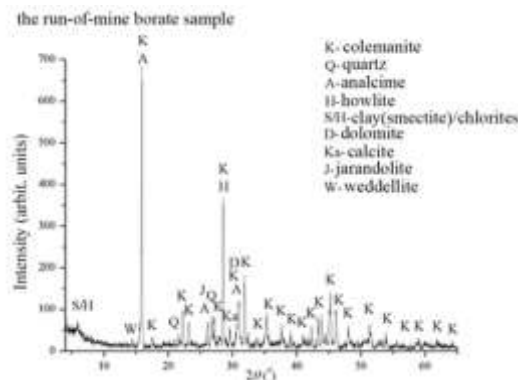
class -30+0.00 mm showed that this sample has a very dirty surface. The dust stuck to its mineral surfaces, despite crushing and dry sieving.

### Mineralogical analysis by X-ray diffraction method

Mineralogical, X-ray diffraction analysis was used to determine and monitor the phase composition of both borate samples. The samples were analyzed on a "PHILIPS" X-ray diffractometer, model PW-1710, with a curved graphite monochromator and a scintillation counter. The intensities of diffracted  $\text{CuK}\alpha$  X-rays ( $\lambda=1.54178\text{\AA}$ ) were measured at room temperature in intervals of  $0.02^\circ 2\theta$  and time of 1 s in the range from  $4$  to  $65^\circ 2\theta$ . The X-ray tube was loaded with a voltage of 40 kV and a current of 30 mA, while the slits for directing the primary and diffracted beams were  $1^\circ$  and 0.1 mm. The following text shows the obtained results.

#### *The run-of-mine borate sample - X-ray diffraction method*

X-ray analysis determined the following mineral composition of the examined sample: colemanite, howlite, quartz, carbonate minerals (calcite, dolomite), clay minerals (smectite)/chlorites, analcime, jarandolite, and weddellite. The absolutely dominant mineral in the analyzed sample is colemanite. After colemanite, quartz is more significantly present, as well as carbonate minerals (dolomite is more dominant than calcite), clay minerals (smectite), analcime, howlite, and jarandolite are less abundant. The semiquantitative share of crystalline phases (minerals) is as follows: colemanite 55-57%, carbonates 18-20% (dolomite 15-17%, calcite  $\leq 2$ -3%), smectites/chlorites  $\sim 10\%$ , analcime 8-10%, quartz 1-2%, other boron minerals (howlite and jarandolite in total  $\sim 5\%$ ). Weddellite is present in the trace. The diffractogram of the tested sample is presented in Figure 1.



**Figure 1** Powder diffractogram of the run-of-mine borate sample

#### *Borate sample of size class -30+0.00 mm - X-ray diffraction method*

X-ray analysis determined the following mineral composition of the examined sample: colemanite, howlite, quartz, carbonate minerals (calcite, dolomite), clay minerals (smectite)/chlorites, analcime, and jarandolite.

The absolutely dominant mineral in the analyzed sample is colemanite. After colemanite, quartz is more significantly present, as well as carbonate minerals (dolomite is more dominant than calcite), clay minerals (smectite), analcime, howlite, and jarandolite are less abundant. The semiquantitative share of crystalline phases (minerals) is as follows: colemanite 35-37%, carbonates 30-32 (dolomite 20-22, calcite  $\leq$  10%), smectites/chlorites 10-12%, analcime 8-10%, quartz  $\leq$  5%, other boron minerals (howlite and jarandolite in total  $\sim$  5%). The diffractogram of the tested sample is presented in Figure 2.

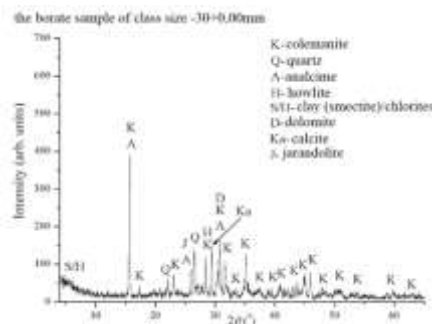


Figure 2 Diffractogram of the borate sample of size class -30+0.0 mm

## RESULTS AND DISCUSSION

Physico-chemical and mineralogical investigations represent the basis for further technological tests that should define the processing procedure of both types of borates. These investigations showed that borates are very complex in terms of their mineral composition. Namely, in addition to boron minerals, they also consist of alumino-silicate tailings, oxide carbonate minerals, zeolite (of the analcime type), and organic matter. Based on the mineralogical analysis, the same minerals are present in both borate samples, Figure 1, Figure 2. According to the mineralogical analysis, the content of boron minerals is higher in the run-of-mine borate sample ( $B_2O_3$ -55-57%, Figure 1), than in the borate sample of the size class -30+0.00 mm ( $B_2O_3$ - 35-37%, Figure 2). In order to examine and determine the possibility of the separation of minerals one from another, it is necessary that the minerals have some different properties by which they can be separated from each other. Regarding their physical-mechanical properties, hardness by Mohs scale, specific mass, etc. the minerals present in the sample have similar properties. According to the specific mass (density), all these minerals have a specific mass of about  $2.5 \text{ g/cm}^3$ , except montmorillonite, whose specific mass ranges from  $2$ - $2.7 \text{ g/cm}^3$ . Chamosite has a higher specific mass than the mentioned minerals with a specific mass of  $3.2 \text{ g/cm}^3$ . This fact tells us that it would be difficult to separate these minerals by gravity concentration because they are close in density (specific mass).

## CONCLUSION

According to the chemical compositions of the minerals present in the borate samples, it can be stated that some of these minerals contain iron, especially smectites,

and chlorites. These minerals can be separated from boron minerals using high-intensity magnetic separation. In addition, montmorillonite itself does not contain iron, but in nature very often binds it to itself, either between lamellae, or by isomorphic replacement, or sometimes both ways. For this reason, montmorillonite very often belongs to the minerals that can be separated by magnetic separation from boron minerals. In any case, in accordance with the mineralogical tests by size classes, the mineral raw material for this purpose should be comminute to a size of -2.83 mm, when the boron mineral is free from accompanying minerals. And after this phase, it is necessary to sieve the raw material prepared in this way into the appropriate size classes that can be subjected to magnetic separation. Through tests, it is necessary to determine the most optimal induction of the magnetic field, during which the magnetic separation of boron and accompanying minerals by size classes is achieved. With these tests, it is necessary to determine the optimal size range of classes that can be subjected to magnetic separation, as well as the last class that cannot be subjected to dry magnetic separation due to its fineness.

#### ACKNOWLEDGEMENT

*This paper is part of the research according to the research funding agreement financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia in 2023 under the number 451-03-47/2023-01/200023.*

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