

**RESEARCH RESULTS ON APPLICATION OF SEMI-LEVEL  
INDUCED CAVING WITH LATERAL LOADING IN ORE BODY  
BORSKA REKA**

**REZULTATI ISTRAŽIVANJA PRIMENE METODE  
POLUETAŽNOG PRINUDNOG ZARUŠAVANJA SA  
JEDNOSTRANIM BOČNIM UTOVAROM U RUDNOM TELU  
"BORSKA REKA"**

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**Abstract:** Ore body Borska Reka in Jama Bor underground mine has been a challenge for experts in underground mining for many years. Specific properties of this ore body, such as great depth, huge ore reserves, low ore grades, infrastructure at ground surface above the deposit, along with variation of metal prices, disable application of traditional and previously applied mining methods.

This paper presents results of researches related to design of new mining method, from the group of induced caving methods, and possibilities for application of such method in ore body Borska Reka, along with calculation of main method parameters.

**Key words:** underground mining, ore body Borska Reka, induced caving methods

**Apstrakt:** Rudno telo "Borska Reka" u Jami Bor je već dugi niz godina izazov za istraživače i stručnjake iz oblasti podzemne eksploatacije ležišta mineralnih sirovina. Specifičnosti ovog rudnog tela, kao što su velika dubina zaleganja, velike rezerve rude, nizak sadržaj korisnih komponenti u rudi, velike varijacije cena bakra i plemenitih metala na svetskom tržištu, infrastrukturni objekti na površini terena itd., onemogućavaju primenu neke od klasičnih i do sada primenjivanih metoda otkopavanja.

U ovom radu su prikazani rezultati istraživanja vezanih za konstrukciju nove metode otkopavanja iz grupe metoda blokovskog prinudnog zarušavanja, mogućnost primene takve metode u rudnom telu "Borska Reka", kao i proračun osnovnih parametara i pokazatelja metode.

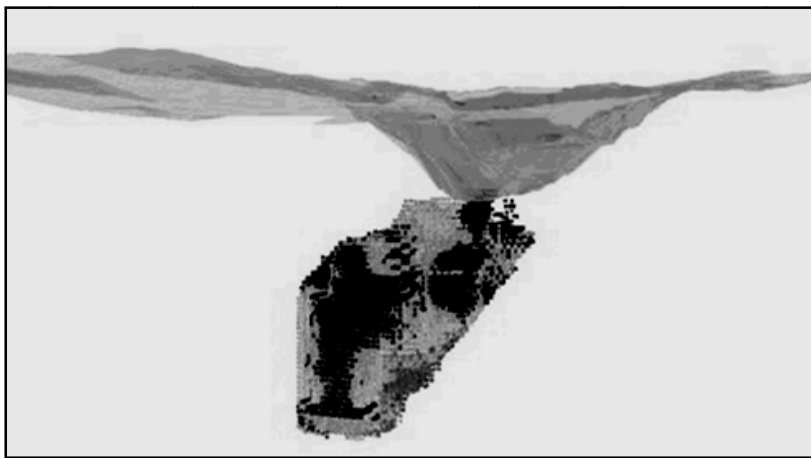
**Ključne reči:** podzemna eksploatacija, rudno telo "Borska Reka", metode blokovskog prinudnog zarušavanja

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## 1. INTRODUCTION

Area of Borska reka ore body is a continuance of hydrothermally altered zone of Bor ore deposit, heading towards northwest. This 1,500 m long and 800 m deep area is inclined towards west with a 45° to 55° dip angle. This inclination matches the inclination of sandstones and conglomerates in this zone, separated from hydrothermally altered zone by Bor Fault. Detailed exploration works reached K-455 m depth, mainly from K-155 m level in Jama Bor. There is a need for further exploration below K-455 m, both in width and in depth (Mining and Metallurgy Institute Bor, 2010).



**Figure 1** - Block model of Borska Reka (Mihajlovic et al. 2008)

Exploration works in Borska Reka had been active from 1976 to 1999, with 53,390 m drilled from the surface, 6,489 m drilled from underground, along with 1,378 m of exploration drifts and 1,119 m of auxiliary exploration works. Exploration drilling and drifting were followed with nearly 20,000 of chemical, petrology and mineral analyses (Mining and Metallurgy Institute Bor, 2010).

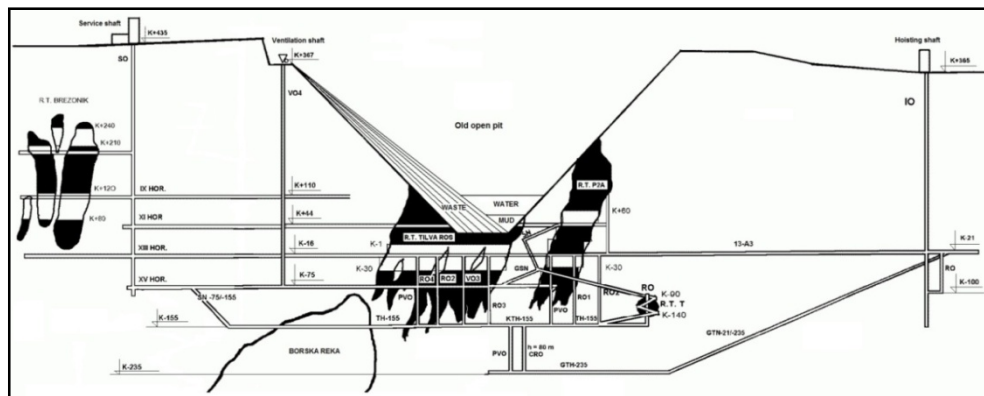
Confirmed copper ore reserves in Borska Reka, till K-455 m depth and inside 0.3% Cu contour reach 556.9 Mt of ore, or 3.15 Mt of copper, with addition of gold, silver, molybdenum, etc. Balance ore reserves were confirmed based on exploration data and techno – economic analysis. Calculation shows 319.9 Mt of ore, containing 0.5% of copper, 0.204 g/t of gold, 1.62 g/t of silver, 35.89 g/t of molybdenum and 7.8% of sulfur (Milić et al. 2011).

Borska Reka is partially developed in Main Level XIX, at K-235 m level. From hoisting shaft ore bunker at K-21 m level, a 750 m long hoisting slope (GIN) is driven down to K-235 m level, with 16.5° inclination. At K-235 m level, slope is connected to main haulage drift (GTH-235 m). This drift is 780 m long and represents a connection with central orepass (CRO).

Ore body is connected with service shaft by 560 m long exploration slope. From the slope, exploration drifts were driven towards ore body contours at K-155 m level.

At Level XVII (K-155 m), main transport drift is driven all along the ore body. It is used for transport of excavations from opening and development drifting. In the latter phase of mining, this drift will be used as a service drift for Level XVII.

Levels XVII and XIX are connected by ventilation shaft (PVO) and central orepass (CRO). Current situation in Jama Bor is shown in Figure 2.



**Figure 2** - Current stage and future plans for opening and development of Borska Reka

## 2. POSSIBILITIES FOR MINING IN ORE BODY BORSKA REKA

This ore body is a challenge for experts for many years. Its specific properties, such as position, depth, ore grade, situation at the ground surface, geomechanics, along with some external factors, such as variation of metal prices, provoked numerous researches and studies. During the years, and even decades, numerous mine designs and mining methods were developed and suggested as a solution for mining of this ore body. Practically, all of the known underground mining technologies and methods were taken in consideration.

Comprehensive researches of this topic were performed in Technical Faculty in Bor, too (Milić, 1996).

Main goal of the researches was to design a new mining method, applicable in Borska Reka, and able to provide improvement of most important method parameters.

Generally, most considered mining methods in researches and studies were block caving, due to its low operational costs and cut and fill methods, in order to preserve ground surface.

Application of block caving requires very detailed geomechanic analyses of ore body and surrounding rock. Since such analyses have never been performed, it is impossible to predict the behavior of rock in a key process, responsible for dynamics, safety and success of mining, and that process is caving. According to available geomechanic data, as well as experience from development of Level XVII and Level XIX in Jama Bor, the rock is firm, hard and compact, which is unfavorable for caving.

Main problem in application of cut and fill method is related to costs. Ore grades are low, which means that designed mining method has to be low-cost, in order to provide positive economic results.

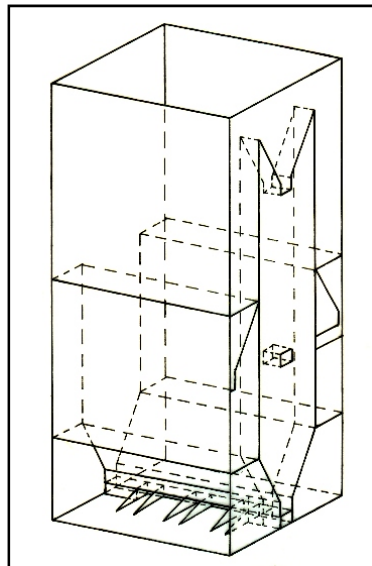
That is why our researches were focused to sublevel caving and induced caving methods. This group of mining methods enables high – capacity production, with acceptable costs. Such mining method would be suitable for Borska Reka, considering its properties.

### 3. RESEARCHES OF INDUCED CAVING METHODS

Entire research has been realized in three phases:

- Phase 1 included laboratory model tests in order to determine optimal parameters of the blocks, based on ore recovery and ore dilution data, along with ore drawing parameters;
- Phase 2 was based on geo – mechanic tests and analyses, using software based on finite element method, in order to determine stability of blocks and drifts inside them. This phase was especially important considering the fact that Borska Reka ore body is situated in significant depth;
- In phase 3, mining method and all of the mining processes included, were theoretically elaborated based on geometry of mining and layout of development drifts (especially loading rooms), in order to determine main techno – economic parameters of a method, based on requirements for its technical and economical applicability.

Considering the specifics of this method and a layout of adjacent blocks in its construction, the method was named 'Semi – level induced caving with single – sided lateral ore loading'.



**Figure 3** - A model of Semi – level induced caving with single – sided lateral ore loading

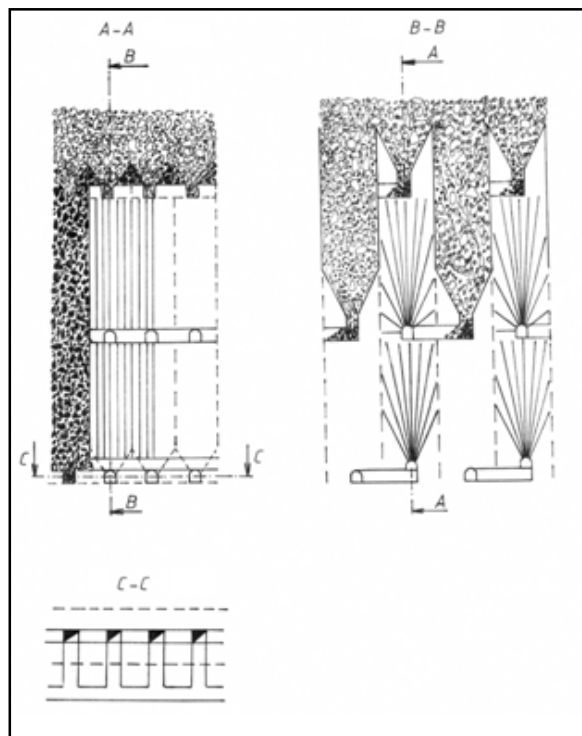
#### 4. SEMI – LEVEL INDUCED CAVING

A method named 'Semi – level induced caving with single – sided lateral ore loading' is the biggest modification of currently known sublevel caving methods.

Principle of this method is caving of ore and a hanging wall. In classification of mining methods, group of methods where ore is excavated in entire block height are named block methods. If ore caves naturally, forced only by gravity, then we talk about block caving methods. If the caving is forced by drilling and blasting, then we have induced block caving (single or double). Considering the fact that in this method ore is caved along entire block height, it belongs to induced block caving methods. However, drilling and blasting is performed in two levels per block, and that is why the method is called 'semi – level'.

Besides, expression 'semi – level' can be referred to a fact that adjacent blocks are displaced by a half of the level height, thus providing ore loading in each 'semi – level', at 40 m spacing.

Ore is blasted in large – scale blocks, 40 m high and 24 m - 42 m wide. Ore is drawn from 10 m - 16 m wide blocks, with a height matching level height. This way high productivity is enabled, which places this method in a bulk mining.



**Figure 4** - Semi – level induced caving with single – sided lateral ore loading, method construction

So, this method is specific thanks to ore excavation in large blocks, whose height match the level height. Adjacent blocks are displaced by a half of level height. Such layout of blocks enables that most of the caved ore is surrounded by a solid rock, thus prolonging the period of clean ore drawing. This way method provides better ore recovery and lower ore dilution in a drawing process. This was possible due to lack of vertical contact between lower half of the block and waste, except front contact of blasted zone (Milić et al. 2011).

Zone of blasted ore is very wide, and thanks to the lateral loading rooms, ore can be drawn simultaneously by entire width of blasted zone. Simultaneous ore drawing from wide blasted zone provides significant increase of productivity, increase of utilization of drilling, loading and hauling equipment and improved ore body development (Mihajlovic et al. 2008).

Successive layout of caved and active blocks (Figure 4), disables concentration of underground pressure. This is also an important advantage of this method, making it even more suitable for application in deep ore deposits.

## 5. ANALYSIS OF MINING METHOD'S MOST IMPORTANT PARAMETERS

In the first phase of researches on semi – level induced caving with single – side lateral ore loading, optimal geometric parameters were determined by laboratory tests, using physical analogy models.

After the analyses of test results and comparison of gained values, optimal geometric parameters were determined. For this mining method, optimal geometric parameters are following: block height,  $H = 80$  m; block width,  $B = 12$  m; spacing between lateral loading rooms,  $l = 12$  m.

### 5.1. Ore recovery and ore dilution

One of the prerequisites in determination of optimal parameters was a demand for maximal ore recovery with ore dilution limited to 10%–15%. Also, focus of optimization was on minimization of ore losses and development ratio, along with increase of output capacity and excavation intensity.

With formerly determined geometric parameters, the results were following: percentage of clean ore,  $Q_{cr} = 22\%$ ; while overall ore recovery is 90%, with 10 % of ore dilution.

### 5.2. Intensity of excavation

Excavation intensity is calculated using following formula (Milić, 1996):

$$I_o = \frac{h \cdot \gamma_r \cdot K_{ir}}{1 - K_{or}} = 224 \text{ t/m}^2 \quad (1)$$

where:

$h = 80$  m - height of block excavated during the year;

$\gamma_r = 2.8 \text{ t/m}^3$  - ore density;  
 $K_{ir} = 0.9$  - ore recovery ratio;  
 $K_{or} = 0.1$  - ore dilution ratio.

Concept of mining in this method is ore blasting at a half of block height, while ore is drawn from an entire block height, made by two semi – level blastings. That is why excavation intensity is calculated with 80 m block height.

### 5.3. Quantity of ore excavated from a block

Quantity of ore gained from a single block in semi – level induced caving is:

$$Q_{rm} = \frac{H \cdot L_b \cdot B \cdot \gamma_r \cdot K_{ir}}{1 - K_{or}} = 322,560 \text{ t} \quad (2)$$

where:

$H = 80 \text{ m}$  - block or level height;

$L_b = 120 \text{ m}$  - block length;

$B = 12 \text{ m}$  - block width.

### 5.4. Development ratio

Development ratio is relation between overall length of necessary drifts and overall quantity of ore gained from a stope, a block or entire deposit.

$$K_p = \frac{L_p}{Q_{rm}} = \frac{423.3}{322,560} = 0.0013123 \text{ m/t} \quad (3)$$

where:

$L_p$  - sum of development drifts' lengths, [m];

$Q_{rm}$  - quantity of ore gained from a stope or a block, [t].

### 5.5. Parameters of drilling and blasting

#### 5.5.1. Coefficient of blasted ore

Coefficient of blasted ore is a relation between quantity of blasted ore and sum of drillholes lengths:

$$K_{ob} = \frac{Q_r}{L_b} = 11.06 \text{ t/m} \quad (4)$$

where:

$Q_r = 32,256 \text{ t}$  - quantity of ore from one stope;

$L_b = 2,916 \text{ m}$  - sum of drillholes lengths in one stope.

### 5.5.2. Specific consumption of the explosive

Specific consumption is calculated by B.N. Kutuzov:

$$q = q_e \cdot e \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6 = 1,0977 \approx 1.1 \text{ kg/m}^3 \quad (5)$$

where:

$q_e = 0.6 \text{ kg/m}^3$  - empiric specific consumption of explosive, determined based on mechanic properties ( $f = 8 - 10$ );

$e = 4330/3872 = 1.12$  - coefficient of explosive ability for selected ANFO explosive;

$K_2 = 1.4$  - correction coefficient based on quality of rock (ore);

$K_3 = 1.2$  - coefficient dependable on drillholes layout ( $K_3 = 1.1 - 1.2$  for drill rings,  $K_3 = 1$  for parallel drillholes);

$K_4 = 1.3$  - coefficient dependable on blasting conditions (for squashed blasting  $K_4 = 1.3$ );

$K_5 = 0.95$  - correctional coefficient, based on density of explosive loading;

$K_6 = 0.89$  - coefficient dependable on drillhole diameter.

### 5.5.3. Quantity of explosive needed for one drill ring

Quantity of explosive needed for loading of drillholes in one drill ring is:

$$Q_e = \frac{d^2 \pi}{4} \cdot L_b \cdot k_p \cdot \rho_e = 0,785 \cdot d^2 \cdot L_b \cdot k_p \cdot \rho_e = 2,100 \text{ kg} \quad (6)$$

where:

$d = 0.089 \text{ m}$  - drillhole diameter;

$L_b = 469 \text{ m}$  - total length of drillholes;

$k_p$  - drillholes loading coefficient, ( $k_p = 0.75 - 0.85$  for drill rings);

$\rho_e = 900 \text{ kg/m}^3$  - explosive density.

### 5.5.4. Blasting burden

$$W = \frac{Q_e}{P_b \cdot q_e} = \frac{0,785 \cdot d^2 \cdot L_b \cdot k_p \cdot \rho_e}{P_b \cdot q_e} = 2 \text{ m} \quad (7)$$

where:

$P_b$  - block area blasted by one drill ring

(at top and bottom semi – level,  $80 \times 12 - 3 \times 14 = 918 \text{ m}^2$ ).

## **6. CONCLUSION**

Semi – level induced caving is a new, improved method design, applicable in thick and steep ore deposits. This method requires modern equipment and technology of mining, maximal mechanization and safety. Gained research results are encouraging; they show that favorable results could be expected in case of application of this mining method, which means that the researches could have a practical value, too.



The next step, next necessary phase in researches is experimental mining. Model testing can't include all of the influential factors. With following of all of the method principles, in situ researches would be able to provide final answer of method applicability, along with minor adjustments of method parameters based on local rock properties.

#### ACKNOWLEDGEMENTS

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