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IMPLEMENTATION OF THE SUBLEVEL CAVING MINING METHOD IN THE T4 ORE BODY AT THE JAMA BOR UNDERGROUND MINE

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Abstract

Within the Bor copper ore field, a total of 33 ore bodies have been exploited since the beginning of the last century, with only two remaining available for future extraction—ore bodies T3 and T4—while the Borska Reka ore body is currently under active exploitation. The T4 ore body represents a massive pyrite-type mineralization, for which the sublevel caving mining method has been selected as the most suitable extraction approach. In order to maximize ore recovery, reduce mining costs, and improve occupational health and safety conditions, modern software tools such as Datamine Aegis have been employed for the design of development and preparation workings, as well as for planning drilling and blasting operations.

***Keywords**: Bor, ore body T4, sublevel caving, Datamine Aegis*

1. INTRODUCTION

The Bor copper ore field is located within the central part of the Timok Magmatic Complex (TMC). Since the beginning of the 20th century, mining activities both underground and open-pit have encompassed a total of 33 ore bodies within this field. Of these, only the T3 and T4 ore bodies remain available for future exploitation, while the Borska Reka copper deposit is currently being mined. As part of the "Geological Exploration Project at the Bor Mine," the exploration drillhole -150ZK350-1 intersected massive pyrite ore located south of the previously identified T ore body, subsequently designated as the T4 ore body. The T4 ore body is situated in the central portion of the Bor deposit, within a fault zone. The surrounding rocks exhibit intense alteration in the immediate vicinity of the ore body, which rapidly diminishes into weakly altered and eventually fresh andesites. The most prominent hydrothermal alterations observed include pyritization, silicification, kaolinization, chloritization, and sulphatization [1].

In the zone of the T4 ore body, the rock mass is characterized by kaolinization and disintegration, with kaolinization occurring as the dominant type of alteration in the footwall and, to a lesser extent, in the hanging wall. Sulphatization is manifested by the presence of anhydrite (gypsum) both within the host rock and along fracture surfaces. This type of alteration has an adverse effect on the physical and mechanical properties of the rock mass and, similarly to kaolinization, negatively impacts overall rock mass stability. Sulphatization within the host rock appears as localized accumulations (nests), while in fractures it forms infillings ranging from a few millimeters to several centimeters in thickness. These gypsum-filled fractures are generally continuous, gently undulating to planar, with smooth surfaces that often exhibit slickensides indicating movement. Such fractures represent weakened zones within the rock mass and are a highly unfavorable factor for the stability of underground openings and the rock mass as a whole. On the other hand, pyritization and associated mineralization (typically accompanied by silicification) generally lead to an improvement in the physical-mechanical characteristics and engineering-geological parameters. A notable increase in all parameter values is observed within mineralized zones. This improvement applies both to the intact rock matrix and, not infrequently, to fractures filled with this type of mineral assemblage [1].

In the selection of a mining method, the most influential factors include the type and value of the ore determined by its metal content, the surrounding rock mass, as well as the specific requirements set by the Investor and outlined in the project design brief. In this case, the geometry and dip of the ore body are considered favorable; however, the substantial size of the ore body, combined with its economic value, strongly suggests the need for a mining method that ensures high ore recovery. In addition to these factors, the engineering-geological characteristics of the rock mass play a critical role in method selection. According to the ore reserves report for the T4 ore body, the intact rock matrix is predominantly affected by pyritization and propylitization, while the fractures exhibit pyritization, mineralization, and sulphatization. Within all fault zones, the rock mass is kaolinized and disintegrated, with kaolinization occurring as the dominant alteration in the footwall and, to a lesser extent, in the hanging wall [1].

2. EXPERIMENTAL

Considering all influencing factors and the requirements set by the Investor, the sublevel caving method was adopted for ore extraction. Sublevel caving is applied under a variety of geological and structural conditions; however, it is most effective in steeply dipping ore bodies, where blasted ore can descend by gravity to the sublevel drift, from which it is subsequently loaded and hauled. Depending on the thickness and dip angle of the ore body, the project provides appropriate design solutions for the development and preparation of the mining blocks. The ore may possess relatively low mechanical strength, as the extraction process does not involve the creation of large open voids; instead, mining is conducted directly from sublevel drifts. In sublevel caving methods, favorable conditions exist when the hanging wall rocks are more prone to caving. This facilitates the natural backfilling of the mined-out voids with caved waste rock, which is one of the most important prerequisites for the efficient and safe application of caving-based mining methods. Additionally, the likelihood of forming large caving arches with wide spans is reduced, which consequently results in lower stress concentrations on the extraction and development drifts Sublevel caving methods are characterized by the ability to integrate the most modern equipment for drilling, blasting, loading, and haulage operations within the stoping blocks. This enables high production rates and increased productivity in the extraction process, ultimately resulting in ore recovery at lower mining costs [2, 3].

The development and preparation of the T4 ore body involves its division into three mining levels, with a vertical spacing of 15 meters, specifically: level k-60 m, level k-45 m, and level k-30 m. Each of these mining levels is accessed through development workings originating from the existing exploration raise of the T4 ore body, Figure 1 and Figure 2 [2].

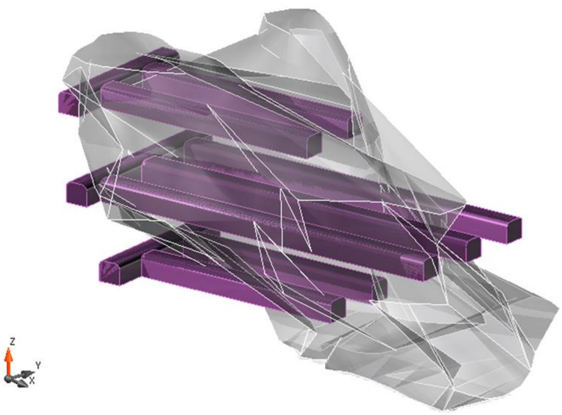

Figure 1 Development of T4 ore body

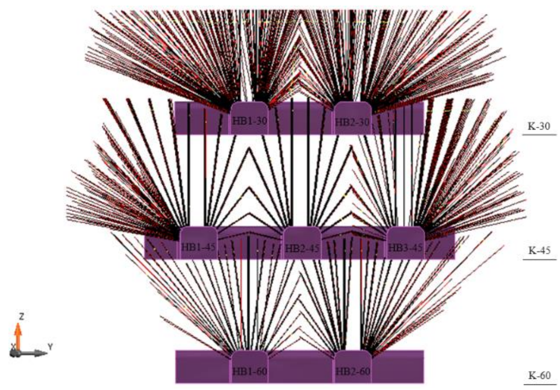

Figure 2 Vertical crosscut of drifts and ring design

At each level, the slot drifts (HZ) and drilling drifts (HB) are developed in a "chessboard" layout, resulting in a rhomboidal shape of the ore block to be extracted. In each slot drift, a slot raise with dimensions of 2×2 meters is constructed at both ends by drilling and blasting operations. Along the entire length of each slot drift, fan-shaped boreholes (rings) are drilled at intervals of 1 meter. [2].

From the drilling drifts, rings are also drilled, spaced 2 meters apart. The height of the drilling is determined by the upper sublevel, while the drilling width is defined by the contour of the ore body, Figure 3 and Figure 4 [2].

The extraction process is preceded by slot development, which involves blasting of slot raises as well as ring drilling and blasting within the slot drifts. Blasting of the rings in the production drifts is carried out only after all rings in the slot drifts have been completed, and is performed uniformly across the level to ensure proper flow control of the blasted material. The blasting proceeds one ring at a time, followed by the draw and loading of the excess broken ore before initiating the next round. Upon completion of ring blasting and removal of excess material at level K-30, the same procedure is repeated at level K-45, and finally at level K-60, following the same sequence of slot raise development and staged ring blasting, leading to the final drawdown and loading of the ore. Ore dilution control is carried out operationally through geological sampling and using loader bucket weight monitoring systems, due to the sharp contact between the ore body and waste rock, as well as their significant differences in bulk density. The extraction sequence proceeds from the upper levels to the lower levels [2].

In the application of the sublevel caving method, the use of long blast holes arranged in a fan pattern is characteristic. When designing drilling and blasting operations, it is essential to consider all relevant characteristics of the explosives and the rock mass. In cases of deviation, changes in drilling geometry, or variations in explosive types, appropriate optimization must be conducted. Poorly designed blasting operations can significantly impact the safety of personnel, equipment, as well as underground structures and production processes, which can also lead to negative economic consequences [4, 5].

The design of drilling and blasting operations for the application of the sublevel caving method in ore body T4 was carried out using the Datamine Aegis software, Figure 3 and Figure 4. Aegis includes an integrated database containing accumulated experience and parameters from various ore deposits related to drilling and blasting activities. This database enables the user to efficiently and effectively perform modeling in geologically similar environments. Furthermore, the user has the ability to create a custom database, which allows for more precise future modeling and optimization [6].

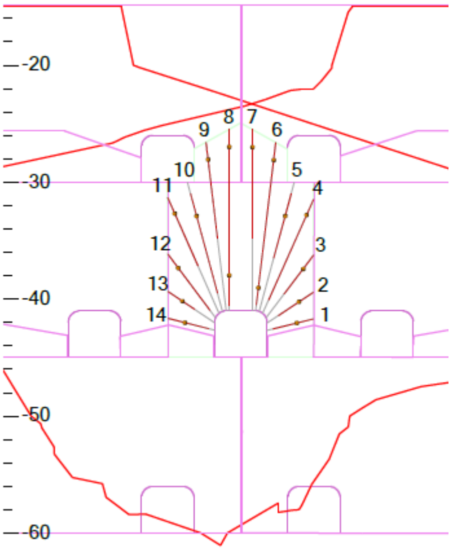

Figure 3 Crosscut of ring design on the level K-45

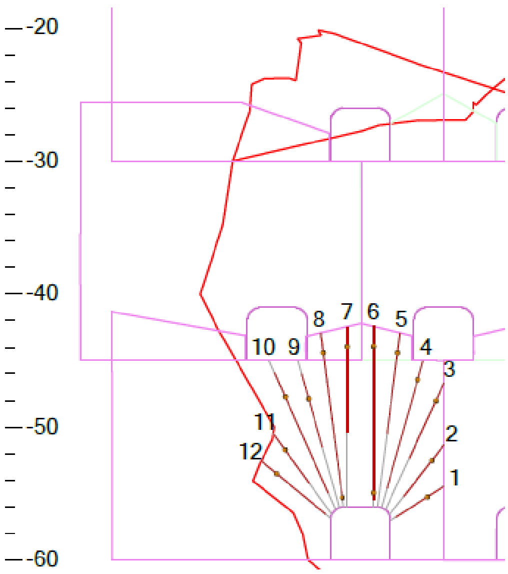

Figure 4 Crosscut of ring design on the level K-60

3. RESULTS AND DISCUSSION

The application of Aegis software enabled a comprehensive spatial visualization of ore body T4. This facilitated the design of an optimal development and preparation layout, as well as the planning of drilling and blasting operations. Through the optimal design of these activities, the resulting benefits include higher ore recovery and reduced dilution.

4. CONCLUSION

Ore body T4, located in the central part of the Bor deposit, is characterized by massive pyritic mineralization, pronounced hydrothermal alterations, and complex engineering-geological conditions. Considering the dimensions of the ore body, its thickness, dip, and the investor's requirements regarding high ore recovery and operational safety, sublevel caving was selected as the most suitable mining method. The analysis of geological, geomechanical, and production-related factors confirmed the justification of this choice. The application of the sublevel caving method enables efficient draw control, gradual extraction by levels, and safe backfilling due to caving of mined-out voids, thereby minimizing the risk of ground instability.

A particular value of this approach lies in the use of the specialized Aegis software, which enabled three-dimensional visualization of the ore body, precise design of development drifts, and drilling and blasting operations. This ensured high ore recovery, reduced dilution, increased productivity, and lower extraction costs.

The results of this study confirm that the application of modern mining methods, combined with advanced software solutions, represents a key factor for the successful exploitation of complex ore bodies in contemporary underground mining operations.

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