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МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО - Скопје, 1952

ЧЕТВРТИ КОНГРЕС
на
Геолозите на Република Северна Македонија

ЗБОРНИК НА ТРУДОВИ

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Охрид, 2021

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Минерални ресурси
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3-EG-03

TECHNO-ECONOMIC PARAMETERS OF THE NORTHEASTERN PART OF CENTRAL PART ORE BODY, BUČIM COPPER MINE, REPUBLIC OF NORTH MACEDONIA

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A b s t r a c t: Calculated ore-bearing coefficient in the Northeastern part of the Central Ore Body, Bučim Mine was 0.51%, meaning that within the ore body boundaries 49% of mass is not mineralized somehow, which is slightly different than the remaining three ore bodies within the Bučim porphyry copper mine. The calculated value of variation coefficient (V) has shown value of 58.65% that is in the range of 43–100%, which displays that this ore body belongs to the third group of deposits with uneven mineralization. An average copper and gold concentrations were determined as 0.229% Cu and 0.232 g/t Au, respectively. Minimal economic content (MEC) within the Northeastern part of the Central Ore Body, as represent of this kind of mineralization, was determined as 0.205% Cu. In similar manner was calculated the lowest copper boundary (cutoff grade), which have shown value of 0.127% Cu and thus allowing certain decrease of contents in exploited ore. Also, there were calculated so called copper monometal values, which included influence of the present gold in the ore. Calculated copper monometal was set at relatively fair 0.2388% Cu that represents solid mainstay for exploitation of copper in these low percentage ores. Calculated ore reserves in this particular part of the Central Part ore body were 12 303 965 t of ore with 0.229% Cu, and 0.232 g/t Au and increased mine life for additional 2.15 years.

Key words: Northeastern part Central Ore Body, copper mineralization, variation coefficient

ТЕХНО-ЕКОНОМСКИ ПАРАМЕТРИ НА СЕВЕРОИСТОЧНИОТ ДЕЛ ОД ЦЕНТРАЛНОТО РУДНО ТЕЛО, РУДНИК ЗА БАКАР БУЧИМ, РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

А п с т р а к т: Пресметаниот коефициент на рудоносност во Североисточниот дел од Централното Рудно Тело, рудник Бучим изнесува 0,51 %, што значи дека границите на рудното тело 49 % од масата не е минерализирана, што е нешто поразлично од останатите три рудни тела во рамките на рудникот за бакар Бучим. Пресметаната вредност за коефициентот на варијација (V) покажа вредност од 58,65% која е во опсегот од 43 до 100%, која покажува дека ова рудно тело припаѓа на третата група наоѓалишта со нерамномерна минерализација. Средните концентрации на бакар и злато се одредени како 0,229% Cu и 0,232 g/t Au, соодветно. Минималната економска содржина (МЕС) во рудното тело Североисточниот дел од Централното Рудно Тело, како претставник на овој тип на минерализација, беше одредена како 0,205% Cu. На сличен начин беше пресметана најниската гранична содржина на бакарот (ГС), која покажа вредност од 0,127% Cu што дозволува одредено намалување на содржините во рудата која се експлоатира. Исто така, пресметани се вредностите за таканаречениот бакар монометал, кои го вклучуваат влијанието на присутното злато во рудата. Пресметаниот бакар монометал е поставен на релативно коректните 0,2388% Cu што претставува солидна основа за експлоатација на бакарот од овие нископроцентни руди. Пресметаните рудни резерви во овој дел од Централното Рудно Тело беа 12 303 965 t на руда со 0,229% Cu и 0,232 g/t Au и го зголеми векот на рудникот за дополнителни 2,15 години.

Клучни зборови: Североисточен дел од Централно рудно тело, бакарна минерализација, коефициент на варијација

INTRODUCTION

The only active porphyry Cu mine, the Bučim Mine is located in the border area between the Serbo-Macedonian Massif (SMM) and the Vardar Zone (VZ) and in terms of metallogeny it belongs to the famous Lece-Chalkidiki metallogenic zone (Serafimovski, 1993). The deposit itself is located in eastern central parts of the Republic North Macedonia, 10 km western of the town of Radoviš. Here we would like to stress some facts for the Northeastern part of the Central Part ore body, which is one of the four bodies within the Bučim copper mine that is in active exploitation. The Cu-Au mineralization within this ore body is mainly of primary type, formed during hydrothermal processes at several subsequent stages within the temperature range 300 – 400ºC (Čifliganec, 1987; Serafimovski et al., 2013). The latest findings defined ores with copper concentrations in the range 0.1 to 0.359% Cu, while gold concentrations were high as well, reaching up to 0.38 g/t Au. Above mentioned features of this ore mineralization gave us an initiative to calculate several important techno-economic parameters, which define the economic type of this mineralization. Namely, the degree of ore bearing in these types of ore mineralization is variable, but calculation at particular levels and different drill holes gave the more realistic ratio of mixed types of mineralization within this ore body. Some techno-economic parameters related to the Northeastern part of the Central Part ore body can be found in previous works (Čifliganec, 1987; Serafimovski et al., 2013).

GEOLOGICAL FEATURES

Geological setting of the Bučim copper porphyry deposit consists of the Precambrian metamorphic (gneiss, micaschist and amphibolite) and Tertiary rocks. Gneisses are the most common lithology members and are the most favorable lithology setting for deposition of ore mineralization. Several alternating varieties of gneisses are determined according to their mineral composition: biotitic, amphibole-biotitic, micas, metasomatic etc. Tertiary magmatic rocks are present as several latitic subvolcanic-volcanic crosscuts and andesite-latites around which three ore bodies are lineated, which points to direct relationship of the magmatism and mineralization in the deposit. Spatially and paragenetically porphyry copper mineralization is related to latites and latite-andesites. They occur as small subvolcanic intrusions (dikes and necks) distributed NNW-SSE and NE-SW along fault structures and with pronounced holo to hipo-crystalline porphyritic structure and massive texture. The age of the rocks ranges from 27.5 to 24.5 m.y. (Stojanov and Serafimovski, 1990).

ORE MINERALIZATIONS

The Bučim deposit is composed of a magmatic complex consisting of three proven finger-like porphyry stocks (Central Part, Vršnik and Bunardžik) while the Čukar ore body, a supergene mineralization developed in gneiss, has already been mined out (Figure 1; Čifliganec, 1987). More than five decades of study of this deposit have shown that it is characterrized by a complex mineral assemblage and mineral paragenesis (Serafimovski, 1993; Stojanov and Serafimovski 1990; Čifliganec 1987; Serafimovski 1990; Serafimovski et al., 1990; Serafimovski et al., 1996; Čifliganec et al. 1997). The Central Part, Bunardžik and Vršnik ore bodies are related to andesitic porphyry intrusions, whereas the Cukar ore body consists of a supergene copper mineralization [9]. The primary sulphide mineralization plays the major role in production of copper. The Central Part ore body is the most important ore body in the Bucim deposit. It hosts nearly 70% of the total mineralization, which are formed in gneiss and round latite dike, and represents a typical example of primary copper mineralization (Čifliganec 1987). The dimensions, registered so far are: (a) about 250 m vertical interval (at the 650-400 m absolute level) and (b) on a plane, the mineralized surface in the upper portion of the ore body, together with the andesite intrusion, has a diameter of some 600 m. That means that the Central part ore body has the form of an irregular ring

There have been identified the following ore minerals: pyrite, magnetite, chalcopyrite, rutile, sphene, ilmenite, hematite, pyrrhotite, vallerite, cubanite, sphalerite, galena, bismuthinite, bornite, enargite, native gold, lineite. Also, there has been confirmed presence of Bi-Se association: bismuthine, galenobismuthine, friedrichite, krupkaite, emplectite, laitakarite, native bismuth and cosalite (Čifliganec 1987).

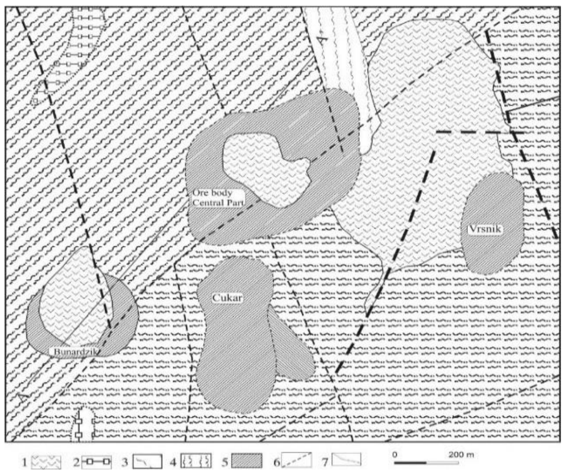

Fig. 1. Simplified geological map of the Bučim deposit (Stojanov and Serafimovski, 1990)
1) Andesite and latite, 2) Amphibolite, 3) Muscovite schist, 4) Gneiss, 5) Ore body, 6) Fault, 7) Ore body contour

TECHNO-ECONOMIC PARAMETERS

Techno-economic parameters are one of the most important links in the chain of economic evaluation of a certain ore deposit, so in this part of the paper we are going to focus on them. The major parameters of the techno-economic evaluation of the Northeastern part of the Central Part ore body situated in the Bučim copper mine directly are pointing out to a possibility of productive exploitation of copper ore from this particular ore body and possibility to create profit. Here in more details are given results from calculations of ore-bearing coefficient, variation coefficient, average concentrations of major ore metals (Cu, Au), minimal economic concentration, cutoff grade, calculation of mine life as a function of calculated ore reserves.

Ore-bearing coefficient. As already mentioned elsewhere [3] the ore-bearing coefficient defines the ratio between the total mineralized area within the ore body and certain poor (waste) zones (content below the limit of 0.15% Cu), within that same ore body. In the Northeastern part of the Central Part ore body from the 8 exploration cross sections with 24 drill holes and 2999.6 m of mineralized area, 1527 m were mineralized above 0.15% Cu while the 1472.6 m displayed mineralization below the limit of 0.15% Cu, but however significantly over the Clark values. Using the formula given below (Čifliganec 1993), we have managed to calculate aforementioned coefficient.

$$K_r = \frac{m_1}{m_2} = \frac{1527}{2999.6} = 0.51$$

where:

K_r – Ore-bearing coefficient,

m_1 – Productive interval (mineralized area >0.15% Cu),

m_2 – Total mineralized interval.

This gave us an opportunity to calculate the ore-bearing coefficient of 0.51, which points out that within the defined ore body there are 49% of rock mass below the accepted minimal economic concentration of 0.15% Cu. Additionally we would like to stress out that the ore-bearing coefficients throughout all drill holes ranged from 0.12 up to 1.00 while along the exploration cross sections those ranges were slightly narrower, 0.15–0.69.

***Variation coefficient*:** This coefficient defines spatial distribution of useful mineral components in the the deposit or more precisely how evenly mineralization is represented in the deposit (ore body). In the Northeastern part of the Central Part ore body's case there were drilled 33 exploration drill holes of which 24 drill holes defined the ore body. In those 24 drill holes were sampled 715 samples, which have defined an average content of Cu, Au, Ag and Fe_3O_4. The basic parameters for calculation of variation coeficient in the Northeastern part of the Central Part ore body were selected from 7 the most representative drill holes totaling 515 m (Table 1).

First of all we have calculated an average copper content, as it is given below:

$$C^{-} = \frac{\sum C}{N} = \frac{165.734}{715} = 0.2318\%$$

where:

N – total number of samples

C – Average copper concentration (Cu%)

Then we have proceeded with calculation of median sqaure deviation and variation coefficient as given below:

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{13.105}{714}} = \sqrt{0.018354} = 0.136$$

where:

$\sum X^2$ – Sum of square deviations from an average values

δ – medium square deviation

$$V = \frac{??x100}{\overline{C}} = \frac{0.231x100}{0.135478} = \frac{23.10}{0.135478} = 58.65\%$$

V – Variation coefficient

The value of 58.65% for the variation coefficient is within the range of 32–92%, which points out to an irregular mineralization representative for most of the hydrothermal copper and polymetallic mineralizations.

An average concentration of useful component(s). An average concentation of useful component represents the average presence of one or more components within an ore body. By the basic method of calculation of ore reserves within the Northeastern part of the Central Part ore body (level blocks) it was determined that for calculated B and C1 category of reserves the average values of useful components are 0.229% Cu and 0.232g/t Au.

T a b l e 1

Basic parameters for calculation of variation coefficient in the Northeastern part of the Central Part ore body, Bučim Mine

Cross section	Drill hole	N Tot. no. samples	C⁻ (%) average contents Cu	$\Sigma(x^2)$ Sum of an average values squares	δ average square discrep.	V (%) variation coefficient
BV-BV'	B-52	2	0.1	0	0	0
	B-157	15	0.161	0.221	0.126	78.26
	B-159	21	0.195	1.055	0.23	117.95
	3	38	0.18	1.276	0.173	96.11
BVI-BVI'	B-51	14	0.27	0.22	0.141	52.22
	B-158	15	0.189	0.086	0.078	41.27
	2	29	0.23	0.306	0.1	43.48
BVII-BVII'	B-40	61	0.17	0.37	0.1	58.82
	B-56	8	0.27	0.15	0.141	52.22
	B-120p	23	0.2	0.1	0	0.00
	B-155	23	0.359	1.344	0.247	68.80
	B-408	8	0.206	0.029	0.064	31.07
	5	123	0.22	1.993	0.141	64.09
BVIII-BVIII'	B-31	15	0.27	0.36	0.173	64.07
	B-32	39	0.21	0.49	0.1	47.62
	B-154	34	0.251	0.639	0.139	55.38
	B-412	70	0.315	3.37	0.221	70.16
	B-412k	63	0.208	0.499	0.09	43.27
	B-413	8	0.17	0.186	0.163	95.88
	6	229	0.25	5.544	0.141	56.40
BIX-BIX'	SB-34	88	0.21	1.27	0.1	47.62
	B-411	33	0.259	0.267	0.1	38.61
	B-411pr	23	0.25	0.095	0.066	26.40
	B-411k	70	0.261	1.65	0.141	54.02
	4	214	0.24	3.282	0.141	58.75
BX-BX'	B-152	15	0.112	0.05	0	0.00
	B-409	36	0.239	0.365	0.102	42.68
	2	51	0.2	0.415	0.102	51.00
BXI-BXI'	B-410	23	0.221	0.200	0.095	42.99
BXII-BXII'	B-417	8	0.209	0.089	0.113	54.07
Σ	**24**	**715**	**0.23**	**13.105**	**0.136**	**58.65**

Calculating the Minimal Economic Concentration (MEC). This calculation should provide a clear answer to the question, does the explored deposit or ore body (represented by calculated reserves within) can fulfill the economic requirements for viable exploitation of that ore body. Aforementioned calculation should display, does the exploitation will cover all the production costs and in the same time to achieve adequate profit, equivalent to the required cost effectives coefficient. Bearing in mind that here we were working only with one small part of the Bučim deposits, we used Gudalin's formula (Janković, S. and Milovanović, D, 1985; Čifliganec 1987) where have been considered the following parameters: exploitation costs, utilization of the mineral resource, price of the final product or more precisely the final ore product (copper, gold and silver). As we already mentioned, this calculation was performed by the formula:

$$MEC = \frac{100 \cdot S}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \dfrac{100 \cdot St}{g \cdot \mathrm{Im}} \right)}$$

where:

S – costs of exploitation and processing of 1 t ore (Te and To) 9.0 US$/t

r – dilution during the exploitation 3%

Ie – dillution coefficient during the exploitation (1 – (*r*/100))

Io – coefficient of extraction during enrihment, 86%

Im – efficiency coefficient during the metalurgical processing, 95%

Co – market price of copper (at the moment of calculation), 6700 US$/t

Sm – costs of metalurgical processing of the final product unit, 1000 US$/t

St – cost for transport per tonne ore concentrate, 30 US$/t

g – concentration of metal in ore concentrate, 20%

$$MEC = \frac{100 \cdot S}{Ie \cdot Io \cdot Im \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot Im}()\right)} =$$

$$= \frac{100 \cdot 9.0}{0.07 \cdot 0.86 \cdot 0.95 \left(6700 - 1000 - \frac{100 \cdot 30}{20 \cdot 95}\right)} =$$

$$= \frac{900}{0.79249 \cdot (5700 - 157.895)} =$$

$$= \frac{900}{4392.063} = 0.205\% Cu$$

MEC = 0.205 % Cu.

Calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.205% Cu.

Calculation of monometal. Ore reserves calculation of the Northeastern part of the Central Part ore body have shown that it is natural product that contains in average 0.229% Cu and associated gold 0.232g/t Au. Comparing those values of useful components with the necessary MEC (0.205% Cu) we may conclude that the ore body have contents higher than the minimal one. In those case we trying to calculate all present useful components to one monometal (in this case copper). That calculation was performed using transformation factor (*f*) for associated component (Au) on the basis of Cu expressed as monometal. The transformation factor is calculated as follows (Čifliganec 1987):

$$f_{\mathrm{Au}} = \frac{C_{\mathrm{Au}} \cdot Io_{\mathrm{Au}} \cdot Im_{\mathrm{Au}} \cdot Co_{\mathrm{Au}}}{C_{\mathrm{Cu}} \cdot Io_{\mathrm{Cu}} \cdot Im_{\mathrm{Cu}} \cdot Co_{\mathrm{Cu}}}$$

C_{Au} – average content of Au in ore (g/t),

Io_{Au} – usage efficiency of Au in flotation process (%),

Im_{Au} – metallurgical usage of Au (%),

Co_{Au} – gold in concentrate (g/t),

C_{Cu} – average content of Cu in ore (%),

Io_{Cu} – usage efficiency of Cu in flotation process (%),

Im_{Cu} – metallurgical usage of Cu (%),

Co_{Cu} – copper in concentrate (%).

In that manner we have calculated for the Northeastern part of the Central Part ore body:

$$f_{Au} = \frac{0.232 \cdot 0.5 \cdot 0.92 \cdot 15}{2.29 \cdot 0.86 \cdot 0.95 \cdot 20} = \frac{1.6008}{37.4186} =$$
$$= 0.04278$$

$$\mathrm{Cu} = C_{\mathrm{Cu}} + (Cu_{Cu} \cdot f_{\mathrm{Au}})$$

$$Cu = 0.229 + (0.229 \cdot 0.42781) = 0.238797\%$$

$$Cu_{monometal} = 0.238797\%$$

The calculation above have shown that useful components calculated to the Cu monometal is 0.238797% Cu, which is higher than the needed one calculated with MEC (0.205% Cu) and in that direction the ore reserves can be considered as economically viable itself.

Cutoff grade.- This grade defined as the level of mineral in an ore below which it is not economically feasible to mine (GS) was calculated after intensive analysis of several parameters such are: dilution coefficient of ore during excavation (3%; L_e=100-(3/100)=0.9), efficiency of usability during enrichment (L_o=86%), efficiency of usability during metallurgical processing (L_m=95.0%), cost for enrichment of 1t ore (S_o=5.60 US$/t), transport costs for 1 t of ore concentrate (S_t=25 US$/t), costs for metallurgical processing per unit of final product (S_m=1000 US$/t), market price of copper at the moment of calculation (C_o=6700 US$/t), costs for excavation of 1t of ore and copper metal content in ore concentrate (g=20%). In that manner we have calculated the cutoff grade as follows:

$$GS = \frac{100 \cdot So}{Le \cdot Lo \cdot Lm \cdot \left(Co - Sm - \frac{100St}{gLm}\right)} =$$

$$= \frac{100 \cdot 5.6}{0.97 \cdot 0.86 \cdot 0.95 \left(6700 - 1000 - \frac{100 \cdot 25}{20 \cdot 0.95}\right)}$$

$$= \frac{560}{0.97 \cdot 0.86 \cdot 0.95 \left(5700 - \frac{2500}{19}\right)} = 0.127\%$$

GS = 0.127% Cu.

The calculated cutoff grade takes only copper in consideration although we have gold as valuable components in the Northeastern part of the Central Part ore body's ore, also. Bearing in mind all the above calculated parameters we have calculated the ore reserves within the Northeastern part of the Central Part ore body and corresponding concentrations of certain metals in them (Table 2).

T a b l e 2

Calculation of ore reserves in the Northeastern part of the Central Part ore body

Parameters		Category		
		B	C_1	$B + C_1$
Commodity	unit	5 455 946	6 848 019	12 303 965
Cu	%	0.240	0.221	0.229
Au	g/t	0.287	0.189	0.232
Cu	t	13 078	15 141	28 219
Au	kg	1 566	1 294	2 860

The total of calculated ore reserves in the Northeastern part of the Central Part ore body are in an ammount of 12 303 965 t ($B+C_1$ category) with an average content of 0.229% Cu and 0.232 g/t Au.

CONCLUSION

The Northeastern part of the Central Part ore body is very important ore body for the production of copper ore in the Bučim Mine with calculated ore reserves of 12 303 965 t of ore with an average content of 0.229% Cu and 0.232 g/t Au and specific style of primary porphyry copper ore mineralization, followed by gold contents, since the calculated reserves are the last ones to be produced fom this mine. The ore bearing coeffiecient was calculated at 0.51, variation coefficient 58.65%, minimal economic concentration 0.205% Cu and cutoff grade of 0.127% Cu. All these techno-economic parameters have positive effects to the exploitation of this ore body, which with existing capacity of the Bučim mine provides additional 2.15 years of production.

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