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МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО

ТРЕТ КОНГРЕС
на
Геолозите на Република Македонија

ЗБОРНИК НА ТРУДОВИ

-КНИГА 2-

Уредници:
Лепиткова, С. & Боев, Б.

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OVERVIEW OF THE NATURAL PARAMETERS FROM THE GEOLOGICAL-ECONOMICAL EVALUATION OF THE BOROV DOL ORE DEPOSIT, REPUBLIC OF MACEDONIA

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Abstract
Attractiveness of the newly explored Cu-Au porphyry Borov Dol ore deposit gave us an initiative to calculate several important techno-economical parameters, which can 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 mineralizations within this ore body. Calculated ore-bearing coefficient was 0.78%, meaning that within the ore body boundaries only 22% of mass is not mineralized somehow, which is highly compatible with neighboring Buchim porphyry deposit and its four ore bodies. The calculated value of variation coefficient (V) has shown value of 52% 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, gold and silver concentrations were determined as 0.247% Cu, 0.19g/t Au and 1.34 g/t Ag, respectively. Minimal economic content (MEC) within the Borov Dol ore deposit, as represent of this kind of mineralizations, was determined as 0.204% Cu. In similar manner was calculated the lowest copper boundary, which have shown value of 0.159% Cu and thus allowing certain decrease of contents in the eventual process of exploitation of ore. Also, there were calculated so called copper monometal values, which included influence of the present gold and silver in the ore. Calculated copper monometal was set at relatively fair 0.272% Cu that repre-sents solid mainstay for exploitation of copper in these low percentage ores. Calculated ore reserves in this particular ore body were 60 Mt of ore with 0.247% Cu, 0.19 g/t Au and 1.34 g/t Ag and projected life of eventual open pit mine of promising 12 years.

Key words: Dol, natural parameters, valorization, copper, gold, porphyry ore

INTRODUCTION

The unique Macedonian Cu-Au porphyry deposit Borov Dol is located on the the border between the Serbo-Macedonian massif and the Vardar zone and in terms of metallogeny it belongs to the Lece-Chalki-diki metallogenic zone. The deposit itself is located in eastern central Macedonia, 10 km west of the town of Radovis. Copper and gold occurrences of in the BorovDol locality and its vicinity surroundings were known as early as the 19th century, which is reflected in the remains of old mining and archaeolo-gical artifacts found. Old gutters along the Kriva Lakavica river show the presence of gold in the recent alluvium of the River Lakavica. In the period from 1952 until today, the site Borov Dol, its immediate vicinity and the connection of Borov Dol with the river KrivaLakavica, have been the subject of regional and detailed geological surveys and studies that resulted in the definition of copper and gold porphyry type of deposit in the locality BorovDol and the presence of alluvial gold in the drainage sys-tems of Borov Dol and along the river Kriva Lakavica. Contributions to these numerous studies are presented in the works of Ivanov (1982), Serafimovski (1990), Stojanov and Serafimovski (1990), Cifliganec (1993), Tud-zarov (1993), Bogoevski (1998), Stefanova (2005), Volkov et al. (2008), Serafimovski et al. (2010), Lehmann et al. (2013) etc..

GEOLOGICAL FEATURES

The Borov Dol deposit is part of the mining region Bucim-Damjan-BorovDol, i.e.it occu-pies its southern parts. The metallogeny of this ore region is closely related to the evolution of the Tertiary magmatism represented with subvolcanic-volcanic facies of andesite, latites, quartz latites, trachyrhyolites etc. which are the product of intermediate to acid calc-alkaline magmatism. Numerous interesting mineralizations of Cu, Fe, Pb-Zn as well as Au mineralizations are related to this magmatism. The geological structure (Fig 1) of the BorovDol deposit, which is quite complex, contains Paleogene, Neogene and volcanogene-sedimentary and volcanic rocks (Serafimovski, 1990; Tudzarov, 1993; Serafimovski et al., 2010; Stefanova, 2015). Paleogene sediments occupy a large part of the terrain and are represented with conglomerates, paleogene flysch and series of tuffites and sands. Conglomerates are heavily modified and built mostly of fragments of gneiss and quartz. Flysch facies is built of thin layers of fine-grained and large-grained sandstone and conglomerates.

Volcanogenic sediment series is built of sandstones, marly sandstone and limestone, and pelitic tuffs and tuffites. Tuffs are determined as andesite and their presence indicates that the volcanic activity is synchronous with sedimentation of paleogenic sediments. Neogenic sediments, which are represented by conglomerates, are built of heterogeneous material dominated by pieces of quartz, crystalline shale and paleogenic sediments. Magmatic rocks are represented by volcanic and subvolcanic facies of latites, quartzlatites and andesites. Andesites in turn, depending on the degree of change and ore amount are divided into: propilitized andesites, hydrothermally altered andesites, hydro-thermally altered and mineralized andesites and andesite lava.

Effusive rocks occur in the form of outcrop and lava. Large porphyritic propilitized andesites, i.e. latites and quartzlatites that occupy most of the terrain, are hydrothermally changed and mineralized. Latites and quartzlatites as products of the older phase hacked with dark grey fine-grained biotite amphibole-andesite which in the form of neck are imprinted in the central part of the Borov Dol circular structure. The magmatism at Buchim–Damjan–Borov Dol occurred between 24.04 ± 0.77 and 24.51 ± 0.89 Ma, as indicated by chemical-annealing (CA)-LA ICP-MS zircon dating (Lehmann et al., 2013).

ORE MINERALIZATIONS

More than three decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis (Tudzarov, 1993; Serafimovski et al., 2010; Stefanova, 2015). In the Borov Dol deposit with the latest geological studies was confirmed porphyry type of mineralization localized in coarsegrained hydrothermally altered andesite to latite and around finegrained dark andesite which kind of breakthrough characterize morphological ratio of volcanics and porphyry mineralization within the Borov Dol ore deposit.

Porphyry mineralization is characterized by stockwork-impregnated types of ore mineralization, where within the Borov Dol dominate stockwork impregnations. As we already mentioned the mineralization is of copper porphyry type with representative mineral association of around 40 minerals and mineral phases.

The main ore mineral and bearer of copper mineralization in this deposit is chalcopyrite. As regular association to this mineral occur pyrite, magnetite, and bornite while in the rim parts of the deposit occur galena, sphalerite, tetrahedrite etc, also. Also, within primary sulfide parageneses native gold occur. In central parts of the deposit were determined series of sulphosalts such are enargite, seligmanite, luzonite, tenanntite etc while as secondary sulphide minerals occur chalcocite and covellite. In the deeper parts was determined presence of molybdenite.

Above mentioned features of this ore mineralization gave us an initiative to calculate several important techno-economical parameters, which can define the economic type of this mineralization. Namely, the degree of ore bearing along vertical extent of ore mineralization is variable, but calculation at particular levels and different drill holes gave the more realistic ratio of mineralization within this ore body. Some techno-economic parameters related to the Borov Dol ore deposit can be found in some previous works (Petrov et al., 2014).

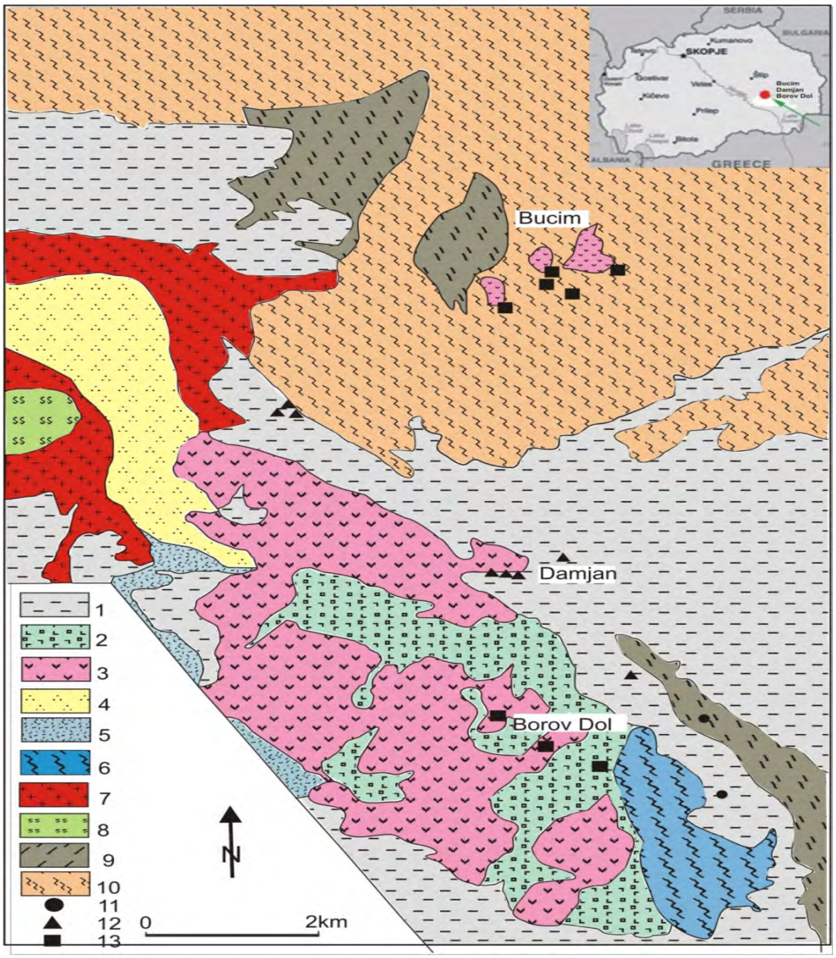

Fig. 1 *Geological setting from Bucim-Damjan-BorovDol ore district (Stefanova, 2005)*

1. Paleogene, neogene quarter sediments, 2. Pyroclasts, 3. Andesite and latite, 4. Cretaceus flysch. 5 Carbontites, 6. Carbonate-schist series, 7. Granite, 8. Serpentinite, 9. Micaschist, 10. Gneiss, 11. Pb-Zn vein type of mineralization, 12. Fe-skarn type of mineralization, 13. Porphyry type of mineralization

TECHNO-ECONOMIC PARAMETERS

Within this chapter we are going to display the major parameters of the techno-economic evaluation of the Borov Dol deposit, which directly are pointing out to a possibility of productive exploitation of copper ore from this particular deposit 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.- 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 Borov Dol ore deposit from the 14 exploration cross sections with 69 drill holes and 6980.7 m of mineralized area, 5421.3 m were mineralized above 0.15% Cu while the 1559.4 m displayed mineralization below the limit of 0.15% Cu, but however significantly over the Clark values. Using the formula given below [10], we have managed to calculate aforementioned coefficient.

$$K_r = \frac{m_1}{m_2} = \frac{5421.3}{6980.7} = 0.78$$

Kr - 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 0.78, which points out that within the defined ore body there are 22% of 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 0.4 up to 1.0 while along the exploration cross sections those ranges were slightly narrower, 0.40-0.86.

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 Vrshnik body's case there were drilled 80 exploration drill holes of which 69 drill holes defined the ore body. In those 69 drill holes were sampled 6416 samples, which have defined an average contents of Cu, Au, Ag and Fe_3O_4. The basic parameters for calculation of variation coeficient in the Borov Dol ore deposit were selected from all the 69 drill holes totaling 3264 m (Table 1).

Table 1. Basic parameters for calculation of variation coefficient in the Borov Dol ore deposit

Дупчотина	N	$\bar{C}$ %	$\sum X^2$	δ	V(%)
BD-8	2	0,37000	0,0882	0,29698	80,27
BD-77	17	0,29188	0,1334	0,09129	31,28
BD-4	2	0,19500	0,0025	0,04950	25,38
BD-342	12	0,16767	0,1081	0,09912	59,12
BD-75	4	0,32150	0,1684	0,23694	73,70
BD-341	8	0,18375	0,0123	0,04186	22,78
BD-303	25	0,18408	0,1239	0,07185	39,03
BD-26	50	0,33490	1,4107	0,16968	50,66
BD-304	66	0,21976	0,5904	0,09531	43,37
BD-3	58	0,21190	1,1643	0,14292	67,45
BD-3K	68	0,28000	1,7288	0,16063	57,37
BD-305	54	0,24344	0,6491	0,11067	45,46
BD-27	97	0,23132	1,0283	0,10350	44,74
BD-306	74	0,19768	0,3005	0,06415	32,45
BD-307	15	0,20208	0,3960	0,16817	82,93
BD-352	48	0,21854	0,5760	0,11070	50,65
BD-308	64	0,20306	0,6150	0,09880	48,66
BD-335	100	0,37762	5,2911	0,23118	61,22
BD-309	111	0,32204	1,5021	0,11686	36,29
BD-336	92	0,21200	0,5157	0,07528	35,51
BD-310	80	0,29828	1,2781	0,12719	42,64
BD-345	46	0,19357	0,2714	0,07766	40,12
BD-72	17	0,18718	0,1020	0,07983	42,65
BD-10	18	0,18667	0,3996	0,15332	82,13
BD-10K	65	0,25768	1,3888	0,14731	57,17
BD-312	46	0,24413	0,4820	0,10349	42,39
BD-9	80	0,40800	5,7911	0,27075	66,36
BD-337	96	0,30031	2,5413	0,16356	54,46
BD-29	88	0,29602	2,3766	0,16528	55,83
BD-338	65	0,35415	0,8722	0,11674	32,96
BD-30	75	0,24851	0,7374	0,09982	40,17
BD-319	60	0,22423	0,6048	0,10125	45,15
BD-33	57	0,19989	0,3926	0,08373	41,89
BD-320	112	0,23955	1,3791	0,11146	46,53
BD-6	57	0,24193	0,5507	0,09917	40,49
BD-321	35	0,24749	1,0824	0,17842	72,08
BD-34	35	0,20571	0,5201	0,12368	60,12
BD-322	70	0,22720	0,5492	0,08922	39,27
BD-343	7	0,18500	0,0535	0,10345	55,92
BD-324	60	0,25003	1,0410	0,13283	53,13

BD-325	88	0,18730	0,6272	0,08490	45,33
BD-326	118	0,27441	2,0159	0,13126	47,84
BD-327	5	0,28080	0,0534	0,11559	41,16
BD-17	110	0,24853	1,5314	0,11853	47,69
BD-1	16	0,15688	0,5175	0,18575	118,41
BD-330	31	0,19581	0,2956	0,09926	50,69
BD-37	26	0,19300	0,4340	0,13175	68,27
BD-38	40	0,34795	1,4715	0,19424	82,00
BD-39	16	0,23300	0,0808	0,07338	31,49
BD-40	66	0,17455	0,5466	0,09171	52,54
BD-22	7	0,19800	0,0856	0,11946	60,33
BD-43	16	0,20188	0,0991	0,08126	40,25
BD-18	87	0,26991	2,4937	0,17029	63,09
BD-19	27	0,20163	0,1988	0,08745	43,37
BD-48	8	0,15650	0,0377	0,03740	46,90
BD-7A	34	0,20124	0,3669	0,10545	52,40
BD-51	9	0,16244	0,0754	0,09707	59,75
BD-21	9	0,17644	0,0419	0,07234	41,00
BD-53	6	0,18800	0,0635	0,11273	59,69
BD-54	60	0,18980	0,5197	0,09385	49,45
BD-55	37	0,23989	0,4231	0,10841	45,19
BD-56	76	0,25079	0,5883	0,08857	35,32
BD-60	53	0,16264	0,1423	0,05231	32,16
BD-61	52	0,22631	0,7204	0,11885	52,52
BD-62	37	0,21527	0,3700	0,10139	47,10
BD-63	27	0,23630	1,1771	0,21277	90,05
BD-73	28	0,17293	0,2252	0,09133	52,82
BD-68	24	0,18550	0,1630	0,08419	45,39
BD-69	15	0,20707	0,2630	0,13707	66,20
∑	**3264**	**0,24829**	**54,4473**	**0,12918**	**52,03**

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

$$\bar{C} = \frac{\sum C}{N} = \frac{810.419}{3264} = 0.2483\%$$

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:

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{54.4473}{3263}} = \sqrt{0.01668627} = 0.129175$$

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

δ -medium square deviation

$$V = \frac{\delta x 100}{\bar{C}} = \frac{0.12918x100}{0.248329} = \frac{12.918}{0.24829} = 52.03\%$$

V-Variation coefficient

The value of 52.03% for 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 Borov Dol ore deposit (level blocks) it was determined that for calculated A, B and C_1 category of reserves the average values of useful components are 0.247% Cu, 0.19 g/t Au and 1.34g/t Ag.

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 effective coefficient. Bearing in mind that here we were working with similar conditions as neighboring Buchim deposits, we used Gudalin's formula (Janković and Milovanović, 1985) 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:

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

where:

- *S*-costs of exploitation and processing of 1t ore (Te i To) 9.0 US$/t
- *r*-dillution during the exploitation 3%
- *Ie*- dillution coefficient during the exploitation (1- (*r/100*))
- *Io*-coefficient of extraction during enrichment, 86%
- *Im*-efficiency coefficient during the metalurgical processing, 95%
- *Co*-market price of copper (at the moment of calculation), 6700 US$/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%

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

$$= \frac{100 \cdot 9.0}{0.97 \cdot 0.86 \cdot 0.95 \left(6700 - 1000 - \frac{100 \cdot 30}{20 \cdot 0.95} \right)} =$$

$$= \frac{900}{0.79249 \cdot (5700 - 157.895)} = \frac{900}{4392063} = 0.204\% Cu$$

MEC = 0.204 % Cu

Calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.204% Cu.

Calculation of monometal.- Ore reserves calculation of the Vrshnik ore body have shown that it is natural product that contains in average 0.247% Cu and associated elements 0.19g/t Au and 1.34 g/t Ag. Comparing those values of useful components with the necessary MEC (0.204% Cu) we may conclude that the ore body have contents higher than the minimal one. In those cases 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 components (Au, Ag) on the basis of Cu expressed as monometal. The transformation factor is calculated as follows:

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

- 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_{Au} – copper in concentrate (%)

In that manner we have calculated for the Borov Dol ore deposit:

$$f_{Au} = \frac{0.19 \cdot 0.5 \cdot 0.92 \cdot 45}{2.57 \cdot 0.86 \cdot 0.95 \cdot 20} = \frac{3.933}{40.3598} = 0.097448$$

$$f_{Ag} = \frac{1.34 \cdot 0.31 \cdot 0.5 \cdot 0.9}{2.47 \cdot 0.86 \cdot 0.95 \cdot 6.7} = \frac{0.18693}{40.3598} = 0.004632$$

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

$$Cu = 0.247 + (0.247 \cdot 0.097448) + (0.247 \cdot 0.004632) =$$
$$= 0.272214\%$$

$$Cu_{monometal} = 0.272214\%$$

The calculation above have shown that useful components calculated to the Cu monometal, is 0.272% Cu, which is higher than the needed one calculated with MEC (0.204% 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 (L_e=3%), efficiency of usability during enrichment (L_o=86%), efficiency of usability during metallurgical processing (L_m=95%), cost for enrichment of 1t ore (S_o=7.0 US$/t), transport costs for 1 t of ore concentrate (S_t=30 US$/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:

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

$$= \frac{100 \cdot 7}{0.97 \cdot 0.86 \cdot 0.95 \left(6700 - 1000 - \frac{100 \cdot 30}{20 \cdot 0.95} \right)} =$$

$$= \frac{700}{0.97 \cdot 0.86 \cdot 0.95 \left(5700 - 1000 - \frac{100 \cdot 30}{20 \cdot 0.95} \right)} = 0.159\%$$

GS= 0.159% Cu

The calculated cutoff grade takes only copper in consideration although we have gold and silver as valuable components in the Borov Dol ore deposit.

Bearing in mind all the above calculated parameters we have calculated the ore reserves within the Borov Dol ore deposit and corresponding concentrations of certain metals in them (Table 2).

Table 2. Calculation of ore reserves in the Borov Dol ore deposit

Parameters		Category			
		A	B	C_1	A+B + C_1
Commodity	**unit**	6570426	14978665	40803745	62352836
Cu	%	0.291	0.263	0.234	0.247
Au	g/t	0.21	0.21	0.18	0.19
Ag	g/t	1.37	1.22	1.37	1.34
Cu	t	19123	39423	95473	154019
Au	kg	1403	3166	7413	11982
Ag	kg	9022	18306	56069	83397

From the total of calculated ore reserves in the Borov Dol ore deposit in an ammount of 62 352 836 t (A+B+C_1 category) with an average content of 0.247% Cu, 0.19 g/t Au and 1.34 g/t Ag to A-category belong 6 570 426 t with an average content of 0.291 % Cu, 0.21 g/t Au and 1.37 g/t Ag, to B-category belong 14 978 665 t with an average content of 0.263 % Cu, 0.21 g/t Au and 1.22 g/t Ag while the rest of 40 803 745 t with an average 0.234%Cu, 0.18 g/t Au and 1.37g/t Ag belongs to C_1-category.

CONCLUSION

The Borov Dol ore deposit is one of the most important newly explored copper ore deposits in the Republic of Macedonia with with calculated ore reserves of 62 352 836 t (A+B+C_1 category) with an average content of 0.247% Cu, 0.19 g/t Au and 1.34 g/t Ag. The ore bearing coeffiecient was calculated at 0.78, variation coefficient 52.03%, minimal economic concentration 0.204% Cu and cutoff grade of 0.159% Cu. All these techno-economic parameters should have positive effects to the eventual exploitation of this ore deposit, which has capacity of 12 years of mine life.

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