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CALCULATION OF VARIATION AND ORE-BEARING COEFFICIENTS IN THE PLAVICA EPITHERMAL POLYMETALLIC DEPOSIT, EASTERN MACEDONIA

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ABSTRACT

Latest calculations of the ore-bearing coefficient in the Plavica deposit for gold and copper displayed values of 0.441 for gold and 0719 for copper, which means that within the deposit only 55.9% and 28.2%, respectively, of mass is not mineralized somehow. The calculated value of variation coefficient (V) has shown value of 271 for the gold and 130 for copper, which displays that this ore body belongs to the group of deposits with extremely uneven mineralization. An average gold and copper concentrations were determined as 0.336% Cu and 0.85g/t Au. Minimal economic content (MEC) within the Plavica deposit, was determined as 0.217 g/t Au and 0.264% Cu. In similar manner was calculated the lowest copper boundary (cutoff grade), which have shown value of 0.156% Cu and thus allowing certain decrease of contents in exploited ore. Also, there was calculated so called copper monometal value, which included influence of the present gold in the ore and it was set at relatively fair 0.371% Cu that represents solid mainstay for exploitation of copper in these low percentage ores.

Keywords: Plavica deposit, high-sulphidation, epithermal, gold, copper, variation coefficient, minimal economic concentration.

INTRODUCTION

Lately, explored in more details, the Plavica high-sulphidation epithermal deposit is situated in the Serbo-Macedonian massif and in terms of metallogeny it belongs to the Lece-Chalkidiki metallogenic zone [1], [2]. The deposit itself is located in eastern central Macedonia, 7 km north-western of the Probistip city and 5 km southern of the Kratovo city. This Plavica deposit is very specific since there were determined several economically interesting commodities (Au-Cu). Here we would like to point out detailed exploration performed by the Genesis Resources International DOOEL Skopje, which study was concentrated mostly in the northeastern part of the Plavica deposit (mineralized area known as Plavica-Zlatica) and hill top where dominate secondary quartzites, where was defined one new Cu-Au mineralization type with dominant epithermal gold of high sulfidation with representative elongated lens-like ore bodies, which follows the structural controlling forms. 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 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 last works related to the Plavica deposit can be found in [2], [3], [4], [5], [6].

GEOLOGICAL FEATURES

The geological setting and structural-tectonic features of the Plavica deposit are part of the well known Kratovo-Zletovo volcanic area. Up to date it was confirmed that the geological setting of the Plavica deposit is dominated by volcanic and volcano-sedimentary rocks, which exact determination is complex due to intesive presence of hydrothermal alterations. Nevertheless, numerous lithostratigraphic and petrographic studies confirmed that from the geological point of view this deposit is built of: ignimbrite, stratified volcanic tuff and breccia, dacito-andesite and their pyroclasts as well as quartzlatites that the most often occur as breaktroughs. Silex-secondary quartzite in the central part of the Plavica have a significant distribution and it is interesting that except traces of sulphides contains some quantities of gold (0.1-3.0 g/t Au) as well.

Spatially and paragenetically mineralization in the north-eastern parts of the Plavica deposit occurs as Au-epithermal mineralization of high sulfidization related to sinter-secondary quartzite, oxidized breccias and stratified tuffs. In general, the ore mineralization within the Plavica deposit, is deposited in empty spaces in fault-crack systems, veins, veinlets and metasomathically has been impregnated in adjacent hydrothermally altered volcanic rocks. Mineralization of impregnated type is the most common near the cracking systems.

ORE MINERALIZATIONS

More than six decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis. The mineralisation occurs in four distinct settings: (i) stockwork and disseminated Cu–Au (+Mo, Ag) mineralisation occurs in the central and deepest part of the system. It is present over an area of 6 km^2 and was still reported at depth in the deepest drill hole (950 m below surface); (ii) veins of quartz, pyrite, sphalerite and enargite (± gold) occur at intermediate levels and appear to be superimposed on the stockwork. Old workings in the area followed these enargite veins for distances up to 200 m and show that they had a thickness from 0,7 to 5 m and a content of Cu around 2% and Au at 1 ppm. They seem to occur where the NW–SE structures intersect E–W veins, mostly in the northern part of the deposit (Figure 1); (iii) silica bodies occur peripheral to the central zone (ore bodies consist of quartz plus some opal and are sub-vertical in orientation); (iv) around the margins of the caldera, there are small veins with enrichments in Pb and Zn (up to 1% combined PbzZn). There are also some U-rich veins, although their exact relationship with the Plavica system is unclear. We would like to point out that the detailed exploration performed by the Genesis Resources International DOOEL Skopje, which study was concentrated mostly in the northeastern part of the Plavica deposit defined one new Cu-Au mineralization type where dominate epithermal gold of high sulfidation with representative elongated lens-like ore bodies, which follows the structural controlling forms and are spread over an area represented at Figure 1. In regards to mineralization the following minerals has been confirmed there: pyrite, pyrrhotite, chalcopyrite, magnetite, rutile, scheelite, hematite, molybdenite, galena, sphalerite, bornite, enargite, native gold, tetrahedrite, tennantite, chalcocite, digenite, covellite, proustite, native copper, malachite, azurite, and some other.

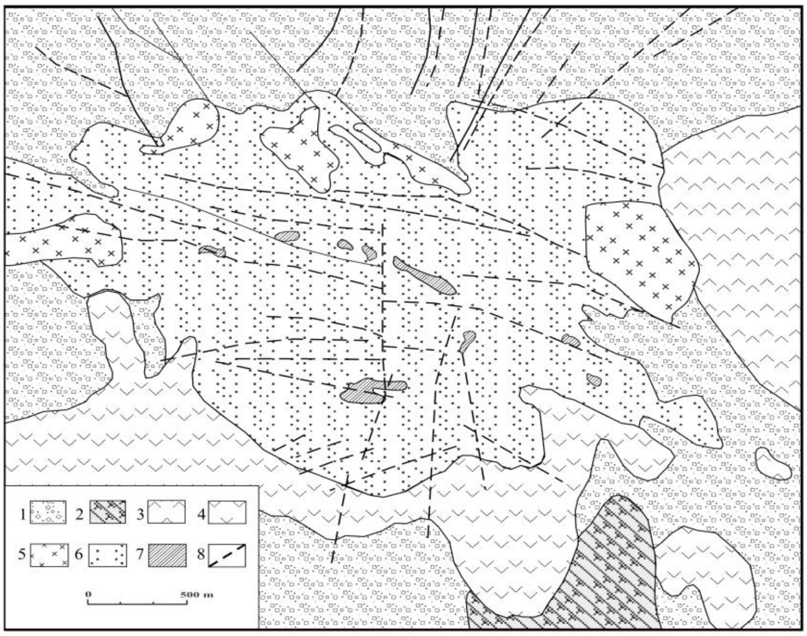

Fig. 1. Simplified geological map of the Plavica deposit [1]
1. Volcanic tuff and breccia, 2. Stratified tuff, 3. Dacite-andesite, 4. Andesite, 5. Quartz latite, 6. Hydrothermally altered and mineralized volcanics, 7. Hydroquartzite, 8. Fault structures

The latest studies have confirmed presence of seligmannite, luzonite, famatinite, petzite, bogdanovite, bezsmertnovite, sylvanite, pearceite, bilibinskite etc.

TECHNO-ECONOMIC PARAMETERS

This part of the paper displays the major parameters of the techno-economic evaluation of the Plavica polymetallic deposit, which directly are pointing out to a possibility of productive exploitation of gold and copper 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 and cutoff grade.

Ore-bearing coefficient.- As we alredy know, 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 Plavica deposit from the 11 exploration cross sections with 29 drill holes and 3374 m of mineralized area, 1498 m were mineralized above 0.4 g/t Au while the 1885 m displayed mineralization below the limit of 0.4 g/t Au, but however significantly over the Clark values. Also, of 1362 m of mineralized area with copper, 979 m were mineralized above 0.15% Cu while the 383 m displayed mineralization below the limit of 0.15% Cu, but however significantly over the Clark values. Using the formula given below [7], we have managed to calculate aforementioned coefficient for both commodities, respectively.

$$K_{r\,Au} = \frac{m_1}{m_2} = \frac{1489}{3374} = 0.441$$

Kr_{Au} - Ore-bearing coefficient for gold
m_1- Productive interval (mineralized area >0.4 g/t Au)
m_2 - Total mineralized interval

and

$$K_{r\,Cu} = \frac{m_1}{m_2} = \frac{979}{1362} = 0.719$$

Kr_{Cu} - Ore-bearing coefficient for copper
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 0.441 for gold and 0.719 for copper, which points out that within the defined ore body there is 55.9% of mass below the accepted minimal economic concentration of 0.4 g/t Au and 28.2% mass below the accepted minimal economic concentration of 0.15% Cu. Additionally the ore-bearing coefficients throughout all drill holes along the exploration cross sectio-ns ranged 0.032 to 0.720 for gold and slightly narrower for copper (0.303 to 0.917).

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. In the Plavica's case there were drilled 67 exploration drill holes that defined the ore body itself. In those 67 drill holes were sampled 15795 samples, which have defined an average contents of Cu, Au, Ag and Pb+Zn. The basic parameters for calculation of gold variation coefficient in the Plavica deposit were calculated from 20 the most representative drill holes totaling 1664 m (Table 1).

Table 1. Basic parameters for calculation of gold variation coefficient in the Plavica deposit

Drillhole	*N*	*C⁻ (g/t)*	*Σ X²*	*δ*	*V (%)*
DDP006	47	4,9304	7716,348	12,952	262,712
PLV011	222	0,6988	184,175	0,91289	130,45
PLV014	20	0,568	3,968	0,45699	80,45
PLV015	32	1,063	28,494	0,9587	90,19
PLV016	34	0,618	3,912	0,344	55,74
PLV017	12	0,694	0,699	0,252	36,31
PLV018	46	0,8154	73,491	1,278	156,72
PLV019	114	0,805	92,088	0,903	112,09
PLV020	10	0,641	0,91	0,318	49,61
PNDD002	109	0,751	44,07	0,639	85,0
PNDD003A	102	0,921	134,33	1,1533	125,2
PNDD004	96	1,046	83,572	0,938	89,67
PNDD005	131	0,758	78,566	0,777	102,6
PNDD006	66	0,422	9,57	0,384	90,93
PNDD013	245	0,696	235,488	0,982	141,2
PNDD014	60	0,422	5,098	0,294	69,73
PNDD015	57	0,564	11,043	0,444	78,69
PNDD016	75	0,675	25,5378	0,5875	87,005
PNDD017	71	1,058	139,443	1,411	133,4
PNDD018	115	0,573	29,11	0,505	88,27
Σ	**1664**	**0,854**	**8899,91**	**2,31338**	**271,039**

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

$$C^{-} = \frac{\sum C}{N} = \frac{1420.26}{1664} = 0.854\%$$

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:

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{8899.91}{1663}} = \sqrt{5.3517} = 2.3133$$

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

δ -medium square deviation

$$V = \frac{\delta x 100}{\bar{C}} = \frac{2.3133x100}{0.854} = \frac{231.33}{0.854} = 271.039\%$$

V-Variation coefficient

The value of 271% for the variation coefficient is within the range of 36-262%, which points out to an extremely uneven mineralization representative for most of the hydrothermal copper/gold and polymetallic mineralizations. In the very same manner calculation of copper variation coefficient in the Plavica deposit was calculated from 34 representative drill holes totaling 1330 m (Table 2).

Table 2. Basic parameters for calculation of copper variation coefficient in the Plavica deposit

Drillhole	N	$\bar{C}$ %	$\sum X^2$	δ	V(%)
DDP006	71	0,437	5,660	0,284	65,14
PLV011	178	0,488	15,160	0,293	59,96
PLV014	0	0,000	0,000	0,000	0,00
PLV015	0	0,000	0,000	0,000	0,00
PLV016	5	0,177	0,001	0,018	9,94
PLV017	6	0,240	0,020	0,063	26,21
PLV018	2	1,030	0,000	0,000	0,00
PLV019	8	0,350	0,320	0,214	61,23
PLV020	38	0,757	8,220	0,471	62,27
PNDD002	30	0,280	0,245	0,092	32,82
PNDD003A	20	0,511	5,640	0,545	106,70
PNDD004	12	0,335	0,910	0,287	85,69
PNDD005	44	0,300	2,280	0,230	76,84
PNDD006	73	0,463	48,910	0,824	177,98
PNDD013	222	0,493	121,950	0,743	150,76
PNDD014	24	0,400	8,960	0,624	156,12
PNDD015	40	0,410	5,320	0,369	89,94
PNDD016	41	0,533	16,870	0,649	121,89
PNDD017	69	0,599	101,250	1,220	203,61
PNDD018	29	0,549	18,100	0,804	146,56
PNDD019	5	0,410	0,112	0,167	40,77
PNDD020	0	0,000	0,000	0,000	0,00
PNDD021	3	0,307	0,090	0,213	69,19
PNDD022	6	0,637	2,170	0,659	103,49
PNRC001A	7	0,667	1,520	0,504	75,61
PNRC012	64	0,409	14,030	0,472	115,34
PNRC014	43	0,241	0,790	0,137	56,82
PNRC063	54	0,365	2,140	0,201	55,13
PNRC015	45	0,676	67,950	1,243	183,69
PNRC016	31	0,435	3,700	0,351	80,81
RP010	77	0,617	45,040	0,770	124,81
RP011A	40	0,577	23,910	0,783	135,71
RP012	32	0,381	4,240	0,370	97,17
RP009A	11	1,264	9,930	0,997	78,86
Σ	**1330**	**0.486**	**535.438**	**0.635**	**130.613**

Here we calculated an average copper content, as it is given below:

$$\bar{C} = \frac{\sum C}{N} = \frac{646.333}{1330} = 0.486\%$$

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:

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{535.438}{1329}} = \sqrt{0.4028879} = 0.63473$$

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

δ -medium square deviation

$$V = \frac{\delta x100}{\bar{C}} = \frac{0.63473x100}{0.486} = \frac{63.473}{0.486} = 130.613\%$$

V-Variation coefficient

The value of 130% for the variation coefficient is within the range of 9-203%, which points out to an extremely uneven mineralization representative for most of the hydrothermal copper/gold and polymetallic mineralizations.

An average concentration of useful component(s) .- An average concentration 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 Plavica deposit (parallel cross sections) it was determined that for calculated A, B and C_1 category of ore reserves an average values of useful components are 0.336% Cu and 0.85 g/t Au.

Calculation of the Minimal Economic Concentration (MEC). – This calculation should provide a clear answer to the question, do the explored deposit (represented by calculated reserves within) can fulfill the economic requirements for viable exploitation. 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. We have used Gudalin's formula [7] 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) 10.00 US$/t
r-dillution during the exploitation 3%
Ie- dillution coefficient during the exploitation (1- (*r/100*))
Io-coefficient of extraction during enrichment, 40%
Im-efficiency coefficient during the metalurgical processing, 90.6%
Co-market price of gold (at the moment of calculation), 40000 US$/kg (1235 US$/troy oz.)
Sm-costs of metalurgical processing of the final product unit, 1150 US$/kg
St-cost for transport per kilogram ore concentrate, 31 US$/kg
g-concentration of metal in ore concentrate, 15 g/t Au.

$$MES = \frac{100 \cdot S}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} = \frac{100 \cdot 10.00}{0.97 \cdot 0.40 \cdot 0.906 \left(40000 - 1150 - \frac{100 \cdot 35}{15 \cdot 0{,}906} \right)} =$$

$$= \frac{1000}{0.352 \cdot (38850 - 25754.2)} = \frac{1000}{4609.7} = 0.217 g/t\ Au$$; **MES = 0.217 g/t Au**

Calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.217 g/t Au.

In the very same manner, using the same MEC formula, with variables set for copper, we have calculated the MEC value for this particular commodity: *S*-costs of exploitation and processing of 1t ore (Te i To) 10.00 US$/t; *r*-dillution during the exploitation 3%; *Ie*- dillution coefficient during the exploitation (1- (*r/100*)); *Io*-coefficient of extraction during enrichment, 70%; *Im*-efficiency coefficient during the metalurgical processing, 95%; *Co*-market price of copper (at the moment of calculation), 7200 US$/t; *Sm*-costs of metalurgical processing of the final product unit, 1150 US$/t; *St*-cost for transport per tonne ore concentrate, 35 US$/t; *g*-concentration of metal in ore concentrate, 20% Cu

$$MES = \frac{100 \cdot S}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} = \frac{100 \cdot 10.00}{0.97 \cdot 0.70 \cdot 0.95 \left(7200 - 1150 - \frac{100 \cdot 35}{20 \cdot 0{,}95} \right)} =$$

$$= \frac{1000}{0.64505 \cdot (6050 - 184.211)} = \frac{1000}{3783.727} = 0.264\% Cu$$; **MEC = 0.264 % Cu**

Calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.264% Cu.

Calculation of monometal.- Ore reserves calculation of the Plavica deposit have shown that it is natural product that contains in average 0.336% Cu and 0.85g/t Au. Comparing those values of useful components with the necessary MEC (0.264% Cu) we may conclude that the ore deposit has contents higher than the minimal one. In those cases we are 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) on the basis of Cu expressed as monometal:

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

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 (%)

$$f_{Au} = \frac{0.85 \cdot 0.4 \cdot 0.906 \cdot 15}{3.36 \cdot 0.70 \cdot 0.95 \cdot 20} = \frac{4.6206}{44.688} = 0.103397$$

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

$$Cu = 0.336 + (0.336 \cdot 0.103397) = 0.371\%$$; **$Cu_{monometal}$ = 0.371%**

The calculation above have shown that useful components calculated to the Cu monometal, is 0.371% Cu, which is higher than the needed one calculated with MEC (0.264% Cu) and in that direction 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 excavate (GS), was calculated after analysis of several parameters: dilution coefficient of ore during eventual excavation (L_e=3%), efficiency of usability during enrichment (L_o=70%), efficiency of usability during metallurgical processing (L_m=95%), cost for enrichment of 1t ore (S_o=6.00 US$/t), transport costs for 1 t of ore concentrate (S_t=35 US$/t), costs for metallurgical processing per unit of final product (S_m=1150 US$/t), market price of copper at the moment of calculation (C_o=7200 US$/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:

$$GS = \frac{100 \cdot So}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \frac{100 St}{g\,\mathrm{Im}} \right)} = \frac{100 \cdot 6}{0.97 \cdot 0.70 \cdot 0.95 \cdot \left(7200 - 1150 - \frac{100 \cdot 35}{20 \cdot 0.95} \right)} =$$

$$= \frac{600}{0.97 \cdot 0.70 \cdot 0.95 \cdot \left(6050 - \frac{3500}{19} \right)} = 0.158\ \%$$ Cu; **GS= 0.158% Cu**

The calculated cutoff grade takes only copper in consideration although we have gold (and some other commodities) as valuable components in the Plavica deposit.

CONCLUSION

The Plavica deposit is one of the most promising newly explored deposits in the Republic of Macedonia with an average grade of 0.336% Cu and 0.85 g/t Au. The ore bearing coeffiecient for gold and copper displayed values of 0.441 and 0719 respectively, variation coefficient has shown value of 271 for gold and 130 for copper (extremely uneven mineralization), minimal economic concentration was determined as 0.217 g/t Au and 0.264% Cu and cutoff grade of 0.156% Cu. All these techno-economic parameters would have positive effects to the eventual exploitation of this ore deposit.

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