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NEW INTERPRETATION OF THE LITHOGEOCHEMICAL DATA FROM THE ALŠAR EPITHERMAL Au-MINERALIZED AREA

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A b s t r a c t : The paper presents a new approach to the interpretation of the geochemical data obtained from samples collected in the wider vicinity of the Alšar deposit. The authors use the results of 288 samples analyzed in the laboratories of the NASSAU Company, USA, during the time period from 1986 to 1989. Gold with average contents of 0.55 ppm Au was found in 156 samples. The lowest anomaly amounts to 0.31 ppm Au and varies from 0.034 ppm to 19.64 ppm Au. The interpretation of the present authors showed that data falls mainly in three major points which follow the fractures of north-northeast – south-southwest strike orientation. A study of the correlation relationships between Au and other accompanying elements indicated good relationship between Au and Sb, in places between Au and As where high correlation coefficients were found between Au and Sb. Those of Hg and Ag are very low and no pertinent correlation between Au and Hg and Au and Ag were found. Three-dimensional presentation of Au contents in the Alšar deposit defines the hypsometric distribution whose highest Au concentrations were found between peaks 800 m and 823 m.

Key words: Alšar deposit; epithermal gold mineralization; lithogeochemical data; gold

INTRODUCTION

The Alšar deposit is related to the Kožuf-Aridea metallogenic district along the Greek-Macedonian border. Several Sb-As-Au and Cu-deposits are so far known in Serbo-Macedonian metallogenic province, and occurences of native sulphur in Greece. Mineralization is associated with a Pliocene volcano-intrusive complex developed along a major regional fault zone between the rigid Pelagonian crystaline block on the west, and the labile Vardar zone on the east.

The Alšar deposit was mined, intermittently, from about 1880 to 1912 for its arsenic ore, when the first discoveries of of Tl-minerals (lorandite, vrbaite) took place. Later exploration for antimony from 1958 until 1965, resulted in significant reserves of low grade antimony ore, however high arsenic contents in Sb-concentrates has precluded economic exploitation. Gold mineralization of probably economic importance has been identified and preliminary explored by Percival (1990). Special interest for thallium as possible solar neutrino detector gave new impulse for systematical investigations of thallium mineralization. It should be epmhasized that the Alšar deposit is not fully explored and the metallogenic studies completed. The current investigations are still in progress. For the results from previous studies of Alšar ore deposit the reader is refered to Percival (1990); Percival and Radtke (1990, 1994); Percival et al. (1974, 1992); Hadži-Petrušev (1987); Janković (1990); Janković et al. (1997); Boev (1988); Boev et al. (1990a, 1990b, 1994, 1996).

GEOLOGY

This igneous complex formed on a basement composed predominantly of the Triassic sediments, the Jurassic ophiolites (gabbro-peridotites prevails), and the Cretaceous sediments. Volcano-intrusive activity took place from 7 m.y. to 1.8 m.y. (Boev, 1988).

The composition of rocks range from andesite-quârtz latite to rhyolite and trachyte, and they enriched in potassium, rubidium, and cesium (Boev, 1988). Voluminous quantities of extrusive facies such as felsic tuffs, ash, tuff breccia and lacustrine volcanoclastic deposit are very widespread in the area; coeval subvolcanic and hypabyssal intrusions have been exposed at several localities. Some of the volcanic complexes display ring-radial structures.

The basement of the Alšar deposit consists of the Triassic rocks such as schists and carbonate rocks. The quartz-sericite-feldspar schists are developed along the eastern flank of the deposit, while the central part is composed of dolomite and marble. Along the western margin of the deposit small outcrops of the Jurassic peridotite occur occasionally. The mesozoic rocks are unconformably overlain by late Pliocene cover, and glacial till. The earliest Tertiary rocks are tuffaceous dolomites locally intercalated with sequence of tuff, waterlain ash and volcanic glass. The felsic tuffs unconformably overlies the tuffaceous dolomite, and locally the Mesozoic basement rocks (Percival et al., 1990). The basal zone between the Tertiary tuffs and tuffaceous dolomite, and underlying the Mesozoic basement consists of detrital fragments. The subvolcanic latite intrusions cross cut both Mesozoic and Tertiary rocks; they outcrop locally as minor exposures, but large latite bodies are revealed by the underground antimony/arsenic mining workings in the central part of deposit.

Latite intrusions have a K-Ar age of 4.5–5.0 m.y. Based on $^{87}Sr/^{86}Sr$ ratio for latite (0.70856), it may be concluded that parent magma derived from lower continental crust/upper mantle domain.

Simplified map of the ore-bearing zones in the Alšar deposit with three major parts (northern, central and southern) is shown in Fig. 1.

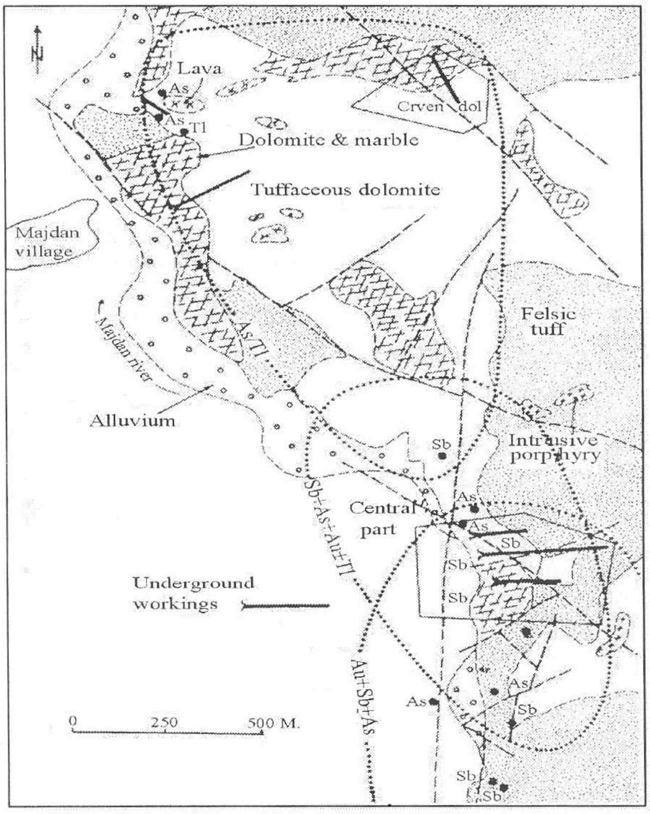

Fig. 1. The ore-bearing zones in the Alšar deposit

The faults and fault-zones are grouped into three sets based on strike orientation (Percival et al. 1990): N–N20E, N35–50E, and N40–50W. The most significant fracture is a major north-trending structural zone about 80 m wide and it was a major path way for hydrothermal fluids.

The localization of mineralization is spatially associated with environments characterized by increased porosity and permeability, typically related to fractures and fractured zones in the vicinity of subvolcanic intrusive bodies. Such steeply dipping ore-bearing structures resulted from slip-type shearing movements represented by brecciated rocks often in a fine-grained gougy matrix. The increased porosity and composition of the tuffs are favourable environment for hydrothermal fluid migration and for introduction of sulphides and gold (Fig. 2). A second favourable environment is a porous and permeable basal zone developed as a stratabound along the Triassic erosion surface; it is 5–10 m thick and several hundred meters long (Percival, 1990).

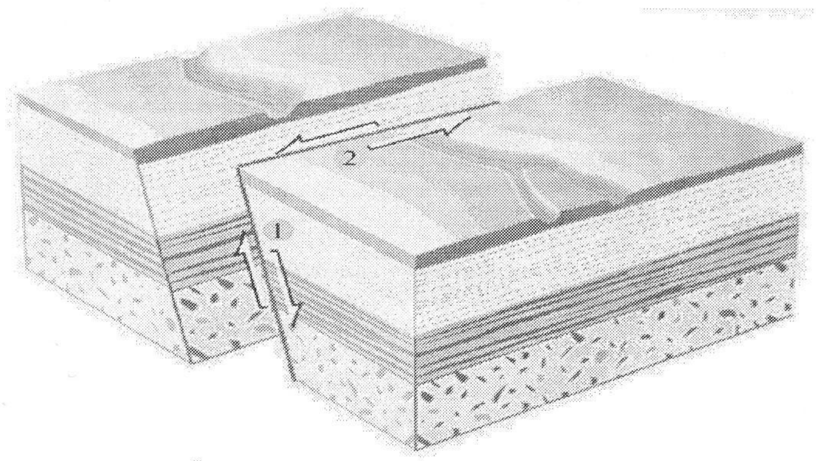

Fig. 2. The most common type of faults in Alšar ore district

Mineralization is hosted by the Triassic carbonates (dolomites and marbles), the Tertiary magmatic rocks and volcano-sedimentary sequence (tuffaceous dolomite). The most significant alteration facies are silification and argillitization. Quartz veins and stockwork-veinlets occur in jasperoids, and in silicified tuffs. Replacement type, silicification occurs where the hydrothermal fluids have replaced Ca- and Mg-carbonates with microcrystalline quartz, and is commonly associated with variable argillitization. Silicification is of variable intensity grading often into jasperoid. Argillitization is mainly developed in tuffs and tuffaceous dolomite. The alteration intensity ranges from week clay replacement to complete destruction of the parent rock textures in the pervasivelly altered host rocks. Distribution of the alteration facies is characteristically zoned from a silicified core grading laterally into argillized rocks. Locally, silicification is intermixed with argillically altered rocks.

Gold mineralization

According to the results gained from the long period of investigations, in the area of the interest are defined few morphostructural types of mineralization (by Janković, 1993):

– Mineralized brecciated zones developed along the contact between the subvolcanic intrusions, dolomite and/or tuffaceous dolomite, or along shear zones in the carbonate rocks.

– Massive sulphide pods (mostly realgar) occur in the carbonate rocks (dolomitic "sand"), grading into stockwork mineralization. Massive sulphide mineralization, mainly pyrite/marcasite, occupies steeply-dipping fault/shear zones.

– A mineralized system of veinlets and fractures occurs in the Tertiary tuffaceous dolomite and the Triassic dolomite.

Stratiform sulphide veinlets in tuffaceous dolomite and/or along unconformity between Mesozoic and Tertiary rocks occur occasionally.

– Disseminated mineralization, mostly stibnite, pyrite/marcasite, and gold occurs (a) as stratabound bodies along the contact between the basal portion of Tertiary volcanic-sedimentary sequence (tuffaceous dolomite and/or tuffs), and underlying Triassic carbonate rocks, (b) in the silicified volcanics, with variable amounts of argillic clays, and (c) as abundant finely disseminated pyrite/marcasite, stibnite and gold in the jasperoids, locally accompanied by As-sulphides (realgar and less orpiment).

In the context of this paper special attention is done to the gold mineralization in the southern parts of the Alšar ore deposit. The epithermal ore is of disseminated replacement-type. Gold mineralization occurs in Mesozoic dolomite, in jasperoids along faults and in an unconformity between the pre-Tertiary age rocks, and micro-quartz veinlets, disseminations and silica replacement bodies in Tertiary tuffaceous dolomite and overlying Tertiary tuffs. Gold is very fine grained (micron to submicron particles), and shows a strong association with introduced silica and antimony.

Although gold mineralization in the Alšar deposits is similar to the Carlin-type, it differs from the typical Carlin-type deposits in the western parts of United States by relatively young Pliocene age, presence of mineralization in volcanics, and sedimentary rocks, as well as very large amount of thallium in both mineralized rocks and wall-rocks.

So far have been identified three principal types of gold ore:

Jasperoidal ore occurs in Tertiary tuffaceous dolomite and volcanic tuff, in Mesozoic carbonate rocks, and in and along the unconformity. This type of gold ore formed by the near complete replacement of the original rocks by introduced hydrothermal silica. The mineral assemblage consists of native gold and, in decreasing abundances, marcasite, pyrite, stibnite, realgar, orpiment, and As-Sb-Tl-Hg sulphosalts. The gold content varies from 1 to 3 g/t.

Siliceous ore deposited in both volcanic tuffs and dolomite replaced by hydrothermal silica. The gold ores, particularly those in tuff, are characterized by brecciation and quartz micro-stockwerks. The content of sulphide minerals such as pyrite, stibnite, marcasite and realgar, is lower than that in the mineralized jasperoids.

The gold ranges from 0.5 to 2 g/t.

Arsenical gold ore is hosted by argillically-altered Tertiary tuffaceous dolomite and tuff. The primary mineral assemblage includes, apart from gold, realgar, orpiment, marcasite, and Tl-minerals. It occurs above and lateral to jasperoidal and siliceous-type ores.

The ore contains high arsenic (up to 10 % As), 1–3 g/t gold, and variable amounts of thallium (from traces to 0.25 % Tl).

SAMPLING AND FIRST INTERPRETATION OF DATA

The most intense geochemical sampling in the area under consideration were carried out between 1986 and 1989 by the NASSAU Company, USA (with full participation of Blažo Boev). Special attention was paid to the jasperoid antimony mineralization in underground workings and to the silicified tuffs in the southern portions of the area. Sampling was carried out in a net of 25 lines of east-west and north-south general strikes (the distance between the lines amounting to 50 m). Samples were taken in 10 m long spacing between lines with hydrothermally altered exposures. The total of 288 samples were collected. The results were compiled as a geochemical map of anomalies the scale 1 : 1000. The aim of this fresh interpretation is the presentation of the geochemical study of the southern portions of the Alšar deposit.

The material collected during the diggings, lithogeochemical prospecting and from level entries was prepared in a Johnson crusher and pulverized. Quartering of the material was also carried out. The material prepared in this manner was analyzed in the Hunter laboratory, USA. One in four samples was also analyzed in the laboratory of the Bučim Mine, Radoviš. The samples sent to the USA were analyzed for gold, silver, arsenic, antimony and mercury with the application of the cupellation and atomic adsorption methods. The samples analyzed in the Bučim laboratories were studied for gold by atomic adsorption method.

The samples collected during geological prospecting were prepared and analyzed in spectrograph and atomic absorber in the laboratory of the Geoinstitute in Skopje. X-ray examinations were carried out in the laboratories of the Faculty of Technology and Metallurgy in Skopje. However, the latter kind of investigation is not the subject matter of this paper.

The study of gold during the lithogeochemical prospecting indicated that 156 samples out of 288 samples collected, indicated gold content of at least 0.03 g/t Au. Statistical analysis yielded the lowest level of anomaly of 0.31 g/t Au (Hadži-Petrušev, 1987). Samples were placed in three categories: category I amounting from 0.31 to 0.93 g/t; category II from 0.94 to 2.79 g/t; and category III ≥ 2.80 g/t Au.

A brief look at the data obtained indicates that all samples of anomalous gold are found in silicified dolomites in the south portions of the area under investigation. Increased concentrations are found in zones of more intense silicification. They are of north-south extension with subsidence beneath unsilicified dolomites in the central parts. The continuation of these anomalous fields is occasionally interrupted by presence of local tectonics in the area.

Samples were also collected from the three horizons that served as major exploitation adits over the past period. Statistical data for all three horizons indicate that the lowest anomaly varies. The lowest anomaly of 0.37 g/t occurs in horizon 823 and of 0.51 g/t in horizon 800. Statistical analysis for horizon 784 was not carried out owing to poor gold distribution. A look at the samples shows that anomalous concentrations are found in areas of intense silicification and mineralized with antimony mineralization. It is noteworthy that certain increases can be encountered in powdered dolomites that are frequently mineralized with antimony-arsenic mineralization. The continuation of anomalous fields is another favourable factor in gold investigation. The graphic presentation of the spatial distribution of gold (Hadži-Petrušev, 1989) shows that it is of northeast–southwest strike orientation.

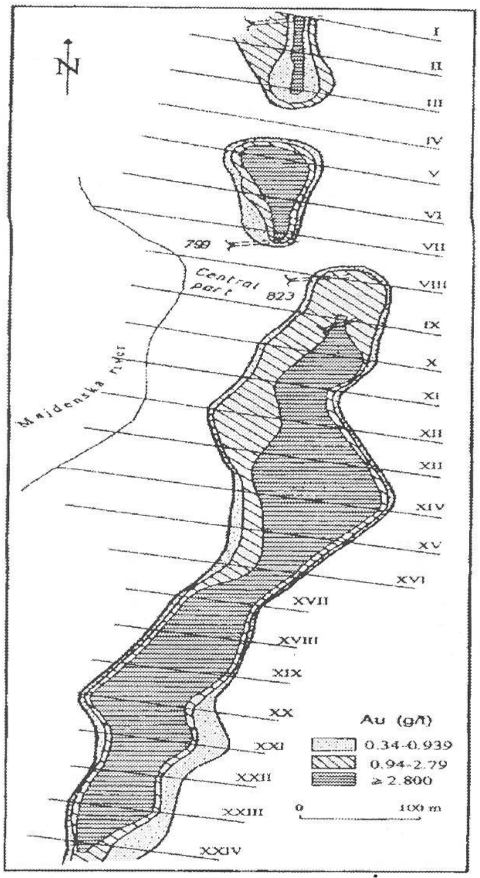

Fig. 3. Distribution of gold anomalies in central and southern part of Alšar ore deposit (Hadži-Petrušev, 1987)

NEW INTERPRETATION OF LITHOGEOCHEMICAL DATA OF THE ALŠAR DEPOSIT

Based on the results gained from earlier investigations which consisted of sampling and laboratory analyses, the present authors offer a new understanding of the area of interest gained from the application of new computer software packages (StatGraph, Surfer, Excel) and resonable geological analysis.

From the total of 288 samples collected during 1986–1989, 156 indicated variable gold contents. The background value calculated for gold amounts to 0.31 ppm. The highest gold content discovered amounts to 19.6458 ppm, whereas the lowest amounts to 0.034886 ppm. The mean value with all samples amounts to 0.557058 ppm. Analysis of data obtained shows that majority of the contents vary from 0.4 to 3.5 (4.0) ppm, particularly in the southern parts of the deposit, but occurrence of samples with amounts of tens of ppm are not rare.

Apart from the contents mentioned above, "hurricane" contents of Au of over 20 ppm are also found. Such contents were not analyzed for the correlation dependencies in StatGraph in order to avoid obtaining erroneous data.

The relationships given in Fig. 4 are obtained based on their geochemical data and the use of Excel programme. The diagram of gold distribution shows that most of the samples studied indicate gold contents of over 1 ppm, most commonly between 1 and 5 g/t.

It is also clear that Au contents are situated in three points: the north location situated between cross-sections 9 and 27 or between samples 22 and 50, the second location in the central portions of the area between samples AL800-28 and AL800-124, as well as the third location whose highest intensity spans from AL823-48 up to ALXXV-28.

It is also noteworthy that all three locations with increased gold contents also display "hurricane" samples whose peaks exceed 15 ppm, sometimes even 20 ppm. Such samples are not the subject of the present calculations and of the correlation relationships between Au and other accompanying metals. This also constitutes an additional proof that fault structures and local lithological control to the silicified dolomites and tuffs played a major role in the spatial distribution of Au in the Alšar deposit.

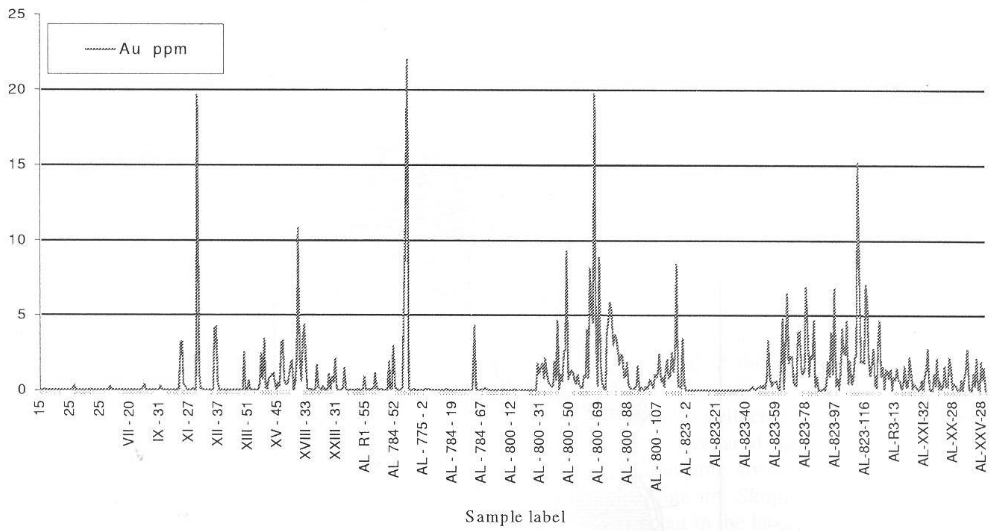

Fig. 4. Diagram of gold content in samples from Alšar ore district

In order to present a spatial review of the vertical distribution of gold in the samples collected from the level entries, the Excel programme placed the samples from each entry into groups and then a histogram of gold distribution was made based on the arithmetic mean values for individual level entries (Fig. 5). The histogram obtained indicates that vertical distribution of gold is the smallest at 775 m above sea level. It increases towards 784 m, but locally only, because contents drop rapidly after the peak up to 790 m above sea level. After that level gold distribution increases rapidly as far as 800 m reaching its highest values. A slight decrease of contents is noticed towards 823 m compared with those of 800 m above sea level which supports the assumption that there is certain continuation in distribution.

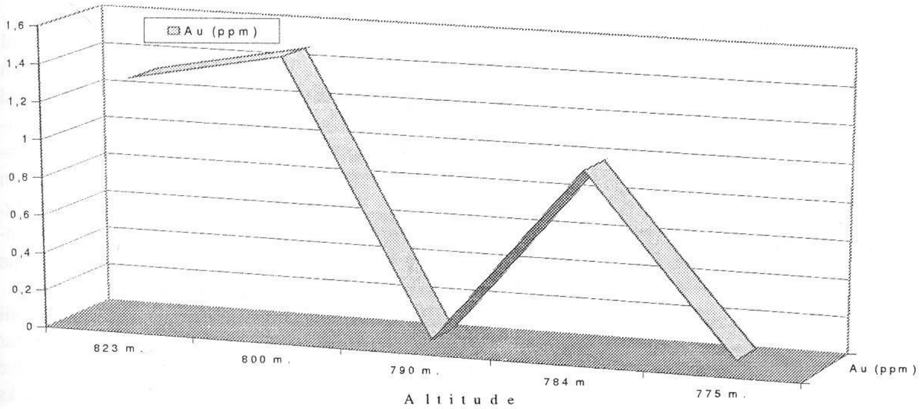

Fig. 5. Histogramic review of gold content in the southern part of the Alšar deposit (by altitude)

Computer software support were used in order to get a complete understanding of the geochemical relationships between gold and other accompanying elements, correlation relationships and the extent of their distribution. The method applied was regression analysis with use of linear model $y = a + B \cdot x$ and exponential model: $y = \exp(a + b \cdot x)$. Investigation of correlation relationships included Au-Sb, Au-As, Au-Hg, Au-Ag as well as many variations between them.

The regression analysis linear model made possible to define the linear correlation between the Au-Sb geochemical pair. The R-squared statistic indicates that the model as fitted explains 21.7901 % of the variability in Au. The correlation coefficient equals 0.466799, indicating a relatively week relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.45864.

The regression analysis exponential model for the same geochemical pair made possible to define the correlation between them. The R-squared statistic indicates that the model as fitted explains 71.071 % of the variability in Au after transforming to a logarithmic scale to linearize the model. The correlation coefficient equals 0.843036, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.858744. For both models (linear and exponential) exist significant statistical relationship between Au-Sb at the 99% confidence level.

The regression analysis exponential model made possible to define the linear correlation between the Au-As geochemical pair, too. The R-squared statistic indicates that the model as fitted explains 38.5624% of the variability in Au after transforming to a logarithmic scale to linearize the model. The correlation coefficient equals 0.620986, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.25145. Statistically significant relationship between Au and As is at 99% confidence level.

Graphic relationships between these pairs (Au-Sb, exponential and linear, and Au-As, exponential) are shown in Fig. 6.

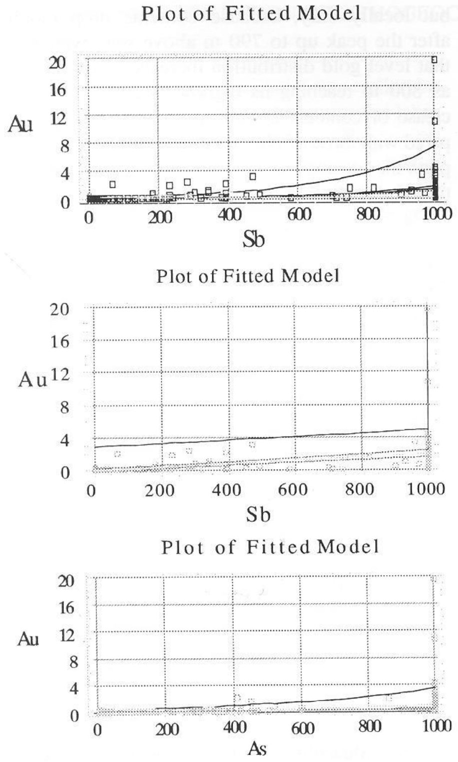

Fig. 6. Correlation diagrams of distribution of Au-Sb (exponential and linear) and Au-As (exponential) pairs from Alšar area

In addition to the correlation relationships between Au-Sb and Au-As presented, the aim of these analyses was defining the correlation dependencies with some other specific accompanying gold elements such as Hg and Ag. However, results obtained did not indicate any closer geochemical association between the pairs Au-Hg and Au-Ag. Interpretation of geochemical data consisted of explanation of the vertical distribution in the area or, more specifically, the relief distribution in the Alšar deposit. In that regard, computer software was applied and data from the geochemical studies (the contents of Au in ppm) were plotted in cross sections (with coordinates north and east and altitude) for each sample in Surfer computer software. Extrapolation of samples with the same contents helped to compile a map of gold distribution with appropriate isolines (3D/Fig. 7) and (2D/Fig. 8) review. Intervals of distribution in every presentation equals 1 ppm. Gold distribution after the study of all samples collected is as given in Fig. 7.

The figure shows that gold was found in all samples starting from 730 m above sea level as far as 900 m. The large size of the area affected is due to the favorable porosity and permeability of rocks (tuffs and dolomites) that compose the terrain in which the hydrothermal solutes migrated. The figure also shows that the major Au contents amount from 1 to 5 ppm, higher contents being rare. Gold occurrences are associated with fault structures that served as path ways for the migration of the hydrothermal solutes that participated in mineralization.

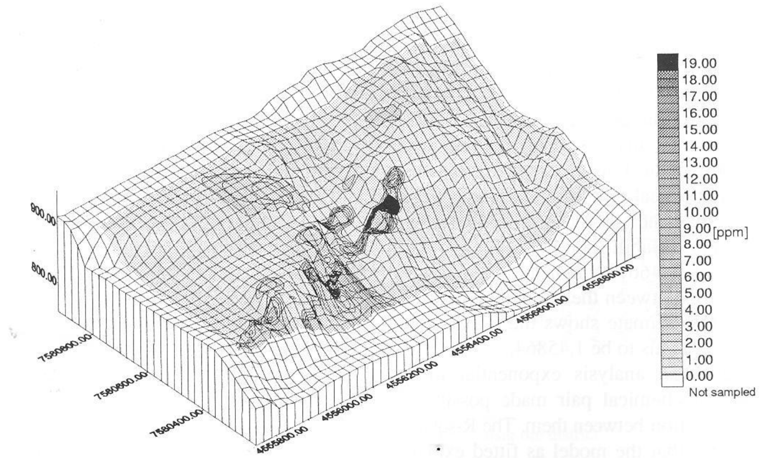

Fig. 7. Hypsometric review of gold contents in all sampled specimens

After determination of the background value of gold (0.31 ppm), samples with gold contents lower than the background values were omitted from the three-dimensional review of gold distribution and from the areal review (background values and above background values). This gave a completely different review of the gold distribution (the oblong large light grey area). It is clear that major ore formations are of north–south strike orientation (northeast–southwest) and follow the fault structures. It can also be said that the contents in the omitted samples can be regarded as dispersion halos of gold mineralization. The figure shows that the spatial review is consistent with the interpretations in the histogram (Fig. 5), or that the highest gold distribution occurs between 800 m and slightly beneath 900 m above sea level.

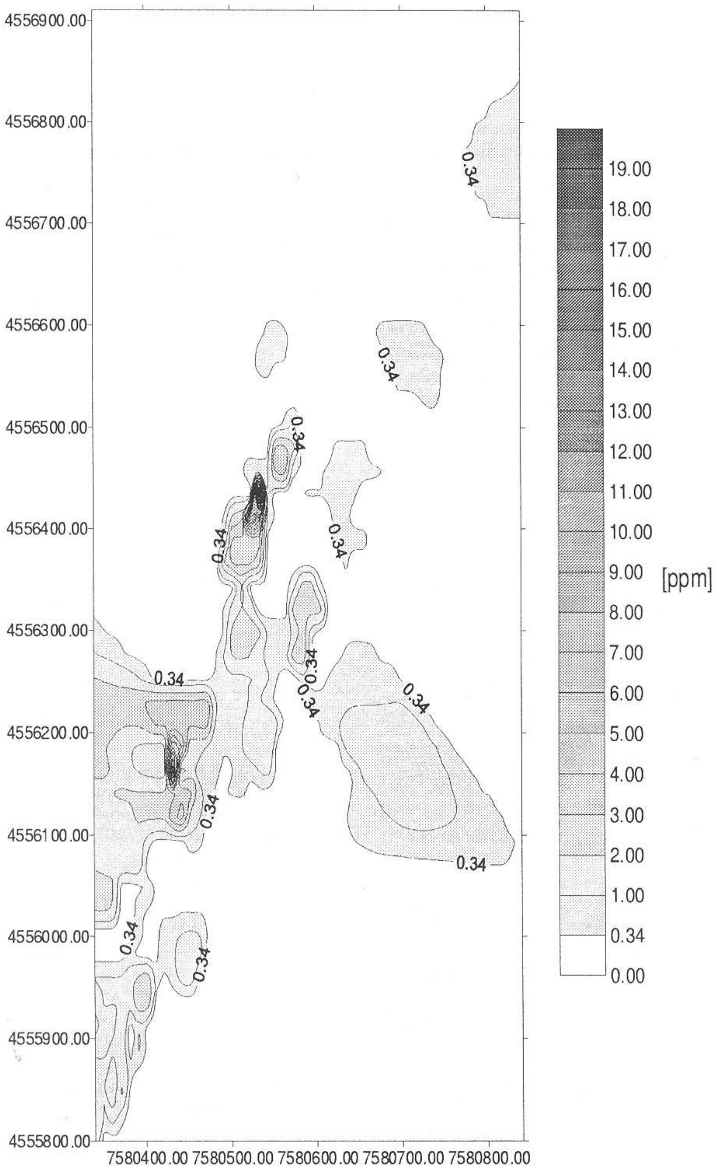

Fig. 8. Distribution of gold anomalies in central and southern part of Alšar deposit

The two-dimensional review of gold distribution (Fig. 8) (anomalous contents only) constitutes another proof of the data given in Fig. 7. Similarities with the two-dimensional model created by Hadži-Petrušev (1987, Fig. 3) are noticeable as well. It is clear that mineralization (above background values) occupies a large portion of mineralized area which is 1100 m × 400 m in size. Inference was made that gold distribution is of northeast–southwest strike orientation and follows the fault structures that served as path ways for the migration of the hydrothermal mineralization solutes. It is also noteworthy that the highest gold concentrations are found in the central portions of the area of interest and along the western side of the net for sample collection. This is due to the favourable lithological environment (in terms of porosity and permeability) for the migration of the hydrothermal solutes into the rocks.

CONCLUSION

Examinations and interpretation of available geochemical data carried out on the south portions of the Alšar deposit discovered some new information.

Interpretation carried out is consistent with the latest geochemical study of samples carried out in software package Surfer (2D view). They indicate that gold mineralization in the area has a north-north-east, south-southwest general strike and coincides with the fault structures in the area. It was also inferred that maximum gold concentration is situated in three locations over the whole area which is not larger than 2 km. "Hurricane" samples collected from these locations indicate contents of over 19 ppm Au, the most common being those of 3–4 ppm Au. Vertical distribution of gold is situated between peaks 725 m and 825 m with pronounced continuity between peaks 800 m and 823 m.

Gold mineralization is located predominantly in silicified tuffs, with some occurrences in dolomites as well. The present study also indicates that this epithermal gold mineralization should be the subject of investigation in future.

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Резиме

НОВА ИНТЕРПРЕТАЦИЈА НА ЛИТОГЕОХЕМИСКИТЕ ПОДАТОЦИ ОД АЛШАРСКИОТ ЕПИТЕРМАЛЕН Au-МИНЕРАЛИЗИРАН ПРОСТОР

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Клучни зборови: наоѓалиште Алшар; епитермална минерализација на злато; литогеохемиски податоци, злато

Со најнови испитувања и со интерпретација на постоечките геохемиски податоци од јужните делови на наоѓалиштето на злато Алшар е констатирано следното:

– Досега извршената геохемиска интерпретација во многу нешта се совпаѓа со најновата интерпретација на геохемиските проби извршена преку софтверскиот пакет Surfer (2D view). Новата интерпретација јасно укажува дека минерализацијата на златото во испитуваниот простор зазема општа ориентација север-североисток – југ-југозапад и се поклопува со утврдените раседни структури на овој простор. Исто така е потврден и фактот дека максималните концентрации на златото главно се концентрирани во три минерализациски пункта, во вкупна должина не поголема од 2 km на целиот истражуван простор. „Ураганските" проби во овие минерализациски пунктови покажуваат содржини и преку 19 ppm Au, со најзачестен интензитет на проби со содржини од 3 до 4 ppm Au. Вертикалната дистрибуција на златото во третираниот простор се наоѓа помеѓу котите 725 m и 825 m, со нагласен континуитет на распределбата помеѓу котите 800 m и 823 m.

Минерализацијата на златото главно се наоѓа во силицифицираните туфови, но интересни содржини се забележани и во доломитите. Во секој случај станува збор за епитермална минерализација на злато која и во иднина треба да се доистражува.