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STREAM SEDIMENTS AND BLEG ANALYSIS BY PROSPECTING OF GOLD IN ALSHAR (CARLIN TYPE DEPOSIT), MACEDONIA

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Abstract. During the process of prospecting for gold aggregates in the stream sediments that are adjacent to the ore bodies in the Alshar deposit (Carlin Type), it was established that the content of this metal is much lower in the sediment materials compared with its concentration in the ores. This fact, as well as the high content of Au in the ore bodies and the assumption of previous researchers for the small size of the gold (about and less than 1 μm), enable to conclude that gold aggregates are not concentrated in the stream sediments which are closely located to the ore bodies, but are rather transported along the lower course of the streams. Therefore, the broadly applied methods of prospecting for gold deposits by analyzing stream sediments should be considered ineffective for the Alshar deposit, and probably for other deposits of the Carlin Type. The statistic processing (cluster analysis) of the element associations in the stream sediments confirms the presence of a number of typomorphic minerals for the ores, as well as the relation of Au with Sb and Te. This gives good grounds to expect gold tellurides in the deposit ores.

Key words: gold, Alshar, Carlin type.

Introduction

The Alshar deposit is referred to the Carlin type and is the only representative of this deposit type in Europe. It belongs to the Vardar zone and is located along the periphery of the Kozhuf volcano. The deposit has been known since the Middle Ages when natural dyes were extracted from it by utilizing weathering products of the Sb–As mineralization. Later, the ores were used for extraction of As. In the middle of the past century more attention was paid to the Sb, with its reserves having been calculated. An intensive research of the Tl-mineralization in the deposit began along with the technological evolution during the 80's, resulting in the discovery of a large group of thallium minerals and the calculation of 500 tons of thallium reserves (JANKOVIC *et al.*, 1997). Meanwhile, research activities were performed in order to determine the gold-bearing capacity of the deposit.

The major objective of this work is to check the possibility for application of conventional geochemical analyses of the stream sediments, as well as slick-mineralogical and mineragraphical analysis in the prospecting for gold ores in the Alshar deposit.

Geological structure of the Alshar deposit

The Tertiary volcanic complex has the greatest importance for the geological structure and ore mineralization in the Kozhuf area. It was formed within pre-Cambrian albitic gneisses and marbles, Paleozoic phyllites and schists, Triassic–Jurassic schists, limestones and dolostones, Upper Cretaceous limestones, Upper Eocene conglomerates and flysch. The Pliocene igneous rocks were emplaced in the framework of an extensional zone with NE direction and are represented by small bodies of alkaline basalts, lava flows of andesites, trachyandesites, latites, dacites and rhyolites (BOEV, 1988). The age of these rocks was determined as Pliocene (3.9–5.1 Ma by the K/Ar method (JANKOVIC *et al.*, 1997; LIPOLT and FUHRMAN, 1986). Along with the formation of lava flows, pyroclastites of similar composition, as well as coarse clastic to clayey sediments, were deposited mostly in the periphery of the volcanic area. The Quaternary sediments are exposed mainly in the river valleys and are represented by inequigranular uncemented sands.

The ore mineralizations have stock morphology with Sb, As, Tl and Au being typical elements. MUDRENIC (1978) mentioned 17 deposits of this type in the metallogenic area but with only two of them having significant Tl concentrations (Lojane and Alsar).

The ore bodies in the Alshar deposit are located in the contact zone between the Pliocene andesites and the older dolostones (Fig. 1). The ore formation was controlled by subvertical faults which were the scene of Pliocene hydrothermal system activity.

The lithological control over the localization of the ore formation was exerted by the dolostones, which represent a favorable milieu for the proceeding of metasomatic processes. As a result, the morphology of the ore bodies is lenticular or columnar. Silicification of the carbonate rocks and andesites took place in close proximity. Argillization is pronounced in the northern part of the deposit (in the Cherven dol locality).

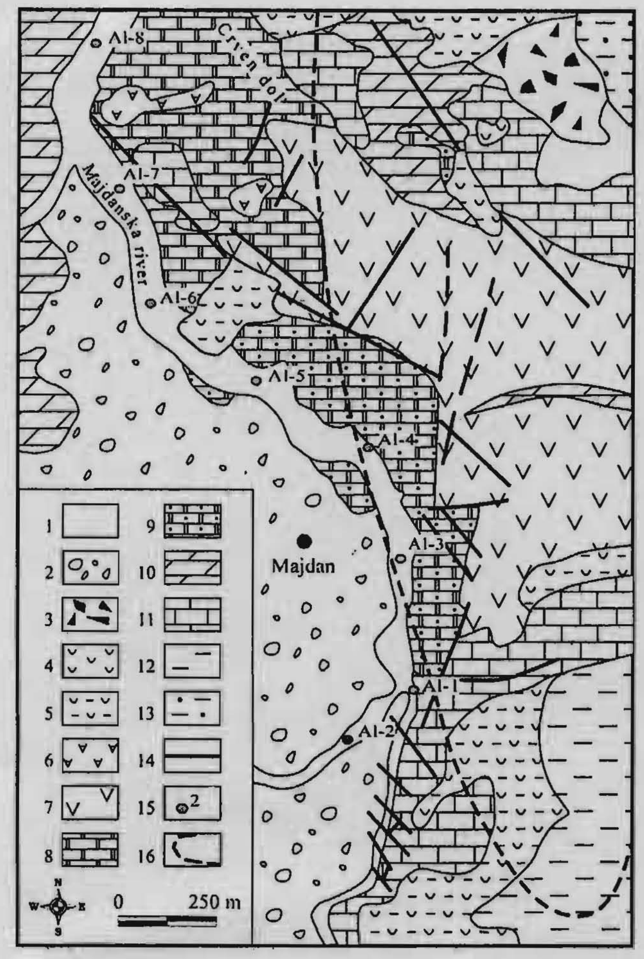

Fig. 1. Geological map of the Alshar deposit (after JANKOVIC *et al.*, 1997). 1. Alluvium and old river terraces; 2. Morrains; 3. Limonitized breccias; 4. Tuffs; 5. Pyroclastites; 6. Argillized andesites; 7. Andesites; 8. Argillized and ankeritized dolostones; 9. Silicified dolostones; 10. Dolostones; 11. Marble-like limestones; 12. Argillites and schists; 13. Sericite-chlorite schists; 14. Faults; 15. Sample location; 16 Distribution of ore bodies.

Mineral composition of the primary ores

The mineral composition of the ores in the Alshar deposit is complex. This is mainly due to the broad development of secondary minerals after As–Sb sulphosalts, as well as to the exotic paragenesis of thallium minerals. The major ore and coexisting non-ore minerals (JANKOVIC *et al.*, 1997) are: quartz, chalcedony, pyrite*, marcasite*, antimonite*, realgar*, orpiment* and barite. The secondary minerals are: magnetite, arsenopyrite, Pb–Sb sulphosalts and cinnabar. The group of rare minerals comprises: bravoite, mauherite, petzite, as well as the thallium minerals lorandite* (KRENNER, 1894), parapierrotite (JOHANN *et al.*, 1975), picotpaulite (JOHANN *et al.*, 1970), raguinite (LAURENT *et al.*, 1969), rebulite (BALIC-ZUNIC and ENGEL, 1982), simonite (ENGEL *et al.*, 1982), vrbait (JAZEK, 1912), weissbergite (RIEC, 1993) and bernardite (PASAVA *et al.*, 1989).

The listed minerals form pyrite-marcasite, antimonite, realgar-orpiment-lorandite associations. Idiomorphic textures are typical for most of them, and hence, facilitate their recognition. The isotopic determinations of sulphur have shown that the source of this element is deeply located (SERAFIMOVSKI *et al.*, 1991).

Mode of presence and content of gold

Despite the numerous previous studies, no mineralogical description of gold was presented in the published materials. This metal was mentioned in some publications as available (JANKOVIC *et al.*, 1997; SERAFIMOVSKI *et al.*, 1999; RIECK, 1993; JANKOVIC, 1993) but with its size being about and less than 1 μm. Most of the authors pointed out that the gold was related to the Mesozoic carbonate rocks, the silicificied rocks and was associated with the antimony mineralization.

The geochemical data on the gold comprise single samples from various rock types, ores and discrete minerals. JANKOVIC and JELENKOVIC (1990) gave summary information about the mean content of Au in the deposit (0.2 ppm). Meanwhile, PERSIVAL and RADTKE (1990) established that the gold content in the dolostones was 0.57 ppm (mean from 3 samples). Much higher are the cited values in the ores from the central part of the deposit (mean 3.24 ppm from 6 samples) and in the antimonite (mean 4.80 ppm from 6 samples). Most representative, however, was the sampling accomplished by the NASSAU Company (USA) during 1986–1989. Data from 288 samples have shown that the mean value of Au in the deposit is 0.56 ppm (SERAFIMOVSKI *et al.*, 1999). These results prove the presence of considerable amount of gold in the central part of the deposit despite the lack of mineralogical occurrences.

Research methods

The current research was accomplished by using a complex of field sampling and laboratory methods for the study of the collected samples. The field investigations comprise sampling of the stream sediments by means of the classical technology. The samples were collected at a distance of 3 km along the course of Majdanska river, below and above the deposit (Fig. 1). The samples total up to fifteen as eight of them are beyond the map range. The slick sampling corresponds (where is possible) to the sample location of the stream sediments. Thirteen samples were collected and later rinsed to obtain heavy fraction in the place itself, and six more samples were collected and processed prior to that. The heavy fraction of the slick samples was studied by means of mineralogical optical methods.

The samples from stream sediments were analyzed for 49 elements with ICP-AES and MS in ALS Chemex Laboratory in Australia. Aiming at more precise determina-

* These minerals are determined and investigated in the present study.

tion of Au, Ag and Cu, all samples were additionally analyzed with BLEG analysis (with cyanide leaching) to establish the possibility for extraction of gold by means of this technology. The analyses were performed in the SGM Welshpool Minerals laboratory, Australia.

Obtained results

The optical study of the heavy fractions from the slick shows the presence of the following minerals: antimonite, realgar, orpiment, marcasite, pyrite, magnetite, chalcopyrite, malachite and sphene, with the first three being represented in largest amounts. Petrogenic minerals such as quartz, biotite, muscovite, zircone, pyroxene, tourmaline, epidote and gypsum are found, too. The presence of gold aggregates in the slick samples is not established.

The chemical analyses of the stream sediments demonstrates that the mean content of Au for all samples is by two orders lesser that the average for the deposit which is obtained from the host rocks and ores (Table 1). There is no substantial difference between the mean values of this element obtained through both analytical methods. The standard deviation testifies to relatively regular distribution of Au along the sampling line. Almost the same is valid for the Ag which is characterized by slightly higher values. Generally, the contents of Au and Ag in the stream sediments are low and exceed the clarke after Vinogradov (VOJTKEVITCH *et. al.*, 1977) by only one order.

Table 1. Statistical parameters for Au and Ag [ppm] determined with ICP-AES, MS and BLEG analyses.

Element/assay	Mean	Min.	Max.	St. Dev.
Au/ICP	0.0051	0.0005	0.016	0.0044
Au/BLEG	0.0042	0.0002	0.010	0.0036
Ag/ICP	0.0090	0.0050	0.020	0.0069
Ag/BLEG	0.0067	0.0050	0.030	0.0065

The elements As, Tl, Ba, Cr, Mn, Ni and Sr are characterized by significant clarke concentrations.

Three pieces of surface samples were collected from the dump_sites of the deposit containing mainly antimonite, realgar and orpiment. The obtained data for the gold concentration are respectively 4.48, 0.34 and 0.69 ppm.

Discussion

The available literature data and the accomplished investigations show that the ores of the Alshar deposit have Au concentrations from 1 to 5 ppm. The values in the stream sediments are between 10 and 100 times lesser despite the enrichment effect which is expected to appear as a result from separation by the water flow. No gold aggregates are established at artificial enrichment by rinsing of stream sediments in order to obtain black slick. The presence of gold in the ores, as well as its low content in the stream sediments, might be explained solely with the small size of the gold aggregates. It is well known that with gold size of <5 μm and in conditions of rapid flow, its aggregates are carried away by the water and are deposited in the lower course where the stream velocity decreases. Additional evidence for the small size of the gold aggregates in the Alshar deposit come from the lack of literature data for optically established, investigated and described gold aggregates in the ores, and also, from the available data on the small size of the gold itself (RIECK, 1993). This fact is confirmed by the mineralogical and geochemical studies in other deposits of the Carlin type.

The most important conclusion is drawn on the basis of the facts discussed above, and it postulates that the application of conventional mineralogical and geochemical methods of prospecting for gold ore bodies in the Alshar deposit should be considered ineffective.

The statistic interpretation of the geochemical data enables to establish the element spatial associations in the stream sediments. Thus the total of 49 studied elements is divided in two parts: ore (Ge, Cd, S, Mo, W, Tl, As, Ag, Zn, V, In, Sn,Ta, Nb, Ga, U, Bi, Th, Pb, Hg, Cu, Cr, Ni, Co, Te, Sb and Au) and rock-forming (Mg, Ca, La, Ce, Be, P, Hf, K, Na, Li, Al). The elements Ba, Cs, Fe, Mn, Rb, Sr, Ti, Y and Zr are included in the two populations because they appear as both ore and rock-forming.

Four clusters are established in the ore population (Fig. 2).

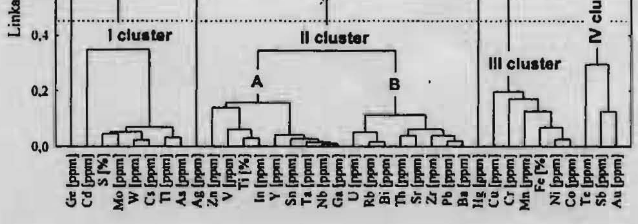

Fig. 2. Spatial grouping of ore elements in the stream sediments. (The discontinuous line designates the level of significance of the correlation coefficient).

The characteristic element associations by clusters are as follows:

Cluster I: [(/W–Cs/–/S–Mo/)–/As–Tl/]–Cd. The element association As–Tl in this cluster, which indicates that thallium minerals exist in the stream sediments, is typical for the deposit.

Cluster II is represented by two subclusters. The first one is {[(/Ga–Nb/–Ta)–Sn]–Y}–[(/In–Ti/–V)–Zn]. A characteristic association for it is Ga–Nb–Ta and Sn. The second subcluster is represented by the elements (/Rb–Bi/–U)–/Th–Sr/–(/Ba–Pb/–Zr).

Cluster III comprises mostly chalcophile elements: {[(/Co–Ni/–Fe)–Mn]–Cr}–Cu. The bearers of this association are the Fe and Cu sulphides. The bulk of the sulphur, however, is related to As minerals, and hence, is included in cluster I.

Cluster IV comprises only three elements: (/Au–Sb/–Te). It is typical for the gold in the deposit, thus confirming the spatial relation between gold and antimonite in the primary ores. The relation between Au and Te gives grounds to assume that both metals have formed common minerals in the ores.

The rock-forming elements comprise three clusters (Fig. 3).

Cluster I comprises the typical association Mg–Ca.

Cluster II is rather complex having the following element relations:||[(/Ce–La/–Be)–Rb]–{[(/Zr–Hf/–/K–Ba/)–Sr]–P}||–Cs. A few characteristic pairs of elements are established: Ce–La, Zr–Hf and Ba–Sr.

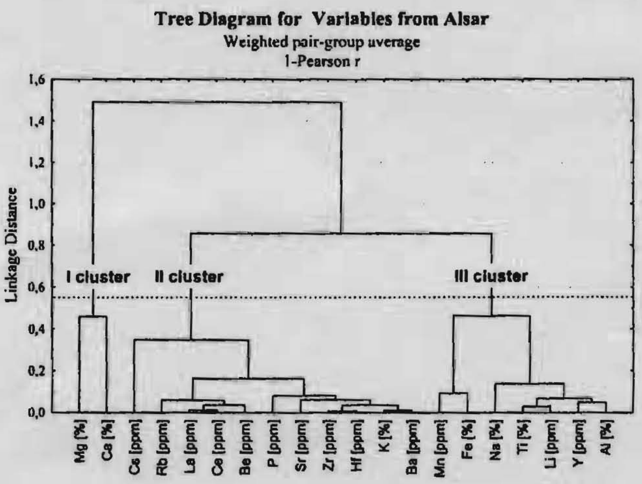

Fig. 3. Spatial grouping of rock-forming elements in the stream sediments. (The discontinuous line designates the level of significance of the correlation coefficient).

Cluster III is also typical for the rock-forming minerals: [(/Ti–Li/–/Y–Al/)–Na]–/Fe–Mn/.

The enumerated element associations might be explained in most cases with their spatial association in various minerals which are found both in the ores and the rocks. This indicates their preservation in the stream sediments over close distances from the ore bodies. The great velocity of the Majdan river (in this part of its upper course) also contributes to this preservation by annually renewing the stream sediments.

Conclusions

The accomplished investigations and interpretation of the obtained results confirm the previously proposed hypothesis on the basis of other mineralogical studies for the small size (about and less than 1 μm) of Au in the Alshar deposit. This suggests that the application of prospecting methods for geochemical investigation of the stream sediments and slick analysis is ineffective, because of the stream transport of gold aggregates far away from the original ore bodies in the studied deposit, and probably in other deposits of the Carlin type. A part of the rock-forming and ore elements are correlated in element associations, corresponding to the minerals in the rocks and ores of the Alshar deposit.

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