Stress analysis in the region of the gold-polymetallic deposit Bakadjik, Burgas ore region, as a tool to interpret the structural control of the mineralization

Анализ на напреженията в района на златно-полиметалното находище Бакаджик, Бургаски руден район, като инструмент за интерпретация на структурния контрол на минерализацията

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Introduction
Deposit Bakadjik is located in Bakadjik ore field (Bonev, 1972), also described as Tamarino ore field (Popov et al., 1977) located in the westernmost part of the Burgas ore region in Southeast Bulgaria. It consists of a vein Cu-Au-polymetallic mineralization. The volcanic rocks in the region is studied by Emanuilov and Stanisheva (1969f) and Banushev (2001, 2003). The position of the ore field is determined by the Bakadzhik volcano-tectonic structure, which is with subequatorial elongation and comprises three volcanic edifices. The central one is Tamarino’s Bakadzhik, containing a plutonic body, to which the polymetallic deposit Bakadzhik is related (Popov et al., 1977). The presence of ore in the area is known from medieval times. In modern time 1959–1960 prospecting began, which resulted in calculation of resources and beginning of mining in 1964. In 1994 the mining was terminated for lack of economic efficiency and the mine is closed as inefficient. This deposit has potential for future development and for this reason some discussion on the structural control of the mineralization is offered here.

Geological settings
According to Lilov and Stanisheva-Vassileva (1998) the volcanic rocks belong to Late Cretaceous magmatic event in the time span 87–76 Ma, Coniacian–early Coniacian. Within the ore field Stanisheva separates three stages in the volcanic activity (Emanuilov, Stanisheva, 1969f). The products of the first stage are characterized by the eruption of basaltic, andesitobasaltic to andesitic materials that form the bulk of the volcanic structure. In the second stage (defined as trachybasaltic), picrites, olivine basalts, leucite basanites, analcime- and ankaramitic basalts and trachybasalts are formed, which alternate repeatedly. The third stage is trachyandesitic, represented exclusively by dykes, flows and pyroclastics.

Several spatially separated ore areas are localized in the ore field, in which accumulations of metasomatic vein bodies are established, composed of low-temperature alterations with compact, porphyry or veinlet accumulation of sulfides, sulfosalts and native gold. They are in paragenesis with iron oxides, chlorite, quartz, carbonates and rarely sulfates. The ore sectors Trapishtata, Baba Gana, Lipite (Chuchurkata), Lyulin, Tamarino, Erkesia and Sinilkata are known.

The Cu-Au-polymetallic mineralizations from Bakadjik ore field are medium-temperature, formed at a small depth as a result of the pulsating nature of hydrothermal solutions (Bogdanov, 1987). Metasomatic processes in the deposit can be attributed to high, medium and low-temperature alteration (Bonev, 1972). The ore field was formed during the Banat-Srednogorie Late Cretaceous metallogenic epoch.

Bonev (1968) identified fault structures of first, second and third order. As a structure of first order, he considers the structure along witch the Bakadjik1 volcanic bodies are aligned (130°). Structures of second order are faults defining the elongation of the individual volcanic bodies (95°). Of the third order are fissures with meridional and submeridional
directions, along which the small volcanic bodies, such as dyke intrusions were intruded.

Emanuilov and Stanisheva (1969f) offered an unproved idea of caldera structure in the central part of the paleovolcano of Tamarino Bakadjik. Later Popov et al. (1977) proposed an improved model, explaining the distribution of faults and ore zones. They found that in the central parts of the Tamarino volcano a small hidden intrusion with dimensions of 3.3 × 2 km, extended in northeast direction, was intruded. It comprises of syenitic or syenodioritic rocks forming a new fourth volcanic stage, according to Stanisheva’s stratigraphic division (Emanuilov, Stanisheva, 1969f). A number of syenite porphyry dykes were intruded after the formation of the intrusion as a result of the fifth stage of the Late Cretaceous magmatic activity. To prove the existence of the volcano-plutonic structure they used lava flows and pyroclastic deposits to reconstruct flow lines indicating the central part and margins of the structure. The obtained results show concentric development in relation to the center of the structure. They describe three systems of joints: bedding-parallel, transverse and longitudinal, oriented with respect to flow lines and layering, and one or two systems of diagonal joints. The syenite porphyry dykes are either parallel to the longitudinal joints or parallel to the transversal joints with respect to the flow lines. This means, that the dykes are localized in radial and concentric volcano-tectonic fractures, in which ore veins are also localized (Popov et al., 1977). Based on these facts the authors define the Tamarino volcanic structure as a cone-shaped central stratovolcano, formed as a result of multistage Late Cretaceous magmatic activity.

Materials and methods
In order to contribute to the structural understanding of the deposit, field work was undertaken by the author. In the southeast area of the ore field, fault data were collected, from which slip directions were measured for 10 faults using the Aki-Richards convention (Marrett, Allmendinger, 1990) for recording the rakes of the striae on the fault planes. This data together with reinterpretation of detailed maps and remapping of the old mine workings are used to elucidate the model of the deposit proposed by Popov et al. (1977).

Since, after 30 years, most of the workings are already collapsed and heavily overgrown. This work aimed at presenting stress data, which should be able to distinguish between stress field of a caldera (Emanuilov, Stanisheva, 1969f) or stress field related to an intrusion. The slip data are processed with a software FaultKin, which uses paleostress tensor calculations (Allmendinger et al., 1989). Paleostress tensors provide a dynamic interpretation (in terms of stress orientation) to the kinematic (movement) analysis of brittle features. The purpose of the study is to compare the inferred stress directions with the orientation of the ore veins. It is common knowledge that vein arrays (an echelons) are formed at small angle to σ3, but individual veins are parallel to σ1 with maximum extension in the direction of σ2, (Dimitrov, 2010, 2018). Thus, the orientation of the vein-forming stresses, with respect to the overall structure, can imply for the tectonic model of vein formation.

Results and discussion
The mapping showed that most of the exposures are not usable because of soil and vegetation cover. Useful exposure were found only in the Tamarino sector, where veins striking to NE-SW are present, with a vein echelon striking N-S. In this area, joints and slip direction along faults were measured. The joint orientations a rather erratic but still three maximums are recognized. One represents E-W striking, subvertical joints. The other is dipping shallowly to SE and is probably parallel to the flow lines in the lavas, which dip 140 to SE. The third maximum represents joint dipping to east most likely transverse to the lava flows.

Fault slip directions were measured only in the SE part of the map area in the Tamarino sector. When processed for the direction of principle stresses (Fig. 1) they indicate for σ3, plunging to SSW (trend 206°, plunge 06°). Respectively, σ2 plunging to NW and σ1 to SE. This implies that σ3 is in the direction of the propagation of the flows away from the central part, where the syenitic intrusion of Popov et al. (1977) exists.

The orientation of the ore vein arrays in the separate sectors of the deposit is different (Emanuilov, Stanisheva, 1969). It can be inferred that each vein echelon is related to local stress field. The regional stress field, as indicated by the regional map pattern showing NW striking fold hinges and faults and E-W striking lithotectonic trends, indicate for σ1 coming from W-NW, as it is assumed that predominantly simple shear formed these structures. Thus, the regional stress field and the stress field derived for the Tamarino vein array are incompatible.

Although insufficient in quantity, the stress data indicates for local stresses, distributed around a dome structure. For the northern veins the local, vein-generating stress field is radial, with respect the central part of the structure, but the southern vein array is formed by a principal stress, which is more or less concentric with respect to the central part of the structure. The slip data also indicate, for stresses in south, complying with the veins and concentric to the structure. This in fact is a mixture between both models those
of Emanuilov and Stanisheva (1969f) and those of Popov et al. (1977). The southern vein array cannot be formed simultaneously with strong pressure, exerted from intrusion located in the central part of the map area. The most likely explanation of the vein distribution is that faults and fissures were formed during the formation of the dome and some of them were later utilized by hydrothermal fluids. This happened at the last stage of volcanic and magmatic activity.

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References