GEOLOGICAL SETTING AND ORE MINERALIZATION CHARACTERISTICS OF BABYAK DEPOSIT, WESTERN RHODOPE, BULGARIA

Nenko Temelakiev, Strashimir Strashimirov, Stefka Pristavova

University of Mining and Geology "St. Ivan Rilski", Sofia 1700; nenkotemelakiev@outlook.com

ABSTRACT. Some new data for ore mineralogy, rock alterations and structure analyses at Babyak Ag-Mo-Au deposit, Western Rhodope, Bulgaria are presented. The result of research suggests distinguishing the tectonic, magmatic and hydrothermal events associated with ore-forming processes. Two main ore mineralization stages related to the chain of structural events are distinguished. The early Mo-Bi-W-Ag mineralization is related to greissen-like type alteration and it is controlled by semi-brittle moderately dipping normal faults, most likely linked to regional detachment faults. The later Au-Pb-Zn-Cu mineralization accompanying by quartz-sericite alteration is controlled by steep dextral strike-slip and normal faults, probably related to the activity of the regional Ribnovo fault zone and Babyak-Grashevo shear zone. Based on the new data obtained by this study could supposed the granite-related ore mineralization of the Babyak deposit.

Keywords: Babyak deposit, ore mineralization, rock alteration, structural control, Western Rhodopes

ГЕОЛОЖКИ СТРОЕЖ И ХАРАКТЕРИСТИКА НА РУДНАТА МИНЕРАЛИЗАЦИЯ НА НАХОДИЩЕ БАБЯК, ЗАПАДНИ РОДОПИ, БЪЛГАРИЯ

Ненко Темелакиев, Страшимир Страшимиров, Стефка Приставова

Минно-геоложки университет "Св. Иван Рилски", 1700 София

Резюме. Представени са нови данни за рудната минералогия, околорудните изменения и структурите на Ag-Mo-Au находище Бабяк, Западни Родопи. Резултатите от изследването позволяват да се отделят тектонски, магматични и хидротермални събития асоцииращи с рудообразователните процеси. Два основни рудообразувателни стадия свързани със структурни събития са разграничени. Ранната Mo-Bi-W-Ag минерализация се свързва с грайзеноподобен тип метасоматична промяна, която се контролира от недълбоки разломи с крехко-пластични деформации вероятно свързани с регионални разломи на отлепване. По-късната Au-Pb-Zn-Cu минерализация е в асоциация с кварц-серицитов тип промяна контролираща се от стръмни разломи най-вероятно свързани с регионалната Рибновска и Бабяк-Грашевска зони. Въз основа на получените резултати от изследването се предполага за рудната минерализацията на Бабяк, че е гранит-свързан тип.

Ключови думи: находище Бабяк, рудна минерализация, околорудно изменени скали, структурен контрол, Западни Родопи

Introduction

The Babyak deposit is located in the municipalities of Belitsa and Yakoruda, Blagoevgrad region, South-Western Rhodopes (Fig. 1).

As a part of the Rhodope massif, two major stages of the Alpine development (compression and extension) form the modern structure of the region (Ivanov, 1988; Ricou et al., 1998; Ivanov, 2000;). The compression stage is associated with the emergence of a system of superposition located thrust plates with south vergence, which caused a significant thickening of the earth's crust. The metamorphic basement in the region of the studied deposit is considered to be a synmetamorphic thrusted complex composed of the plates of the Ograzhden, Maliovishka and Sarnishka lithotectonic units. The thickening of the earth is followed by the processes of the Late Alpine regional extension and the formation of extension structures such as the "metamorphic core complexes" (Ivanov, 1998; Ivanov et al., 2000) and the main first order positive structure in the region was formed – Rila-West Rhodope complex Dome intruded by abundant granitoids of the early extensive stage. The internal structure of the region is complicated by Mesta graben, Ribnovo fault and Babyashko-Grashevo dislocation. The last is tracked from west to east in the immediate vicinity of the southern boundary of Babayk area.

In the 70's of the 20th century a surface and underground study was carried out in the area of the Babiak locality and the presence of Mo, Bi, Ag, Au, Ph, Zn and Cu mineralization was found (Delchev, Dimitrov, 1964; Mileva, 1964). The Babyak ore field is interpreted in the different away during the years – as a quartz-molybdenite mineral formation closely related to the aplitic granitoids and greisen type alteration by Maneva et al. (1994) or as Mo-hydrothermal mineralization with zonal structure genetically related to the late phases of the West Rhodope batholith (Kolkovski, Georgiev, 2006). The Babyak - Mo (Ag- and Au-bearing) deposit is considered as a part of the Babyak orefield related to the Maastrichtian–Lutetian Rila-Rhodope Metallogenic Zone by Popov et al. (2019).

The present article is a result of the ore mineralization and rock's alteration study in the region and structure analyses for the clarification of the structural control of the ore formation processes in the Babyak deposit (Temelakiev et al., 2017).

Geological setting

The investigated ore zones from the Babyk deposit are located in the close proximity to the contact between Rila-

Western Rhodope batholith (granitoides and related pegmatites and aplites) and the metamorphic frame represented by high-grade metamorphic rocks of the Sarnitsa lithotectonic unit (aplitic and biotite gneisses – Fig. 2).

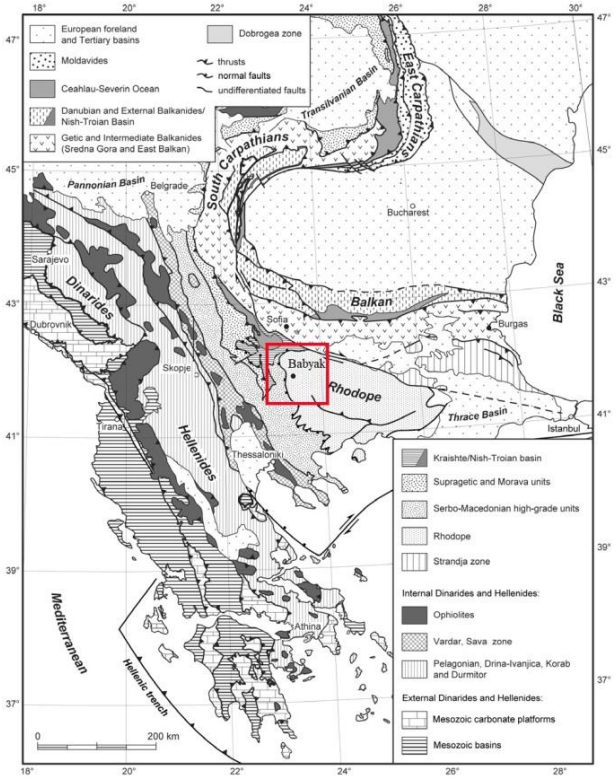

Fig. 1. Tectonic map of the south-western Balkan Peninsula (after Bernoulli, 2001; Schmid et al., 2008)

Sarnitsa lithotectonic unit. It croups out in the frame of the Rila-Western Rhodope batholith in the valley of the Mesta River, from Dagonovo to Yakoruda villages to the North. The rock association of this unit is presented by biotite and amphibole-biotite gneisses, marbles and lens-like bodies of metagabbro and ultrabasites. The leptitic gneisses are the most distributed in this unit. The rocks are folded and intersected by pegmatites and quartz veins oftenly parallel to the gneiss's foliation.

Rila-Western Rhodope batholith. Three types of granitoids are distinguished in the frame of batholith: 1) coarse, irregularly-grained and sometimes porphyry, amphibole-biotite and biotite granodiorites; 2) medium grained biotite and less often two-micas granites; 3) fine-grained biotite-muscovite aplitic granites, such as lenses, veins and stock bodies. The batholith is made up of two plutons differing in age and tectonic position according to Kamenov et al. (1999). The granodiorites of the first type are part of an older (~80 Ma) synmetamorphic pluton with calcium-alkaline composition and mantle magma contaminated by earth material. The granites of the second and the third types, aged 35–40 Ma, are genetically interconnected phases of a post-metamorphic pluton with high alkaline-calcium character.

Dykes. They include lamprophyres, dioritic, granodiorites and quartz-diorite porphyrites, granite porphyry, gabbro-diabases, meta-dolerites and micro-gabbros among the rocks of the Rila-West Rhodope batholith and more rarely in the metamorphites are established. They have different thickness and direction – from centimetres to several meters, and from 300–340° to N and NE (10–70°) direction with sharp intrusive contacts without visible hydrothermal alteration.

Paleogene. It comprises Priabonian breccias, conglomerates and breccia-conglomerates along to the two boards of the grab are involved. The Oligocene rocks are grouped into two facies: volcanogenic (rhyolites and trachy-andesites) and sediment-tuffogeneous (molasse-like and tuffogeneous horizont).

Neogene. Includes clayey-sandy, sandy and conglomerate facies formed in the northern part of the Mesta Depression. The Neogene in the area is perceived as one unit - upper sandstone-conglomerate formation (Sarov et al., 2011).

Quaternary. It has a relatively limited distribution in the area of study. Fluvio-glacial, delluvial and alluvial sediments are presented.

Ore setting

The magmatic-hydrothermal stage of the Rila-Western Rhodope batholith is characterized by the development of a large number of aplites, pegmatites and quartz veins (with and without ores). The latters are oriented mainly to the NE or NW following the main geological structures in the region. The veins without ores are with irregular thickness and the contacts with the hosted rocks are weakly hydrothermally altered. This type of veins contains milky whitish quartz with rare pyrite crystals. The ore-containing veins are with regular thickness, massive structure and consisted of grey-whitish quartz. The established ore minerals into them are pyrite, molybdenite, galena, sphalerite, chalcopyrite, specularite and wolframite. The contacts with the hosted rocks are sharp ones accompanying with thick (up to 10 m and more) zone of hydrothermal alteration. Two zones (zones 5 and 6) enriched of ores exist in the central part of the studied deposit.

Zone 5 is the best developed ore zone in the deposit according to thickness and intensity of the ore mineralization. It is composed by quartz-iron oxide-sulphide vein with a variable thickness from 0.3 to 20.0 m with a slope of 45–60° at the surface and up to 25–35° in depth. The vein is sunk to the W-SW conforming to the metamorphic foliation of the hosted rocks. Close to its lower contact with the hosted gneisses shear zone is developed followed by reactivation accompanied with brittle deformations.

Zone 6 includes two parallel quartz-pegmatite veins with apophysis developed west of the zone 5. The thickness of the veins is from 0.5 to 10.0 m. The slope is to W-SW and varies from 40–45° on the surface to 30–35° in the depth. Both zones are developed close to the contact between Rila-Western Rhodope batholith and hosted metamorphic rocks.

Materials and methods

The study was made on 120 representative drill rock and ore samples. The petrographic and ore thin-sections were used to obtain information for textures and minerals composition of the primary and altered rocks and ores. The microscopic investigation was made using microscope Meiji7390 for transmitted and reflected light and digital camera Olympus 5050 for microphotos.

The phase composition of the hydrothermally altered was determined by powder X-ray diffraction (XRD), at the University of Mining and Geology "St. Ivan Rilski". The powder XRD

patterns were recorded on a Bruker D2 Phaser diffractometer using Ni-filtered Cu Kα radiation in the 2Θ range 4–80º, step size 0.02º. The textures and chemical composition of the ore mineralization were characterized by Scanning electron microscopy fitted with energy dispersive spectrometer JEOL JSM-6010 PLUS/LA in the University of Mining and Geology "St. Ivan Rilski" using nature etalons.

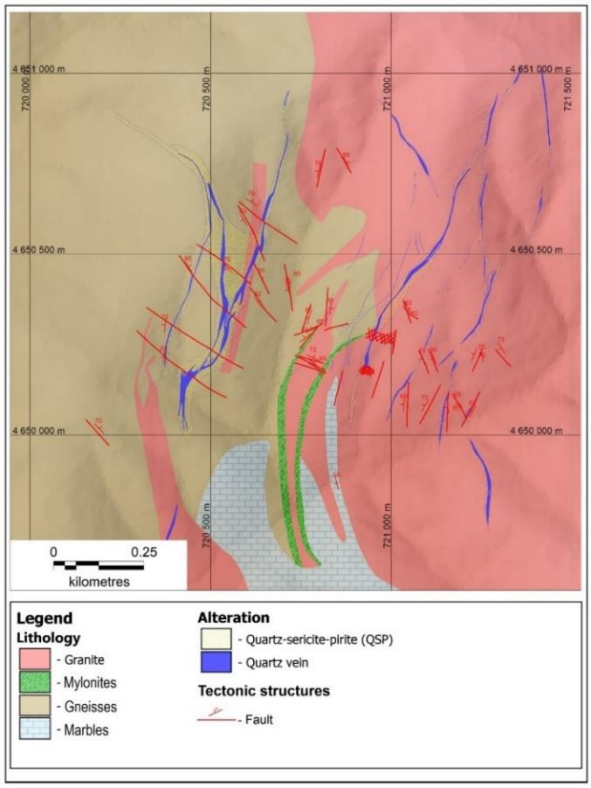

Fig. 2. Detailed geological map of the Babyak ore deposit

Results

Rock composition

The investigated ore zones from the Babyk deposit are located in the close proximity to the contact between Rila-Western Rhodope batholith (granitoids and related pegmatites and aplites) and the metamorphic frame represented by high-grade metamorphic rocks of the Surnitsa lithotectonic unit (aplitic and biotite gneisses).

Gneisses are light grey to milky white in colour aplitic and biotite gneisses, fine-grained with a fine layered structure, lepido-granoblastic texture and mineral composition of quartz, feldspars (microcline and acid oligoclase), muscovite and biotite and accessories of zircon, apatite and garnet.

Granites are also light grey in colour, hetero-grained with massive fabric intersected by nets of open fractures. Their textures are granitic and poikilitic in places. The granites are with mineral composition of quartz, plagioclase, K-feldspar, biotite and accessories – zircon, apatite, titanite and ore mineral (magnetite?).

Pegmatites are with mineral composition of quartz, K-feldspar, acid oligoclase and muscovite. All investigated pegmatites are brittle (mainly) to plastic deformed – cracked, brecciated to cataclazed and mylonitized.

Rock alterations

Greisen-like type alteration (GTA). It has a local development with formation of coarse flaked white mica (individual flakes or aggregates), clay minerals, K-feldspar, albite and tourmaline. Quartz, sericite-muscovite and fluorite fill the open cracks, also. This type of alteration in the studied ore field is mentioned by Delchev and Dimitrov (1964) and Maneva et al. (1994), also.

Quartz-sericite-pyrite type (QSP). Wide developed alteration with uneven intensity among gneisses, granites and pegmatites. The alteration is associated with intensive brittle deformations and formation of breccia and cataclastic textures in the rocks. The relics of the primary minerals (if they are preserved) are cracked to defragmented and replaced by hydrothermal sericite and quartz, mainly. The hydrothermal mineral association is the most intensive developed in the inter-clast interstices and in the plane of the metamorphic foliation in the gneisses, also. In the vicinity to the zones with the intensive formation of hydrothermal quartz and ore mineralization QSP alteration totally erased the primary features of the primary rocks.

Ore mineralization

On the base of the study the followed characteristics of the distribution and features of the ore mineralization could be pointed: 1) the presence of pyrite, galena, sphalerite, chalcopyrite, molybdenite, gold, electrum, lead-bismuth minerals, bursaite(?), covelline, chalcosine, arsenopyrite, tennatite – tetrahedite and malachite; 2) the ore minerals are presented as finely disseminated crystals with sizes 1.0–2.0 mm; thick layers (veins), irregularly in shape aggregates (from 2.0–3.0 up to 30–40 mm) and massive ore-bunch of pyrite and molybdenite (mainly) ± chalcopyrite; 3) the wide distributed ore assemblages in the deposit are: (I) pyrite-molybdenite associated with Pb-Bi sulphosalts related to the greisen-like type alteration and (II) pyrite-galena-sphalerite-gold mainly related to the QSP alteration; 4) the ore textures supposed that during formation of the second ore assemblage there are remobilization of the minerals like molybdenite (mainly) and Pb-Bi sulphosalts (limited?).

Relation ore-mineralization/rock alteration

The formation of the Mo-Bi-Ag mineralization with pyrite I, molybdenite I, Pb-Bi sulphosalts and wolframite could be related with the appearance of the GTA. The ore texture of this assemblage shows clear post-deformation genesis – short veins, fine layered aggregates developed around quartz and rock fragments, fills up the fragment interstices or the open fractures.

The main part of the studied ore mineralization is situated among QSP type altered rocks developed among intensively tectonized gneisses, granites and pegmatites. This type of hydrothermal alteration associated with the Au-Pb-Zn-Cu and the ore assemblage is presented by pyrite 2, chalcopyrite, galena, sphalerite, gold, electrum, remobilized molybdenite II. They are fine disseminated among quartz-sericite mass or are concentrated in the fragment's interstices as spotty aggregates, cracked to defragmented crystals, long prismatic to flaked aggregates (for molybdenite) plastically deformed or segregated in the sphere aggregates.

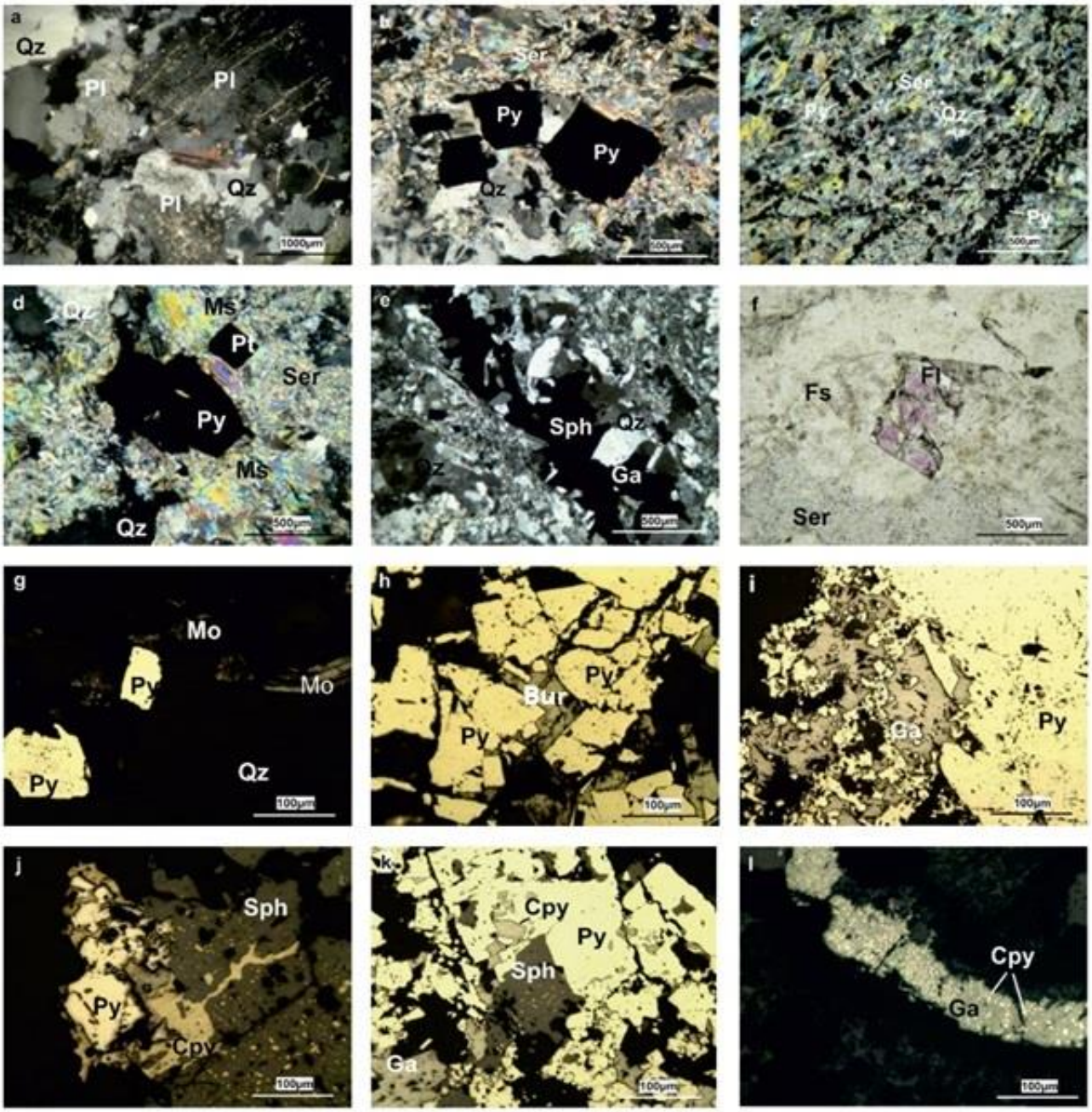

Fig. 3. Microphotos of rocks and ore mineralization: *a*, well preserved biotite granite, transmitted light; *b–c*, QSP type metasomatites, transmitted light; *d–f*, GTA, transmitted light; *g–h*, first stage ore mineralization, reflected light; *i–l*, second starde of ore mineralization, reflected light. Abbreviations: *Qz*, quartz; *Pl*, plagioclase; *Ser*, sericite; *Ms*, muscovite; *Fs*, feldspar; *Fl*, fluorite; *Py*, pyrite; *Sph*, sphalerite; *Ga*, galenite, *Mo*, molybdenite; *Cpy*, chalcopyrite; *Bur*, bursaite (?)

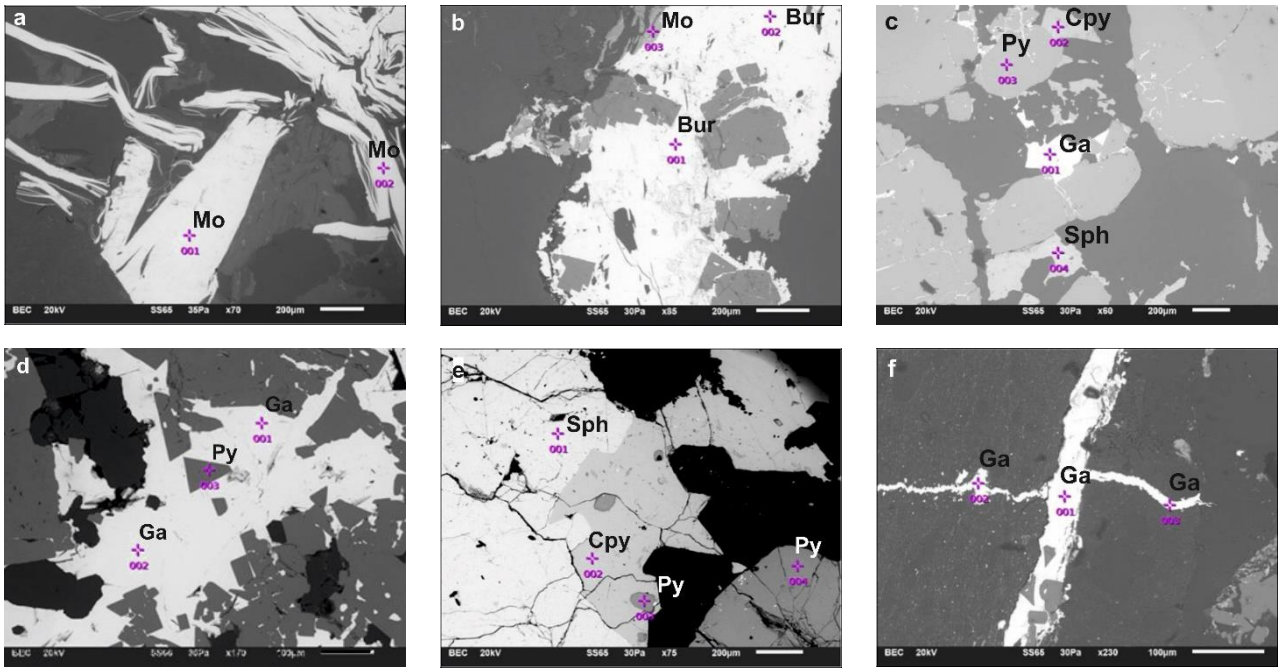

Fig. 4. SEM- EDX images of the studied ore mineralization

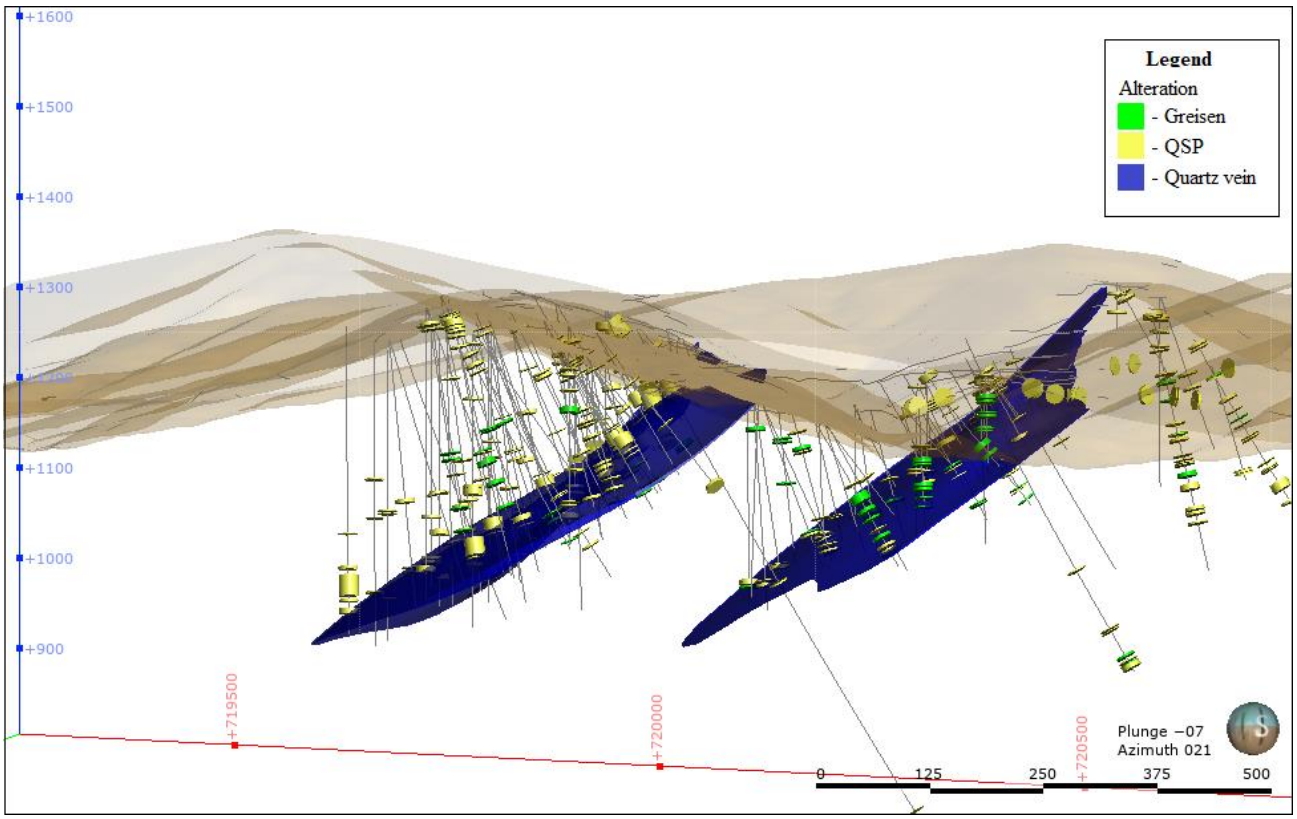

Fig. 5. 3D geological model presenting the alteration and ore zones

Tectonic, magmatic and hydrothermal events associated with ore-forming processes at Babyak Ag-Mo-Au deposit

In order to establish the structural control of the Babyak deposit an attempt to distinguish the time and nature of the main structural, tectono-magmatic and mineralization events observed in the area of the deposit was made. The following events (from the earliest to the latest) are distinguished:

D1. Formation of a regionally expressed foliation S1 that has entirely affected the rocks of the Surnitsa lithotectonic unit. Its formation is related to the Early Alpine structure (Sarov et al., 2011);

D2. Locally developed slanted plastic shear zones with formation of imposed mylonitic foliation S2. These shear zones

kinematically are oriented to the W and SW and are with extension character. Their formation probably predetermined the elevation of the region, the intrusion (emplacement) of the Rila-Western Rhodopes batholith and the formation of the Western Rhodope Dome (Ivanov, 1998);

D3. The intrusion of the Rila-Western Rhodope batholith. It is considered to be a post-tectonic event due to the fact that the contacts of the batholith with the metamorphic hosted rocks are clearly intrusive and the granites cross up the plastic structures described above;

D4. Late magma activity, characterized by the emplacement of a large number of aplites and pegmatites, passing through quartz hydrothermal veins in the contact zone of the batholith. During this event brittle to brittle-plastic shear zones parallel to the regional foliation and the earlier extensional plastic shear zones and inclined to the west shear zones of brittle deformation type are developed. This deformation event can also be interpreted as genetically related to the regional extension and elevation of the pluton and the associated with this process detachment faults. They are associated with local development of hydrothermal high-temperature alteration (GTA) in the granites (mainly) and quartz - pegmatite contacts and formation of Mo-Wo-Bi-Ag mineralization.

D5. It is presented by late steep to sub-vertical fault destructions with NW-SE direction, intersecting the earlier structures. These faults are with brittle character, dip to WSW or ENE direction and they affected and brecciated all rocks - metamorphites, granites, aplites, pegmatites and quartz veins. With this event could be related the wide developed quartz-sericity-pyrite (QSP) hydrothermal alteration in the ore field and formation of Au-Pb-Zn-Cu mineralization.

Conclusions

The obtained data of this study for the Babyak deposit assumes at least two stages of formation on the ore-forming structures in the locality. The first stage includes Mo-Wo-Bi-Ag mineralization, which is probably genetically linked to the formation of pegmatites and quartz veins. It is concentrated in the inclined to the west shear zones of brittle deformation type D4 affects mainly the quartz-pegmatite periphery areas followed the crystallization. The steep dextral strike-slip faults of type D5 which are related to the activity of the regional Ribnovo fault zone and Babyak-Grashevo shear zone,mainly, control the deposition of the second stage Au-Pb-Zn-Cu mineralization. It should be note that this mineralization is observed along the structures type D4, also, in the southern part of the deposit which is result, probably, of the late re-activation during formation of structures type D5 (Temelakiev et al., 2017).

Based on the new data obtained by this study could supposed the granite-related ore mineralization of the Babyak deposit.

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