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The Govezhda gold deposit, Western Balkan Mountains, Bulgaria

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Abstract. The Govezhda gold deposit is situated in the Western Balkan mountains, NW Bulgaria. It has been operating during the 1961-1992 period, but the mineralization remains not completely well known. Four mineralization stages, reflecting the following geochemical trend are defined: Fe-As-Au; Pb-Zn-Cu-Ag-Au; Ag-Pb-Cu-Sb; Ca. (1) The products of the first stage are Fe sulphides. Prevailing species are arsenopyrite and pyrite, while pyrrhotite and marcasite are less frequent. (2) The second stage bears the main sulphides and gold. The gold, together with the sulphides most commonly fills cracks in arsenopyrite and pyrite. (3) During the third stage a complex assemblage, comprising different Sb sulphosalts (tetrahedrite, boulangerite, bournonite, pyrargyrite, owyheeite) is deposited. (4) The fourth stage is characterized with the deposition of calcite and less frequent gypsum.

The gold is the economically important component in the deposit. It is found in three mineral associations. We suggest that it is initially deposited as invisible gold in arsenopyrite and pyrite during the first stage and later part (or all) of it is remobilized and redeposited together with the sulphides of the second stage.

The Govezhda deposit, just like Svishti Plaz in central Balkan Mountains has the typical features of some great mesothermal gold deposits in shear zones, deposited in Archaean or Hercynian greenschist terrains, known from South Africa, Western Australia, Canada, Portugal and France.

Key words: Govezhda deposit, Balkan Mountains, gold, arsenopyrite, sulphides

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Резюме. Златорудното находище Говежда се намира в Западна Стара планина в СЗ България. То е експлоатирано в периода 1961-1992, но минерализацията не е добре изучена. Отделени са 4 стадия на минерализация, които отразяват следната геохимична тенденция на хидротермалния процес: Fe-As-Au; Pb-Zn-Cu-Ag-Au; Ag-Pb-Cu-Sb; Ca. (1) През първият стадий се отлагат железни сулфиди. Преобладават арсенопиритът и пиритът, а пиротинът и марказитът са в незначителни количества. (2) Вторият стадий е носител на основните сулфиди и златото. Златото съвместно с минералите от стадия най-често запълва микропукнатини в пирита и арсенопирита. (3) През третия стадий се отлага парагенеза със сложен състав, включваща разнообразни антимонови сулфосоли (тетраедрит, буланжерит, бурнонит, пираргирит, оуихиит). (4) В края на процеса се отлагат калцит и малко гипс.

Златото е икономически важният минерал в находището. То е отделено в три минерални асоциации. Предполагаме, че златото се отлага първоначално като невидимо злато в арсенопирита и пирита от първия стадий, а по-късно част от него (или всичкото) се ремобилизира и преотлага със сулфидите от втория стадий.

Находище Говежда, както и Свищи плаз в Централна Стара планина, притежава характерните черти на някои от големите златорудни находища, отложени в зоните на срязване в архайски или херцински зеленошистни терени в Южна Африка, Западна Австралия, Канада, Португалия, Франция.

Introduction

The Govezhda deposit is located in the western part of the Balkan mountain in NW Bulgaria. It is known from Roman times. Lots of ancient mine workings from this time are found in the region. The recent exploitation period of the deposit is 1961-1992. It is closed because of strong environmental and economical problems despite the fact that the deposit still has unexploited reserves of gold ore (Kalaidjiev et al., 1989). The mine has produced 1.1 million tons of ore with average Au content of 3.5 g/t, and 3863 kg of pure gold (Milev et al., 1996). The gold content in the ore varies from 1.0 to 8.3 g/t, and the silver content – from few to 30-35 g/t.

The most comprehensive information about the deposit can be found in the unpublished exploration reports, concerning mostly the geology of the region and the preliminary mineralogical data ([1]Nikolaev, Tonev, 1947; [2]Petrov, 1981) as well as in the few published papers (Nikolaev, Tonev, 1961; Obretenov, Peev, 1971). Mineralogical studies of the ores are done by Velchev (1965a, b), Velchev and Vassilev (1966). The micro distribution of gold in sulphide minerals from various deposits in West Balkan Mountain, including Govezhda deposit, has been reported by Todorov and Jankova (1989). Several publications and reports concerning different minerals from the deposit appeared recently (Kerestedjian et al., 1999; Mladenova et al., 2003).

Geological setting

The Govezhda deposit comprises ore veins in the regions of the villages Kopilovtzi, Elovitza, Glavanovtzi, Diva Slatina and Govezhda (Fig. 1).

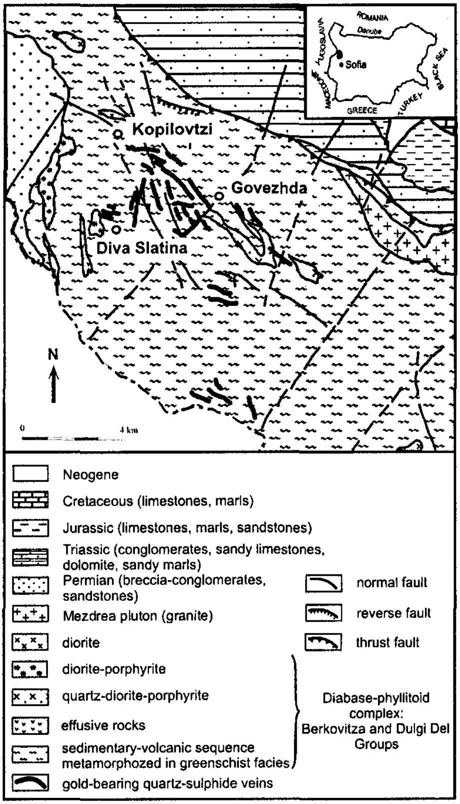

Fig. 1. Simplified geological map of the Govezhda deposit (according to Petrov, 1981)

Фиг. 1. Схематична геоложка карта на находище Говежда (по Petrov, 1981)

Three types of rocks are widespread in the region. The main rock complex is the diabase-phyllitoid metamorphic complex, represented by the rocks of Berkovitza and Dulgi Del Groups (Haydoutov, 1991). The complex comprises an alternation of diabase, diabasic tuffs, phyllites, marbles, diorite porphyrites, chlorite-sericite- and quartz-chlorite schists. The rocks of this complex strike 130-185°C and dip SW. Diabasic tuffs and phyllites are the most widespread rocks of this complex. Diabase outcrops as stocks or dykes. Marbles are found as bands or lenses with thickness from several cm to 30 m and maximal length to 2 km. Serpentinized ultrabasic and gabbro bodies as

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1 Nikolaev, G., I. Tonev. 1947. Report on exploration in the region of Kopilovtzi village. *Geofond Comm. Geol.*, I-90.

2 Petrov, H. 1981. Report on exploration in 1974-1980 in Brezov Rat, Cherna Reka, Izvora and Debeli Rat subsections of the Central part of the Govezhda gold deposit, Mihaylovgrad district. *Geofond Comm. Geol.*, I–1030.

lenses, and basic dykes outcrop eastwards from the Kopilovtzi village. Their place in the sediments of the diabase-phyllitoid metamorphic complex is connected to olistostrome processes (Kolcheva, Jordanov, 1989).

The intrusive rocks belong to the Balkan Ca-alkaline formation. The rocks of the Mezdrea pluton are leucocratic and melanocratic granitoides and granites (Haydoutov, 1971). Granodiorite and diorite porphyrites from the Balkan dyke formation cut diabase-phyllitoid metamorphic complex, as well as other intrusive rocks. In most cases they are concordant to the rocks of diabase-phyllitoid metamorphic complex. They strike 100-130° and dip 60-70°S. Contact metamorphic rocks (hornfelses) are formed around the intrusive bodies in diabase-phyllitoid metamorphic complex. The contact zone reaches a maximum of 200 m.

The sediments are deposited during Permian-Lower Triassic, Middle Triassic, Lower Jurassic and Quaternary periods. Permian-Lower Triassic are characterized by sediments formed in Buntsandstein facies – conglomerates, sandstones and sandy limestones - westwards from the Kopilovtzi village around the Kopren peak. Middle Triassic sediments are represented by limestones and dolomitic limestones. Lower Jurassic sediments are presented by conglomerates with pieces from Middle Triassic limestones and Lower Triassic sandstones. Quaternary sediments are deposited along the river valleys of Ogosta, Milina and Kopilovska Ogosta rivers (Nikolaev, Tonev, 1947).

Ore structures and ore bodies

The rocks of the Paleozoic low-crystalline diabase-phyllitoid metamorphic complex host the ore veins. The ore-controlling structures are veins, infilling tension related fissures and shear faults. They are also located in strongly fractured and deformed tectonic zones or at the contacts between different rock types. According to the exploration data the ore is concentrated in several ore locations – Kumanov Dol, Milev Dol, Rupski Dol, Zeleni Dol, Svidnichki Dol and Drenjaka. The veins strike 270-320° and dip 30-70°. The vein lengths vary from few to 600 m and thicknesses from several cm to 5-6 m. The ore veins are often cut and shifted horizontally from few to several meters (Nikolaev, Tonev, 1961). The ores are preferably localized at boundaries between rocks with different physical and mechanical properties, in schists, in places where the dykes change their direction, contact zones of the dykes. The hydrothermal alterations of the host rocks are sericite, silicite, carbonate and chlorite ones.

In tectonic respect, the area is localized in the core of the Berkovitza anticline, which is formed by the rocks of diabase-phyllitoid complex. The Vidlitza and Plakalnitza thrusts outline the S and N boundaries of the area respectively. In crosscut view the area represents an S dipping paraautohtonous thrusting plate (Ivanov et al., 1987). In lateral direction it extends from Kopren peak to the Petrohan pass. Other smaller fold structures in the area are the Treshtena synclinal and the Chereshovo and Elovitza anticlinal folds. Other important fault structure here is the Balkan front line, passing NE from the area, between the Kotenovtzi and Leskovetz villages (Petrov, 1981). The ore field is limited by the Zheleznitza fault at its NW (Obretenov, Peev, 1971; Doychev, 1979) and by the Berkovitza fault at its SE (Gochev et al., 1963).

Materials and methods of analysis

Specimens were collected from mining dumps at numerous exploitation points. Over 200 ore samples were collected from 14 mine workings of different parts of the Govezhda deposit. Representative samples, registered under M.1. 2003.6.1-5 are deposited in the Geocollection of the Geological Institute.

About 130 polished sections were prepared and the minerals were identified in reflected light. The goniometric measurements of arsenopyrite were performed on two-circle Goldschmidt goniometer, using laser beam and single crystals up to 1 mm in size.

The chemical composition of the minerals was determined using JEOL JSM 35 CF microprobe with Tracor Northern TN-2000 analyzing system at the laboratory of Eurotest AD, Sofia. Accelerating voltage of 25 kV and sample current of 10^{-9}A was applied. The following standards were used: PbS for PbL_α, $CuFeS_2$ for CuK_α and SK_α, pure Ag for AgL_α, native Au for Au L_α, Bi_2S_3 for BiL_α. Acquisition times for all elements were 100 s. All analyzed minerals were examined by back-scattered electron imaging in order to proof their homogeneity. The atomic absorption analyses of gold were performed on AAS Perkin Elmer 3030 at the Sofia University.

Mineral parageneses

Previous studies

The few published descriptions of mineral parageneses and minerals from the Govezhda deposit date from the time of its exploration. The mineral assemblage of the quartz-sulphide veins is investigated by Nikolaev and Tonev (1961). They have established two types of minerals: hypogene (scheelite, arsenopyrite, pyrite, gold, quartz, chalcopyrite, proustite, sphalerite, tennantite, galena, muscovite, chlorite, calcite and gypsum) and supergene (smithsonite, anglesite, cerussite, pyromorphite, hydrogoethite, scorodite and malachite). These authors recognize three stages of hydrothermal deposition at the Govezhda deposit namely (1) scheelite-arsenopyrite-pyrite, (2) quartz-sulphide, (3) quartz-carbonate.

The mineralogical position and distribution of the economically important mineral - the gold is reported by Velchev (1965b), Velchev and Vassilev (1966) and Todorov and Jankova (1989).

This study

Based on crosscutting relations and electron microprobe analyses the hydrothermal mineralization in Govezhda deposit can be divided into four paragenetic stages (Table 1). Among the 26 minerals established, four are reported for the first time: cubanite, bournonite, owyheeite and cassiterite.

Stage 1 (Fe-As-Au) has simple mineral composition. Pyrite and arsenopyrite are the main ore minerals and gray quartz is the principal gangue (Fig. 2a). Residual pyrrhotite occurs within pyrite. Single euhedral arsenopyrite and pyrite crystals are finely disseminated in the wall rocks. More often the relationships between arsenopyrite and pyrite suggest co-precipitation, although in some places both minerals have variable positions. Scheelite is deposited during this stage too (Fig. 2c) as established by Nikolaev and Tonev (1961). Strong fracturing took place after stage 1 and fractures are filled with the products of stage 2 (Fig. 2b).

Stage 2 (Pb-Zn-Cu-Ag-Au) has a complex composition. This is the main Au-Ag-bearing stage. Sphalerite, galena, chalcopyrite, cubanite, gold and tetrahedrite, intergrown with gray quartz represent this mineral assemblage. Chalcopyrite is frequently included within early sphalerite as blebs or single crystals (Fig. 2d).

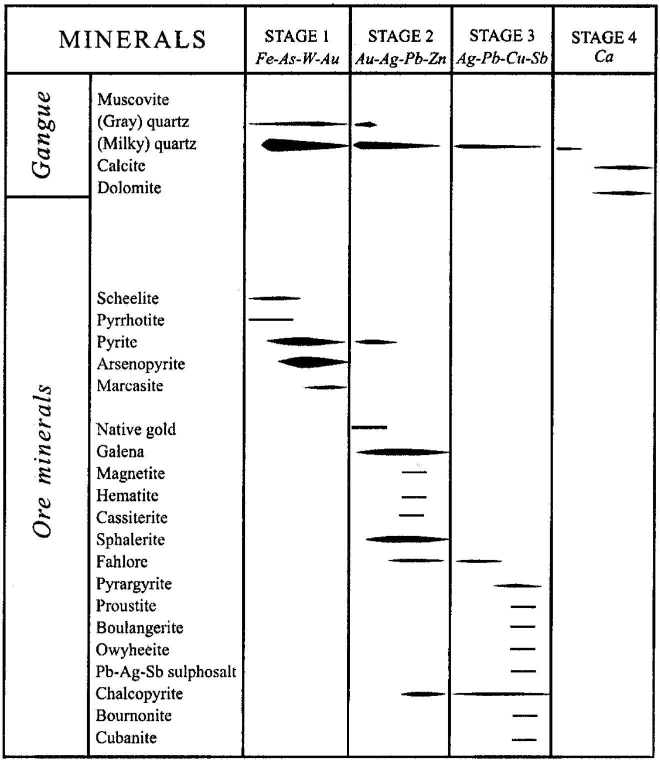
Stage 3 (Ag-Pb-Cu-Sb) occurs in nests, discordant veinlets or replacements in earlier minerals (Fig. 2e, f). During this stage tetrahedrite, boulangerite, bournonite, pyrargyrite, proustite, owyheeite and cubanite have been deposited in microfractures mainly in sphalerite and galena.

Stage 4 (Ca) is characterized by white calcite and in some places scarce gypsum filling vugs and fractures in earlier minerals. Calcite often encloses fragments of earlier assemblages, indicating that yet another fracturing took place prior to the late carbonate phase.

Minerals

Pyrite is the main mineral in the deposit. It is established in all the stages of the mineralization. Pyrite I together with arsenopyrite are the principal minerals of the first stage and in the deposit in general. Both minerals are deposited almost contemporaneously, thus intergrowths between them are very typical. Single crystals are rare. In some samples pyrite is obviously earlier. Pyrite II is

Table 1. *Paragenetic sequence of the hydrothermal mineralization*
Таблица 1. *Парагенетична последователност на хидротермалната минерализация*



deposited during the second stage as euhedral inclussions (several microns in size) in sphalerite and galena (Fig. 2d, 3b). Electron microprobe analyses of pyrite indicate that it contains systematically as trace elements only As from 0 to 2.26 wt. % and Cu from 0.10 to 0.53 wt. % (Table 2).

Arsenopyrite is the second main ore mineral in the Govezhda deposit. Single crystals are found dispersed in host rocks or are concentrated in groups and aggregates of numerous intergrown individuals in veins. The crystals commonly range in size between 50 μm and 2-3 mm.

Arsenopyrite is deposited in close relation with pyrite. Two basic groups of crystal shapes are represented - platy to isometric and long prismatic. Based on goniometric measurements, these shapes consist of {100}, {001} and $\{1k\bar{1}\}$, where k varies between 1 and 10. Less common are $\{2k\bar{2}\}$, with k 5 to 7 and {010} forms (Fig. 4). Apart from flat face shaped crystals, with k 2 or 3, all higher k values are recorded as peaks in continuous goniometric reflections on almost perfectly rounded terminal faces. All indices are given in the monoclinic setting of Morimoto and Clark (1961) and drawings are based on cell parameters refined by Fuess et al. (1986).

Electron microprobe analyses of arsenopyrite show As-contents ranging from 26.5 to 32.5 at. %, S 33-41.5 at. % and Fe 32-34 at. %. The most informative As vs. S distribution of the analytical results is shown on Fig. 5. Both compositions and shape varieties show

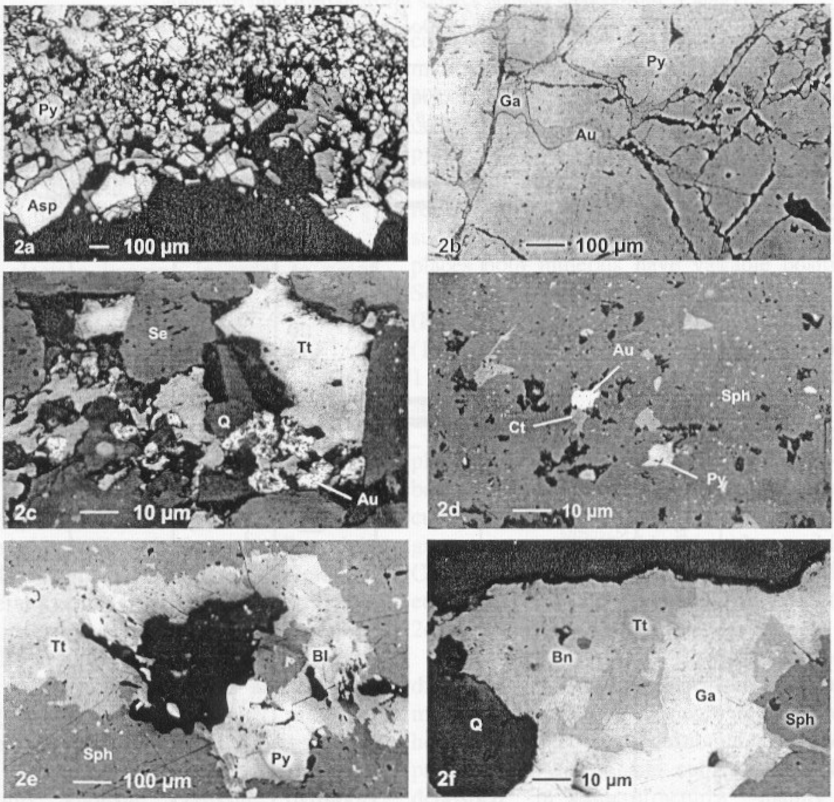


Fig. 2. Photomicrographs of mineral assemblages of the different stages. a. Fractured pyrite and arsenopyrite from (Fe-As) stage. Late galena, sphalerite and tetrahedrite cement the fractured grains. Sample 610/11b$_5$. b. Native gold and galena infilling fractures in strongly cataclased pyrite from (Fe-As) stage. Sample g3/7. c. Native gold, tetrahedrite and quartz crosscutting scheelite from the (Fe-As) stage. Sample 520/13a. d. Sphalerite from (Pb-Zn-Cu-Ag-Au) stage with chalcopyrite blebs and crystals, pyrite, cassiterite and native gold. Sample 610/23a. e. Tetrahedrite and boulangerite from the (Ag-Pb-Cu-Sb) stage fill microfractures in sphalerite. Sample 610/5. f. Tetrahedrite and bournonite from (Ag-Pb-Cu-Sb) stage embrace galena from (Pb-Zn-Cu-Ag-Au) stage. Sample 610/15a$_1$. Abreviations: Asp – arsenopyrite; Ga – galena; Py – pyrite; Au – native gold; Tt – tetrahedrite; Bl - boulangerite; Bn – bournonite; Sph – sphalerite; Se – scheelite; Ct – cassiterite; Q – quartz

Фиг. 2. Микроскопски снимки на минералните асоциации на различните стадии. a. Катаклазиран пирит и арсенопирит от (Fe-As) стадий, споен от по-късните галенит, сфалерит и тетраедрит. b. Самородно злато и галенит, запълващи микропукнатини в катаклазиран пирит от (Fe-As) стадий. c. Самородно злато, тетраедрит и кварц пресичат шеелит от (Fe-As) стадий. d. Сфалерит от (Pb-Zn-Cu-Ag-Au) стадий с халкопирит, пирит, каситерит и самородно злато. e. Тетраедрит и буланжерит от (Ag-Pb-Cu-Sb) стадий запълват микропукнатини в сфалерита. f. Тетраедрит и бурнонит от (Ag-Pb-Cu-Sb) стадий обхващат галенит от (Pb-Zn-Cu-Ag-Au) стадий

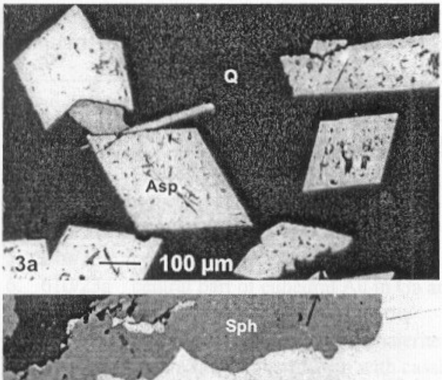


Fig. 3. Photomicrographs of some minerals. a. Arsenopyrite. b. Native gold and pyrite metacrystals in galena from (Pb-Zn-Cu-Ag-Au) stage. Sample 610/23a. c. Cubanite. Abreviations: Asp – arsenopyrite; Ga – galena; Py – pyrite; Au – native gold; Cb – cubanite; Tt – tetrahedrite; Sph – sphalerite; Q – quartz

Фиг. 3. Микроскопски снимки на някои минерали. a. Арсенопирит. b. Самородно злато и пиритови метакристали в галенит от (Pb-Zn-Cu-Ag-Au) стадий. c. Кубанит

slight evidence of clustering around two feature types (possibly two generations), but the amount and quality of the data available do not permit more definite conclusions. Almost always arsenopyrite is strongly fractured and late galena, tetrahedrite, sphalerite, chalcopyrite and gold infill the fractures (Fig. 2a).

Special analytical conditions were tried in the EPMA laboratory of the Bristol University (EUGF project), to detect possible "invisible gold" in 6 samples of this arsenopyrite. The detection limit obtained was 37 ppm at 95% confidentiality level. The analyzed samples did not show any gold within the mentioned detection limits.

Pyrrhotite is found as small oval inclusions in pyrite I. It looks likely that they are relicts from slightly earlier pyrrhotite grains.

Gold is the economically important ore mineral in the deposit. It is observed in almost all the investigated polished sections.

On the basis of structural microscopic observations three distinct types of gold occurences could be distinguished.

a. With pyrite and arsenopyrite from the first stage. It is deposited in microscopic veinlets and voids in arsenopyrite and pyrite I. This gold is located only inside the grains of the above-mentioned host minerals, alone or with some minerals from the base metal stage 2, usually galena, tetrahedrite and sphalerite (Fig. 2b). This occurrence is the most abundant one in the deposit.

b. Within galena and sphalerite from the second stage. The gold in this assemblage forms single grains in some cases with well-expressed crystallographic shapes (Fig. 3b). Its grain size is larger than that in the pyrite-arsenopyrite assemblage.

c. Within sphalerite, closely intergrown with cassiterite (Fig. 2d). The size of gold here is up to several μm.

For the gold in the first two occurrences, like in the very similar Svishti Plaz deposit (Mladenova, Kerestedjian, 2002) we suggest that a part or all of the gold is initially deposited as "invisible gold" in the arsenopyrite and pyrite from the Fe-As-Au stage. Later, during the stage 2, this gold is remobilized and redeposited. The considerations of its origin expressed for the Svishti Plaz gold are valid here too.

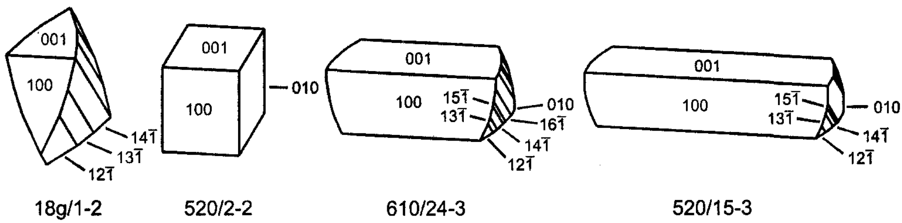


Fig. 4. Typical shapes of Govezhda arsenopyrites
Фиг. 4. Типични форми на арсенопирити от Говежда

Concerning the third occurrence it is evident that this gold is deposited contemporarily with sphalerite during the second stage of mineralization.

Table 3 presents analytical results for analyzed gold grains, indicating mineral association and position of spot analyses within the grain. In order to proof the homogeneity of the native gold several analyses in one grain were performed. Electron microprobe analyses revealed that the gold is always alloyed with silver (argentiferous gold to electrum). Silver content of gold grains range from 13.90 to 25.14 wt. %. The gold grains are generally homogeneous in respect to their silver content. In comparison with the native gold from the same type Svishti Plaz deposit, the native gold from Govezhda deposit contains lower quantities of silver (Mladenova et al., 2003).

Marcasite occurs rarely as aggregates or intergrown with pyrite. Most probably it is a primary constituent of the ore and reflects local increases in oxygen fugacity and/or lower pH.

Sphalerite is deposited during the second stages of mineralization. It forms irregular grains and contains lots of inclusions of chalcopyrite, pyrite, gold, cassiterite, magnetite and hematite (Fig. 2d). The presence of chalcopyrite and pyrite reflects most probably a process of decomposition of primarily Fe-Cu-bearing sphalerite, forming an aggregate of

Table 2. *Chemical composition of pyrite*
Таблица 2. *Химичен състав на пирит*

Nr.	Sample	Mineral association	Element. wt. %						
			Fe	Ni	Cu	Zn	As	S	Total
1.	g3/7	Pyrite I close to gold	47.14		0.22		0.51	51.67	99.54
2.	g3/7	Pyrite I close to gold	46.59		0.17	0.22	0.18	51.25	98.41
3.	g3/7	Pyrite I close to gold	47.46		0.14			52.19	99.79
4.	g3/7	Pyrite I close to gold	47.81		0.10		0.19	52.17	100.27
5.	g3/7	Pyrite I far from gold	47.46		0.12		2.26	50.90	100.74
6.	g3/7	Pyrite I far from gold	46.84		0.22		1.57	51.02	99.65
7.	610/5	Pyrite I	46.69	0.12	0.53		1.96	50.20	99.50
8.	610/15a_1	Pyrite II intergrowth with gold and cassiterite	47.15	0.24	0.25			52.07	99.71

Table 3. *Chemical composition of gold*
Таблица 3. *Химичен състав на самородно злато*

Nr.	Sample	Mineral association	Element. wt. %				
			Au	Ag	Cu	Fe	Total
1.	610/23a	gold in galena and sphalerite	84.33	15.77	0.38		100.48
2.	610/23a	gold in galena and sphalerite	85.18	14.46	0.39		100.03
3.	610/23a	gold in galena	85.26	14.20	0.39		99.85
4.	610/23a	gold with galena and sphalerite	84.10	14.65	0.19		98.94
5.	610/23a	peripheral part of euhedral Au in Ga and Sph	85.15	13.90	0.33		99.38
6.	610/23a	central part of euhedral Au in Ga and Sph	83.62	15.11	0.31		99.04
7.	610/23a	central part of gold in sphalerite	84.76	14.30	0.49	0.16	99.71
8.	610/23a	peripheral part of gold in sphalerite	84.11	14.68	0.35	0.64	99.78
9.	610/23a	Au in Sph as intergrowth with cassiterite	84.24	14.81	0.37		99.42
10.	610/23a	Au in Sph as intergrowth with cassiterite	83.40	14.95	0.34		98.69
11.	g3/7	Au veinlet in pyrite	80.88	17.95	0.41	0.23	99.47
12.	g3/7	Au veinlet in pyrite	74.42	25.14	0.40	0.14	100.10
13.	g3/7	central part of Au grain in pyrite	82.94	16.50	0.34	0.15	99.93
14.	g3/7	peripheral part of Au grain in pyrite	83.08	15.56	0.52	0.43	99.59
15.	g3/7	Au grain in pyrite	79.91	19.13	0.49	0.24	99.77
16.	g3/7	Au intergrowth with cassiterite in pyrite	81.07	17.85	0.36	0.39	99.67
17.	g3/7	Au in pyrite	80.40	16.97	0.63	1.38	99.38
18.	g3/7	Au in pyrite	82.53	16.38	0.44	0.16	99.51

Ga – galena, Sph – sphalerite, Au – gold
Ga – галенит, Sph – сфалерит, Au - злато

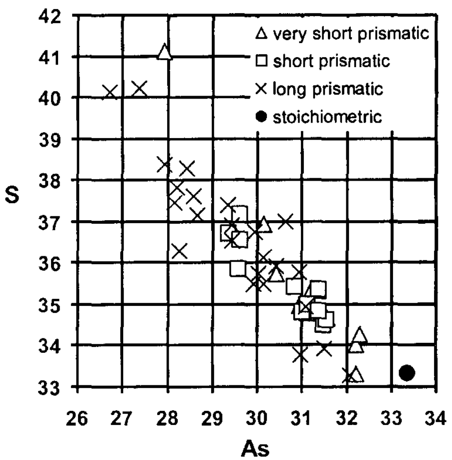


Fig. 5. Correlation between As and S (in at. %) in arsenopyrite from the Govezhda deposit. The solid circle represents the stoichiometric composition
Фиг. 5. Съотношение между съдържанията на As и S (в at.%) в арсенопирита от находище Говежда. Плътният кръг изобразява стехиометричния състав

chalcopyrite, pyrite and low-Fe sphalerite (Barton, Bethke, 1987). The Sn content in sphalerite is noticed by Nikolaev and Tonev (1961) but without any comment. Sphalerites from many gold deposits are characterized by elevated Sn contents that is explained with the existence of solid solutions of stannite in sphalerite (Nekrasov et al., 1979). In the ores of Govezhda deposit the presence of native gold and cassiterite, systematically as intergrowths in sphalerite (Fig. 2d) suggests a co-precipitation during the second stage. There is no evidence of later deposition (like connection to microfissures) for any of these minerals. Sphalerite often fills microfissures in earlier pyrite and arsenopyrite (Fig. 2a). The sphalerite contains very low Fe, Cu and Cd concentrations never exceeding 1.0 wt. %. (Table 4).

Galena is the main mineral of the second stage. It is deposited as massive aggregates, irregular grains or veinlets in quartz or fills

Table 4. *Chemical composition of sphalerite*
Таблица 4. *Химичен състав на сфалерит*

Nr.	Sample	Mineral association	Element. wt. %					
			Zn	Fe	Cd	Cu	S	Total
1.	610/23a	Sph with inclusions Ct, Py, Asp, Mt	68.17	0.35	0.32	0.22	30.47	99.53
2.	610/23a	Sph with inclusions Ct, Py, Asp, Mt	67.46	0.75	0.18	0.24	31.11	99.74
3.	610/15a$_1$	galena, tetrahedrite, bournonite	67.80	0.42	0.76	0.42	30.33	99.73
4.	g3/7	intergrowth with Au in pyrite	62.30	4.66	1.25	0.11	32.26	100.58

Py – pyrite, Asp – arsenopyrite, Mt – magnetite, Ct – cassiterite, Au - gold
Py – пирит, Asp – арсенопирит, Mt – магнетит, Ct – каситерит, Au – злато

fissures in pyrite I and arsenopyrite (Fig. 2a and 2b). Galena is very pure, only with small quantities of Cu (Table 5).

Tetrahedrite. It is the most common sulphosalt in all parts of the deposit. Tetrahedrite as subhedral grains is commonly deposited in association with other sulphosalts or is observed as 5-10 μm inclusions within sphalerite. Occasionally it is found with sphalerite, gold and galena as grains and fissure fillings in quartz, pyrite I or arsenopyrite (Fig. 2e). All analyzed tetrahedrites contain As in the range 0-1.36 wt. % (Table 6). They show strong substitution of Cu by Ag, Fe and Zn.

The compositional range of Ag is 11.17 to 21.45 wt. %, of Fe – 0.79 to 3.47 wt. % and Zn – 3.40 to 8.18 wt. %. Tetrahedrite is the second most important Ag-bearing mineral in the deposit after the native Au-Ag alloy.

Sb-sulphosalts. The antimoniferous association includes several sulphosalts: boulangerite, pyrargyrite, owyheeite, bournonite and undistinguished sulphosalt. They occur in veinlets or nests usually together or in different relations. They embrace or cut the minerals from the Pb-Zn-Au-Cu stage (Fig. 2e and 2f). Microprobe analyses of the minerals are given in Table 7.

As-sulphosalts. The only sulphosalt from this group is proustite.

Comparison with other Balkan gold deposits

Based on our investigations both on the Govezhda and the Svishti Plaz (Mladenova, Kerestedjian, 2002) gold deposits a wide set of similarities can be outlined. Both deposits are hosted in the Prealpine basement of the Balkanide zone. The structural characteristics of the ore in both deposits are an evidence for tectonic control and tectonic activity during the ore deposition. Strong fracturing of already

Table 5. *Chemical composition of galena*
Таблица 5. *Химичен състав на галенит*

Nr.	Sample	Mineral association	Element. wt.%				
			Pb	Cu	Ag	S	Total
1.	g3/7	sphalerite	86.85	0.22		12.64	99.71
2.	610/15a$_1$	tetrahedrite, bournonite	86.14	0.48		12.55	99.17
3.	610/15a$_1$	tetrahedrite, bournonite	87.64	0.15		12.36	100.15
4.	610/5	Ag-Sb sulphosalts, sphalerite	85.83	0.56		13.02	99.41
5.	610/2	Ag-Sb sulphosalts, sphalerite	85.42	0.79	0.45	12.88	99.54

Table 6. *Chemical composition of tetrahedrite*
Таблица 6. *Химичен състав на тетраедрит*

Nr.	Sample	Mineral association	Element. wt. %								
			Cu	Ag	Fe	Zn	Sb	As	Te	S	Total
1.	610/2	tetrahedrite	26.19	15.54	1.85	3.97	28.24	0.52		23.28	99.59
2.	610/2	tetrahedrite	25.14	16.11	1.09	4.61	28.46	0.87		23.42	99.70
3.	610/5	tetrahedrite	21.83	18.57	1.62	4.38	26.32	1.36	4.45	21.30	99.83
4.	610/5	tetrahedrite	23.55	20.08	3.47	3.40	25.98	1.40		22.16	100.04
5.	610/5	tetrahedrite	22.48	21.45	3.17	3.78	25.85	0.98		21.94	99.65
6.	610/23a	Tt intergrowth with Ga in Sph	28.32	11.17	0.86	8.18	27.67	1.20		22.81	100.21
7.	610/23a	Tt inclusion in Sph	28.70	11.52	0.94	7.98	27.80			22.58	99.52
8.	610/15a$_1$	galena, sphalerite, bournonite	24.71	15.78	0.90	5.37	28.24	0.97	3.25	21.79	101.01
9.	610/15a$_1$	galena, sphalerite, bournonite	24.81	15.15	0.79	4.99	28.70	0.66	2.92	21.39	99.41
10.	610/15a$_2$	gold	23.68	16.25	3.29	7.57	26.95		0.66	22.11	100.51
11.	610/15a$_2$	sphalerite	25.86	15.58	1.58	6.44	26.47	0.81	0.83	21.98	99.55

Ga – galena, Sph – sphalerite, Tt - tetrahedrite
Ga – галенит, Sph – сфалерит, Tt - тетраедрит

deposited minerals and subsequent precipitation of next portion accompanied all stages of ore deposition

The mineral associations in both deposits indicate that at the beginning of the deposition, during the first two stages, the mineralization formed from relatively reduced ore fluids. Probably most of the gold in both deposits is initially precipitated as invisible gold in arsenopyrite and pyrite. Most or all of it was later mobilized and reprecipitated with the sulphides from the second stage. The occurence of abundant local hematite precipitation in Svishti Plaz is an evidence for opening of the vein system and increase of fO_2 at the end of the ore deposition, which caused hydrothermal oxidation of earlier sulphides. In Govezhda deposit hematite is scarce and is observed as single grains in sphalerite. In both deposits a sulphosalt stage is established but with quite different minerals comprised. The sulphosalts in Govezhda deposit are sulphoantimonides (tetrahedrite, boulangerite, bournonite, owyheeite) and in Svishti Plaz they are sulphoarsenides (tennantite) and sulphobismuthides (matildite, bismuthinite-pekoite, aikinite-friedrichite, berryite, benjaminite). The complex Ag-Cu-Pb-Bi mineralization in Svishti Plaz seems to be a result of superimposition of the late bismuthiferous solutions from Sredna Gora mineralization fluids on the earlier minerals (Mladenova et al., 2001).

The economically important mineral in both deposits is the native gold with variable Ag contents. The native gold in Govezhda deposit contains more Au than that in Svishti Plaz.

Amov et al. (1981) date the Paleozoic granitoids and ore mineralizations in the Western Balkan Mountain and conclude that the gold mineralization in the Govezhda and Svishti Plaz deposits have different ages and are related to different types of granitoids. The age of 270-285 Ma (Permian) based on Pb isotopes in galena from Svishti Plaz present a genetic relationship to common endogene source of hydrothermal mineralization and granite magmatism in the region. An age of 360 Ma (Middle Devonian) is approved for the ore deposition in Govezhda deposit.

The Govezhda and Svishti Plaz deposits show quite a lot of similarities to some mesothermal gold deposits in shear zones in Archaean and Hercynian terrains in South Africa, Western Australia, Canada, Portugal and France (Bouchot et al, 1989; Touray et al., 1989; Foster, 1990; Cassidy et al., 1998; Groves et al., 1998; Oberthür et al., 2000).

Conclusions

Despite that the Govezhda mine is already closed the region has still non-prospected and

Table 7. *Chemical composition of sulphosalts*
Таблица 7. *Химичен състав на сулфосоли*

Nr.	Sample	Mineral	Element. wt. %							
			Ag	Pb	Cu	Fe	Sb	As	S	Total
1.	610/5	pyrargyrite	57.46		0.65	0.26	20.16	2.91	17.77	99.21
2.	610/5	pyrargyrite	60.28		0.58	0.19	13.10	7.42	18.58	100.15
3.	610/5	proustite	64.06		0.95	0.14	0.39	14.96	19.35	99.85
4.	610/5	proustite	61.26		1.07		4.73	12.22	18.87	98.15
5.	610/5	proustite	64.24		0.62			15.03	19.29	99.18
6.	610/5	proustite	65.19		0.62			14.42	19.02	99.25
7.	610/5	proustite	65.20		0.62			14.43	19.02	99.27
8.	610/5	proustite	63.38		0.80		1.10	14.73	18.99	99.00
9.	610/5	boulangerite		55.07	0.67		24.73		19.54	100.01
10.	610/5	boulangerite		55.67	0.56		24.93		18.86	100.02
11.	610/2	bournonite		41.44	13.20		23.70		20.72	99.06
12.	610/2	bournonite		41.47	13.91		24.61		19.88	99.87
13.	610/2	bournonite	0.33	40.21	12.86		25.92		19.99	99.31
14.	610/5	owyheeite	6.67	44.57	0.60		28.75		19.42	100.01
15.	610/5	owyheeite	6.51	45.18	0.61		28.98		18.79	100.07
16.	610/5	(unidentified)	24.85	24.91	1.34		29.21		19.44	99.75
17.	610/5	(unidentified)	24.32	24.00	0.51		30.87		19.52	99.22

non-operated reserves. The deposit is closed because of the high As-quantity and the environmental problems it causes. With the development of modern flotation and metal extraction technologies, the deposit will represent an interest in the future because of the high Au content in the ore. The new data established show that the Govezhda deposit has still to be studied and modern paragenetic studies including quantitative data on all stages of mineralization is worth. Precise geothermometric and isotopic data on distinct mineralizing events should give a whole picture of the mineralizing process. The form of deposition of native Au is not completely resolved too.

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