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The Svishti Plaz gold deposit, Central Balkan Mountain, Bulgaria

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Abstract. The Svishti Plaz gold deposit has been explored during the 1970-ies, but the mineralisation there has not been fully studied. Using samples from 15 mine workings, authors established 5 mineralisation stages, reflecting the following geochemical trend of the hydrothermal process: Fe-As; Pb-Zn-Cu-Ag-Au; Bi-Pb-Ag-Cu; Fe; Ca-Ba. The first stage is characterized with the deposition of iron sulphides. Arsenopyrite and pyrite are deposited in almost equal amounts, while pyrrhotite is much less frequent. The second stage is more variegated in geochemical respect. It bears the main sulphides and gold. The gold is most often found with sulphides in fissures and cracks in arsenopyrite and pyrite. It seems likely that the gold has initially been deposited as "invisible" gold in the early arsenopyrite and pyrite. Part or all of it is later redeposited together with the sulphides of the second stage. During the third stage, as a result of local reheating, Bi influx and remobilization of already deposited chemical constituents, a complex Bi mineralisation is established. The next stage, characterized by hematite deposition is represented in few locations only. It causes local hypogenetic oxidation of earlier minerals. At the end of the process (fifth stage), calcite and barite are deposited in varying amounts. The Svishti Plaz deposit has the typical features of the deposits in share zones in Archaean and Hercynian green-schist terrains, known from South Africa, Western Australia, Canada, France and Portugal.

Keywords: Svishti Plaz deposit, Balkan Mountains, gold, arsenopyrite, Bi-minerals
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Резюме. Златорудното находище Свищи плаз е проучвано през 70-те години на 20-ти век, но минерализацията не е добре изучена. В резултат на изследване на образци от 15 минни изработки бяха установени 5 стадия на минерализация, отразяващи следната геохимична тенденция на хидротермалния процес: Fe-As; Pb-Zn-Cu-Ag-Au; Bi-Pb-Ag-Cu; Fe; Ca-Ba. Първият стадий се характеризира с отлагане на железни сулфиди. В почти еднакви количествени взаимоотношения се образуват арсенопирит и пирит и в незначителни количества пиротин. Вторият стадий е с по-разнообразна геохимична характеристика. Той е носител на основните сулфиди и златото. Златото съвместно с минералите от стадия най-често запълва микропукнатини в пирита и арсенопирита. Вероятно златото се отлага първоначално като невидимо злато в арсенопирита и пирита от първия стадий. Част от него (или всичкото) по-късно се ремобилизира и преотлага със сулфидите от втория стадий. През третия стадий в резултат на локално подгряване, привнос на бисмут и заимстване на елементи от отложените вече минерали, се образува бисмутова парагенеза със сложен състав. Следващият стадий, характеризиран от отлагането на хематит, не е проявен повсеместно. Той предизвиква хипогенно окисление на минералите от предишните стадии. В края на процеса се отлагат калцит и барит в променливи количества. Находище Свищи плаз притежава характерните черти на големите златорудни находища, отложени в зоните на срязване в архайски и херцински зеленошистни терени в Южна Африка, Западна Австралия, Канада, Португалия, Франция.

Introduction

In the Zlatitsa part of Central Balkan Mountains three types of ore deposits are presented: gold-sulphide, copper and barite - base metal. Several gold occurrences and gold deposits are prospected in the 1970^{-ies}. None of them is exploited and therefore the obtained data is based on prospecting results only.

The gold-bearing Svishti Plaz deposit is situated in the Central Balkan Mountain, at an altitude of about 1500 m. The ancient mine workings and vast dumps are an evidence for the exploration activity in far and recent past. The deposit has been explored during the 1964-1979 period. As a result, dozens of small quartz-gold-base metal ore veins with average contents of Au 6.6 g/t, Ag 16.6 g/t, Pb 0.62% are established (Parvanov, Mateev, 1980, unpublished report).

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 (Antonov, 1969; 1979, unpublished reports). Mineralogical studies of the ores are done by Baltov and Gizdov (1977), Kujkin et al. (1972) and Mileva and Mileva (1977). The distribution of gold in sulphide minerals from various deposits in West Balkan Mountain, including Svishti Plaz deposit, has been reported by Todorov and Jankova (1989). The deposit has never been operating because of the high altitude and the high As content.

The purpose of this study is to report new mineralogical data for the Svishti Plaz gold deposit. The timing of mineralizing events and genetic implications of the new findings are discussed.

Geological Setting

Two rock complexes determine the geology and metallogenic features of the region (Kujkin, Milanov, 1970; Kujkin et al., 1972). The rocks of the Paleozoic low-crystalline diabase-phyllitoid metamorphic complex (DPC) are the most widespread in the region (Fig. 1). It comprises quartz-sericite-chlorite schists, small diabasic bodies and diabasic tuffs. The Ordovician magmatic rocks of the Vejen complex, comprising diorite, granodiorite and granite-porphyrite as well as numerous dykes of the same composition intrude DPC. The contact zones of DPC rocks are transformed in hornfelses, porphyroblastic schists and amphibolites.

The rocks of the Late Paleozoic (Late Carboniferous-Early Permian) dyke complex, including quartz-syenodiorite and granodiorite porphyrites as well as granite-porphyries, are widespread as a belt around the south border of the Vejen intrusion, parallel to the Kashana thrust (Kujkin, Milanov, 1970).

Triassic calcareous sediments are widespread at the northeastern, northern and southeastern slopes of Svishti Plaz peak. They overlay discordantly the rocks of DPC and dip 25-45° S. Spessartites, gabbro-diorites, diorites, quartz-diorites, granodiorites and granite-porphyries from the Late Alpine dyke complex (Late Cretaceous-Late Eocene?) are widespread in the Kashana thrust zone.

Three fracture directions are distinguished in the granodioritic intrusions and metamorphic rocks of the region. The faults striking N and 300-330° NW are ore-bearing. The faults striking NE are barren. The most important structure in the region is the Kashana fault (Kujkin et al., 1972).

The vein type mineralization is hosted in Paleozoic low-crystalline schists, granodioritic, dioritic and quartz-dioritic plutonic bodies and related hornfelses. The ore-hosting structures are veins, infilling fissures related to tension and shear faults. Some ore veins are situated in the contact zone of the dykes. The distribution of dykes and ore veins is probably controlled by the Late Paleozoic activation of the Kashana fault (Kujkin, Milanov, 1970).

More than 30 ore veins, striking 150-160° and 175-180° SE, 0-10° NNE and 65-70° ENE were explored. They dip 60-90° SW. Most of the ore veins can be followed horizontally

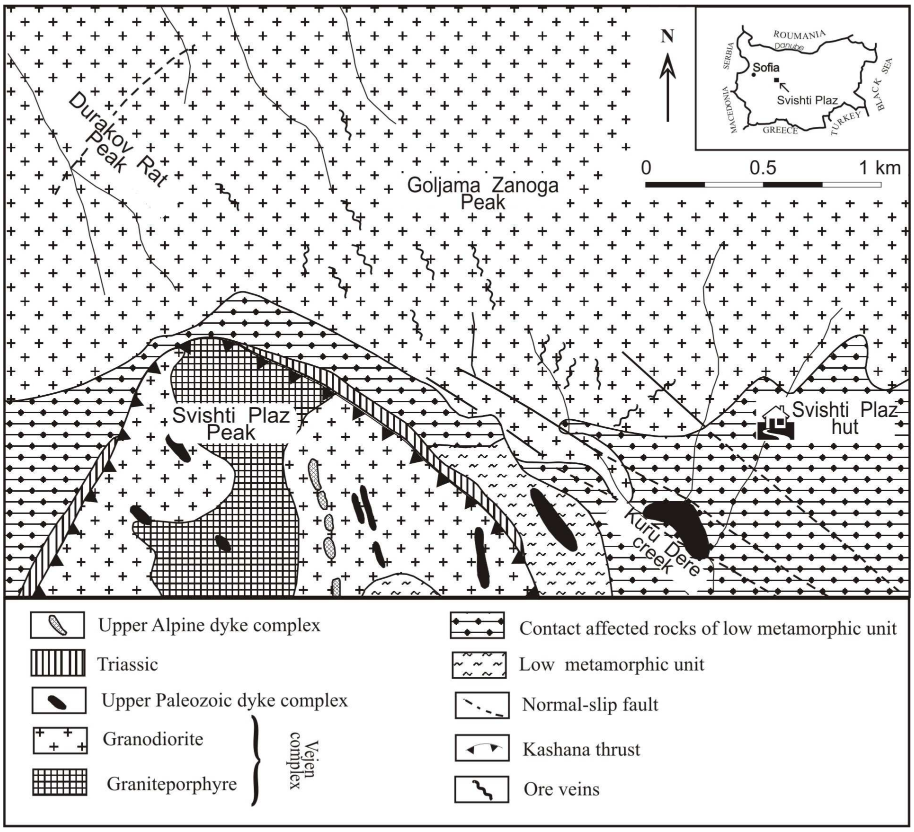


Fig. 1. Geological map of the Svishti Plaz deposit (after Kujkin et al., 1972)
Фиг. 1. Геоложка карта на находище Свищи плаз (по Куйкин и др., 1972)

for around 100-350 m and some of them - up to 1 km. Their thickness varies from 0.20 to 2.5m, usually 0.8-1m (Kujkin et al., 1972).

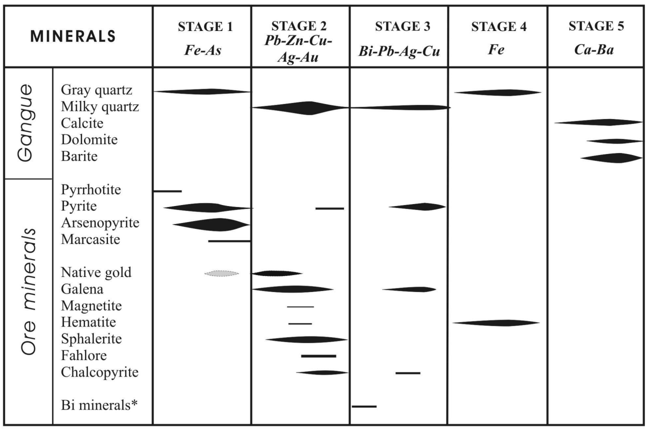
The thickness of vein-related wall-rock alteration is proportional to vein thickness and bleaches the rocks up to a few meters from the veins. Alteration is characterized by silicification, sericitization of plagioclase, kaolinization of potassium feldspar and chloritization of biotite (Kujkin et al., 1972).

Materials and methods of analysis

Around 200 samples were collected from dumps of 15 mine workings in Svishti Plaz deposit. Representative samples, registered under M.1.2002.12.1-2 are deposited in the Geo-collection of the Geological Institute, BAS. About 90 polished sections were prepared and the minerals were identified in reflected light. The goniometric measurements were performed on Goldschmidt two-circle goniometer, using 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. Accelerating voltage of 25 kV and sample current of 10^{-9}A was applied. The following standards were used: PbS for PbLα, $CuFeS_2$ for CuKα and SKα, pure Ag for AgLα, native Au for Au Lα, Bi_2S_3 for BiLα. Acquisition times for all elements were 100 s. The atomic absorption analyses (AAS) were performed on Perkin Elmer 3030 at the Sofia University.

Table 1. *Sequence of mineral deposition*
Таблица 1. *Последователност на минералоотлагане*



Bi- minerals : native bismuth, aikinite-friedrichite, bismuthinite-pekoite, matildite(?), benjaminite (?), berryite, unifedntified Pb-Ag-Bi sulfosalt

Mineral parageneses

Antonov (1969, unpublished report) suggests six stages of mineralization: quartz-sericite, pyrite-arsenopyrite, quartz-hematite, sphalerite-quartz-pyrite, gold - base metal and quartz-carbonate. Kujkin et al. (1972) recognize four stages of hydrothermal deposition at Svishti Plaz deposit namely (1) pyrite-arsenopyrite, (2) hematite, (3) gold-galena-sphalerite, and (4) carbonate. Mileva and Mileva (1977) give the same succession with quartz-sericite stage at the beginning of the process.

According to our data, the hydrothermal mineralization in Svishti Plaz deposit can be divided into five paragenetic stages based on crosscutting relations and electron-microprobe analyses (Table 1). 21 minerals have been established.

Stage 1 (Fe-As) consists mainly of pyrite, arsenopyrite and gray quartz (Figs. 2a, b). Rare pyrrhotite occurs within pyrite. Euhedral arsenopyrite and pyrite crystals and small veinlets and aggregates up to few millimeters in size are finely disseminated in the vein walls and adjacent wall rocks. Arsenopyrite is more common than pyrite. The relationships between arsenopyrite and pyrite suggest co-precipitation, although in some places arsenopyrite encloses pyrite.

Stage 2 (Pb-Zn-Cu-Ag-Au) is the main Au-Ag-base metal stage. It is characterized by sphalerite, galena, chalcopyrite, gold and tennantite intergrown with gray quartz (Figs. 2d, 2e). Minor, fine- to medium-grained pyrite, hematite and magnetite are found within sphalerite (Fig. 2c). Chalcopyrite is frequently included within early sphalerite as blebs or subparallel chains (Fig. 2c). Small breccias of earlier vein material are often enclosed in base metal sulphides, indicating that intense fracturing took place during their deposition.

Stage 3 (Bi-Ag-Pb-Cu) occurs in discordant veinlets and more complex relations. The bismuth minerals with chalcopyrite are neither cut nor replaced by later minerals.

Stage 4 (Fe) has a very simple mineral composition. The only mineral is hematite and gray quartz as gangue (Fig. 2f).

Stage 5 (Ca-Ba) is characterized by white calcite and milky barite, filling vugs and fractures in earlier minerals. Small breccias of earlier vein material are often enclosed in the carbonates, indicating that yet another fracturing took place prior to the late carbonate phase. The geochemical characteristics of this mineralization closely resemble the Paleogene

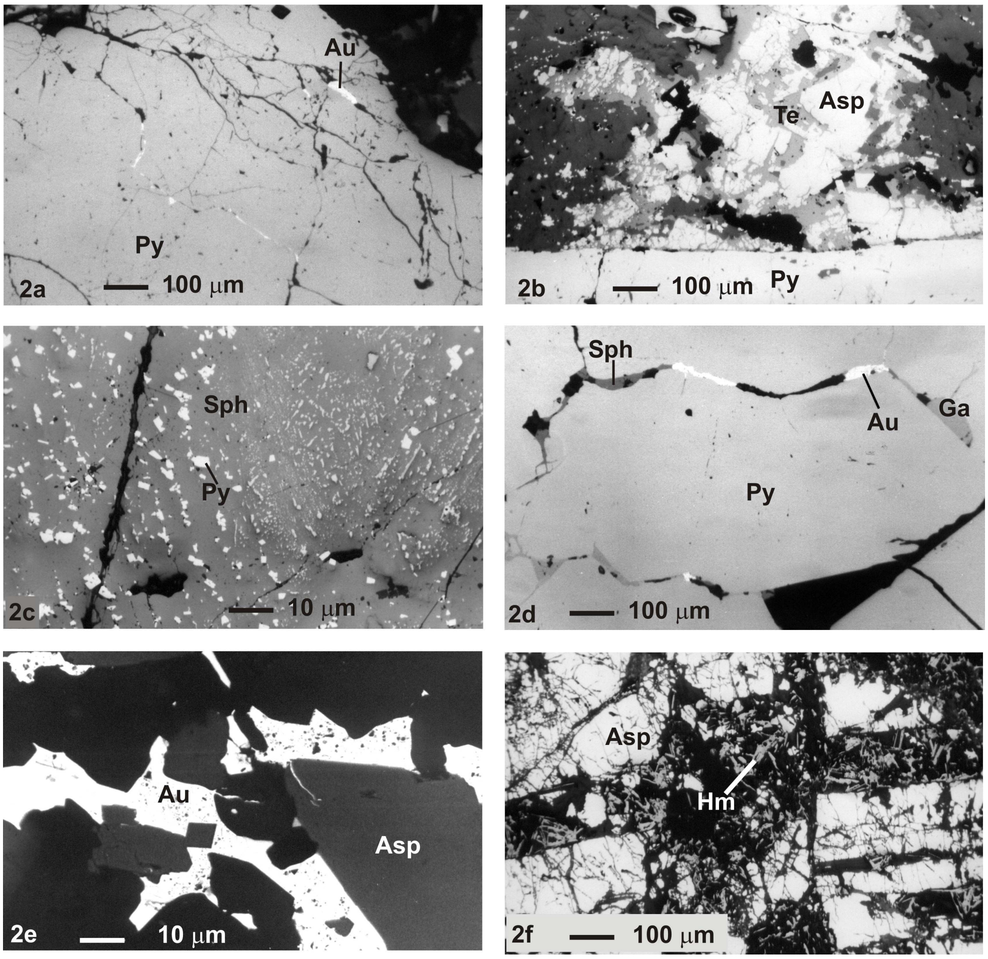


Fig. 2. Photomicrographs of mineral relations. a. Massive pyrite from the (Fe-As) stage. The native gold is placed in microfractures in pyrite. b. Tennantite infilling fractures in strongly cataclased arsenopyrite from the (Fe-As) stage. The pyrite from the same stage is less fractured. c. Sphalerite from the (Au-Ag-Pb-Zn) stage with chalcopyrite blebs and semihedral pyrite grains. d. Native gold with galena and sphalerite from the second stage fill microfractures in pyrite I. e. Native gold embracing arsenopyrite. f. Quartz-hematite vein crosscutting fractured arsenopyrite. Abreviations: Py - pyrite; Ga - galena, Sph – sphalerite, Aspy – arsenopyrite, Au - native gold; Te - tennantite; Hm – hematite; Q – quartz

Фиг. 2. Микроскопски снимки на минерални отношения. a. Масивен пирит от стадий (Fe-As). Самородното злато е вместено в микропукнатини в пирита. b. Тенантит запълващ пукнатини в силно катаклазиран арсенопирит от (Fe-As) стадий. Пиритът от същия стадий е по слабо нарушен. c. Сфалерит от (Au-Ag-Pb-Zn) стадий с халкопиритови включения и пиритови кристалчета. d. Самородно злато с галенит и сфалерит от втория стадий запълват микропукнатини в пирит I. e. Самородно злато, обрастващо арсенопирит. f. Кварц-хематитова жилка пресичаща раздробен арсенопирит

Ba-base metal mineralization in the nearby Kashana deposit (Trashliev, 1961). This is why we are to suggest that it is overimposed on Paleozoic mineralizations of Svishti Plaz.

Minerals

Arsenopyrite is the dominant ore mineral in the Svishti Plaz 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. All crystals represent platy or isometric shapes. 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. 3). Apart from flat face shaped crystals, with k 2 or 3, all higher k values are recorded as peaks in continuous goniometric reflexions 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). Almost always arsenopyrite is strongly fractured and late galena, tennantite, sphalerite, chalcopyrite and gold infill the fractures (Fig. 2b). Lamellar replacement of arsenopyrite by tennantite and sphalerite affects the zones of [010] faces.

Electron microprobe analyses of arsenopyrite show As-contents ranging from 29 to 32 at. %, S 33-38 at. % and Fe 32-34 at. %. The most informative As vs. S distribution of the analytical results is shown on (Fig. 4). The mean composition of the Svishti Plaz arsenopyrites is $FeAs_{0.93}S_{1.07}$. The mean As/S ratio is 0.87 – a value typical for the above described platy to platy-isometric shapes (Kerestedjian, 1997). This is also the composition range where rounded terminal faces are most common.

Special analytical conditions were tried in the EPMA laboratory of the Bristol University (EUGF project) to detect possible "invisible gold" in 10 samples of this arsenopyrite. The detection limit obtained was 37 ppm at 95% confidence level. The analyzed samples did not show any gold content within the mentioned detection limits.

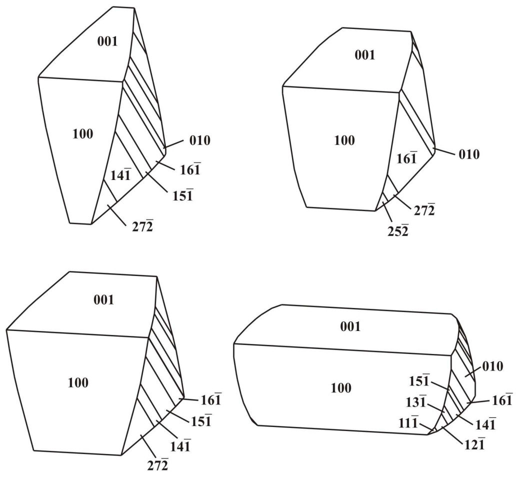


Fig. 3. Typical shapes of arsenopyrite crystals
Фиг. 3. Кристални форми на арсенопирит

Pyrrhotite is found as 5-10 μm roundish to oval inclusions in pyrite I. Partial to complete replacement of pyrrhotite by marcasite and/or pyrite is common.

Gold is the only economically important ore mineral in the Svishti Plaz deposit. It is recorded in almost all the investigated polished sections. On the basis of structural microscopic observations two distinct types of gold could be distinguished according to their deposition forms.

The *first* type 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 (Fig. 2a).

The *second* type of gold is bigger sized (up to 100 μm) and is deposited both in sulphides or gangue minerals (Fig. 2d and 2e).

Two possible genetic concepts, fitting this observation, emerge:

a. The gold is genetically correlated with arsenopyrite and pyrite I. It is primarily deposited

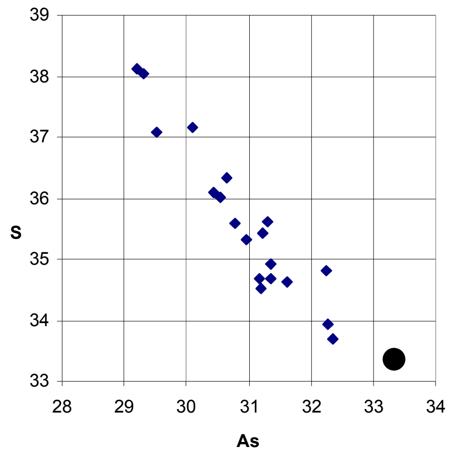


Fig. 4. Correlation between As and S (in at. %) in arsenopyrite. The solid circle represents the stoichiometric composition

Фиг. 4. Съотношение между съдържанията на As и S (в ат.%). Плътният кръг изобразява стехиометричния състав

as invisible gold in these minerals. During the next stage of sulphide deposition (stage 2), driven by induced heating, it is remobilized and redeposited in cracks, formed during the cataclastic events of this stage. Normally, the gold mobility was not high, that restricted its deposition only within the grains of its origin. Locally, where the gold enrichment in the surrounding fluid reached higher values, gold precipitated as larger grains in other sulphides or gangue minerals.

b. The gold is genetically connected to the base-metal stage (stage 2). The reason why it is found in arsenopyrite and pyrite preferably is their semiconductor features, causing gold precipitation through galvanic mechanism (Möller, Kersten, 1994). Thus, arsenopyrite and pyrite act as a geochemical barrier for the transportation of gold.

Of coarse, dual generation of gold, related to both stages 1 and 2 can not be excluded, and as a matter of fact, this is what we believe, but we can not provide unquestionable argumentation for a clear separation of two generations.

Both types of interpretation, as well as dual generation concepts are given for deposits in similar geological environments and similar mineralogical relations (Mumin et al., 1994; Oberthür et al., 2000; Touray et al., 1989; Boiron et al., 1989)

Along with the special EPMA investigation of arsenopyrite, aimed on the detection of invisible gold, AAS determination of gold in this and other sulphides have been performed. Unfortunately, the results ranging from none to 160 ppm were not genetically conclusive. As also noted by Todorov and Jankova (1989), this kind of investigation can not distinguish between invisible and microscopic gold in cracks and voids. Obtained values have completely casual character and depend entirely on the presence of gold containing microfractures. Therefore the obtained gold contents in different probes vary significantly.

Electron microprobe analyses revealed that the gold is always alloyed with silver (argentiferous gold to electrum in composition). Silver contents of gold grains range from 17.76 to 31.73 wt. % (Table 2). The gold grains are generally homogenous in respect to their silver content. Lower Ag contents prevail in large gold grains deposited in quartz.

Pyrite is deposited in several generations, differing in its morphology, chemistry and assemblages.

Pyrite I together with arsenopyrite is principal mineral in the deposit. Single crystals are rare. It is deposited always with arsenopyrite and the two minerals are intergrown, but pyrite is obviously earlier. It is cataclased and the cracks are filled with late minerals like galena, tennantite, gold, sphalerite (Fig. 2b).

Pyrite II is deposited in the second stage as small isometric inclusions in sphalerite (Fig. 2c).

Pyrite III is zonal, with solid central part and porous periphery, probably as a result of skeletal growth or replacement. This pyrite is

Table 2. *Chemical composition of gold*
Таблица 2. *Химичен състав на самородно злато*

Nr.	Sample	Mineral association	Elements, wt. %							Elements, at. %					
			Au	Ag	Cu	Fe	Te	As	Total	Au	Ag	Cu	Fe	Te	As
1.	tr. 7	sulphide veinlet in Py	66.84	31.43	0.71	0.55		0.22	99.75	51.86	44.49	1.70	1.49		0.45
2.	g.6/2	pure Au veinlet in Py	71.32	26.40	1.10	0.72			99.54	56.88	38.40	2.69	2.03		
3.	g.6/2	pure Au veinlet in Py	71.28	26.13	1.19	0.69			99.29	57.01	38.12	2.93	1.94		
4.	g.6/2	pure Au veinlet in Py	68.05	31.73	0.97				100.75	52.79	44.90	2.32			
5.	g.6/2	grain with Ga in Py	69.55	27.00	1.04	0.44	0.50	0.54	99.07	55.33	39.17	2.55	1.23	0.61	1.12
6.	g.6/2	grain with Ga in Py	65.54	33.69	0.99	0.51			100.73	49.73	46.62	2.32	1.35		
7.	g.6/2	grain with Ga in Py	69.50	27.79	1.10	1.08			99.47	54.56	39.79	2.66	2.98		
8.	g.6/5	in Q, embracing Aspy	80.66	17.92	0.48	0.17		0.94	100.17	68.42	27.72	1.26	0.50		2.10
9.	g.6/5	in Q, embracing Aspy	79.39	17.82	0.49	0.54	0.46	0.43	99.13	67.77	27.75	1.28	1.63	0.60	0.97
10.	g.6/5	in Q, embracing Aspy	76.87	21.33	0.63	0.55		0.51	99.89	63.53	32.16	1.62	1.59		1.10
11.	g.6/5	in Q, embracing Aspy	81.11	18.14	0.63	0.52	0.29		100.69	68.50	27.94	1.64	1.54	0.38	
12.	g.6/5	in Q, embracing Aspy	77.97	20.22	0.45	0.43	0.19		99.26	66.06	31.25	1.17	1.28	0.24	
13.	g.6/5	in Q, embracing Aspy	76.41	17.76	0.58	1.34	0.36	2.35	98.80	62.61	26.55	1.47	3.86	0.45	5.05

susceptible to atmospheric corrosion. Some parts of the crystals show strong tarnishing few days after polishing. Microprobe analyses of unaltered parts established high Co content up to 4.52 wt % (Table 3). It is likely that the cobalt enrichment is due to later fluids, affecting pyrite and replacing some parts of it. The replacement was facilitated by the porosity of pyrite III. The observations in back-scattered electrons and microprobe analyses reveal that pyrite III includes small needle-like crystals of Bi-containing sulphosalts. However, more precise determination of these phases is impossible because of their small sizes.

Marcasite occurs as separate crystals and aggregates or rarely intergrown with pyrite. It seems to be a primary constituent of the ores, unrelated to recent supergene alteration. Its presence most probably reflects local increase in sulphur and/or oxygen fugacity.

Sphalerite is deposited during the second stage of mineralization. It forms anhedral to subhedral grains intergrown with chalcopyrite, galena, late pyrite, gold or fills microfissures in earlier minerals (Fig. 2c and 2d). Rows of chalcopyrite and pyrite inclusions oriented along cleavage directions are abundantly found in most sphalerites (Fig. 2c). Most probably these inclusions reflect a process of decomposition of primarily iron-bearing

Table 3. *Chemical composition of Fe-S phases*
Таблица 3. *Химичен състав на Fe-S фази*

Nr	Sample	Mineral and association	Element, wt. %									
			Fe	Co	Ni	Cu	Zn	Ag	As	Sb	S	Total
1.	g.12/1	pyrrhotite – in pyrite	59.45	0.16	0.09	0.81		0.14	0.40		38.42	99.47
2.	g.12/1	pyrite I - arsenopyrite	46.01			0.98		0.30			52.06	99.35
3.	g.12/1	pyrite I- arsenopyrite	46.44			0.86			0.39		52.71	100.40
4.	g.7/1	pyrite I - arsenopyrite	46.21			1.14			0.44		52.01	99.80
5.	g.6/8	pyrite I - arsenopyrite	47.19			1.37	0.18		0.60		50.84	100.18
6.	g.6/8	pyrite I - arsenopyrite	47.55			0.61	0.11		0.28		51.33	99.88
7.	x3/3	pyrite I - arsenopyrite	47.10	0.19		0.65		0.21	0.71		51.38	100.24
8.	6/2	pyrite I close to gold	46.35			0.58			1.93		51.25	100.11
9.	6/2	pyrite I close to gold	45.83			0.64			2.47		50.74	99.68
10.	6/2	pyrite I close to gold	46.54			0.53			0.35		51.80	99.22
11.	6/2	pyrite I - far from Au	46.77			0.55					52.52	99.84
12.	g.6/5	pyrite I - arsenopyrite	46.42			0.41	0.30				52.44	99.57
13.	tr. 7	pyrite I - with Au veinlets	44.56			0.66	0.23		0.30		54.30	100.05
14.	g.6/8	pyrite II - inclusion in Sph	46.59		0.16	0.29	1.83				51.13	100.00
15.	g.6/8	pyrite II - inclusion in Sph	46.58		0.14	0.51	2.03		0.37		50.04	99.67
16.	g.6/8	pyrite II - inclusion in Sph	45.48	0.81		0.30	2.07	0.13	0.23		50.33	99.35
17.	g.5/5	pyrite III - Bi-sulfosalts	45.68			0.50					53.55	99.73
18.	g.5/5	pyrite III - Bi-sulfosalts	43.10	3.45	0.24	0.68			0.20		51.64	99.31
19.	g.5/5	pyrite III - Bi-sulfosalts	45.06	0.15	0.22	0.86					53.14	99.43
20.	g.5/5	pyrite III - Bi-sulfosalts	40.04	4.52		0.94		0.17			53.79	99.46
21.	g.5/5	pyrite III - Bi-sulfosalts	45.89	0.42		0.69					52.97	99.97
22.	8/15a	porous Py, porous periphery	46.56			0.73	0.17				52.19	99.65
23.	8/15a	porous Py, porous periphery	46.70			0.67		0.15			52.27	99.79
24.	8/15a	porous Py, solid centre	45.89			0.61				0.26	52.85	99.61

sphalerite, forming an aggregate of chalcopyrite, pyrite and low-Fe sphalerite. The rows of blebs and isometric crystals in sphalerite suggest disequilibrium distribution of Cu in Fe-rich sphalerite (Barton, Bethke, 1987). This sphalerite shows clearly expressed hardness anisotropy. Less frequently euhedral grains of magnetite and hematite are also found here.

Microprobe analyses revealed different Fe contents in the sphalerite free of chalcopyrite inclusions (0.40 wt. %) and the one containing blebs (2.82 wt. %) (Table 4). The absence of Cd is another peculiarity of the first one.

Galena is less abundant than sphalerite. It is represented by irregular grains or veinlets in quartz or fills fissures in pyrite I and arsenopyrite (Fig. 2d). Galena from the bismuthiferous association shows high concentrations of Bi and Ag (Table 5).

Tennantite is commonly deposited in association with chalcopyrite and galena. Occasionally it is found with sphalerite as grains and fissure fillings in quartz, pyrite I or arsenopyrite (Fig. 2b). Its chemical composition is shown in Table 6.

Bi-minerals. Based on microprobe data, several groups of bismuth minerals are distinguished: native Bi, bismuthiferous galena, Pb-Bi-, Cu-Pb-Bi-, Ag(Pb)-Bi and Ag-Cu-Pb-Bi- sulphosalts. They are undoubtedly later than the pyrite-arsenopyrite and base-metal assemblages. Detailed characteristic of the bismuthiferous association and Bi-minerals of the deposit is given by Mladenova et al. (2001).

Discussion and conclusions

The Svishti Plaz gold deposit shows lots of similarities to mesothermal gold deposits in shear zones in Archaean and Hercynian terrains. This especially concerns their connection to granodiorite magmatism, the mineral parageneses and the gold associations. Unfortunately, the insufficient knowledge of the Prealpine development of the Balkan zone prohibits an explicit attribution of the Svishti Plaz gold mineralization to this structural type.

Most of the worldwide lode gold mineralizations are established in Archaean terrains and were introduced during a period of multi-phase deformation, magmatism and metamorphism which marked the final stabilization of the Archaean crust in Superior Province of Canada, the Yilgarn Bloch of Western Australia and the Zimbabwe craton of southern Africa (Foster, 1990; Cassidy et al., 1998; Groves et al., 1998; Oberthür et al., 2000). Gold mineralizations are specifically related to a late brittle event superimposed on early ductile shearing (Robert, Brown, 1986; Mueller et al., 1988). The gold-bearing hydrothermal activity generally postdates peak metamorphism and at least one phase of granitoide magmatism (Marmont, Corfu,

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

			Element, wt. %					
Nr.	Sample	Mineral association	Zn	Fe	Cd	Cu	S	Total
1.	x2/10	galena, tennantite	67.16	0.41	0.46	0.21	32.26	100.50
2.	6/2	galena, pyrite II	67.96	0.99	0.57	0.27	29.44	99.23
3.	g.7/1	galena, tennantite	64.52	1.34	0.44	1.41	32.05	99.76
4.	g.7/1	inclusion in pyrite I	63.22	2.82	0.41	0.76	32.76	99.97
5.	g.7/1	galena, tennantite, pyrite II	66.54	0.63		0.89	32.24	100.3
6.	g.7/1	galena, tennantite, pyrite II	66.15	0.79		0.82	32.26	100.02
7.	g.7/1	galena, tennantite, pyrite II	65.65	1.23	0.34	0.93	31.93	100.08
8.	x3/3	galena, tennantite	66.37	0.89	0.41	0.77	31.32	99.76

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

Nr.	Sample	Mineral association	Element, wt. %						
			Pb	Cu	Ag	Bi	Te	S	Total
1.	g.7/1	sphalerite	83.61	0.40	1.22		0.45	13.92	99.60
2.	x2/10	sphalerite	87.18	0.18			0.18	13.36	100.90
3.	x2/10	sphalerite	85.48	0.38			0.20	12.90	98.96
4.	8/15a	tennantite, chalcopyrite	85.41	1.70				12.31	99.42
5.	x3/3	sphalerite, tennantite	86.94	0.86				12.50	100.30
6.	x3/3	sphalerite, tennantite	85.51	0.49	0.28			12.88	99.16
7.	g.7/1	Bi-minerals	80.12	0.68	1.11	4.72		13.13	99.67
8.	g.7/1	Bi-minerals	79.79	0.28	1.64	3.54	0.26	13.55	99.06
9.	g.7/1	Bi-minerals	78.80	1.25	1.86	2.88		14.71	99.50

1989). Similar complex tectonic events are recorded in Europe during the Hercynian orogenesis of northern and northwestern part of Massif Central, France (Bouchot et al., 1989; Touray et al., 1989).

The Prealpine basement of the Balkanide zone hosts the Svishti Plaz gold deposit. The structural characteristic of the ore is an evidence for tectonic control and tectonic activity during the ore deposition. All stages of ore deposition were accompanied by strong fracturing of already deposited minerals and subsequent precipitation of next portion.

A genetic connection with the Vejen Hercynian granitoide intrusion and related dykes is believed (Kujkin et al., 1972). The Hercynian granitoids in the Balkan Mountain are post-collision calc-alkaline magazines I-type. Their isotopic ratio Sr^{87}/Sr^{86} indicates that the magma was generated in the lower parts of the crust or in the mantle (Haydoutov, 1991)

The possible role of mantle-linked

Table 6. *Chemical composition of tennantite from Svishti Plaz deposit*
Таблица 6. *Химичен състав на тенантит от находище Свищи плаз*

Nr.	Sample	Mineral association	Element, wt. %								
			Cu	Ag	Fe	Zn	Sb	As	Bi	S	Total
1.	g.17/1	inclusion in sphalerite	46.88	0.54	2.33	6.47	0.89	13.36		29.31	99.78
2.	g.17/1	inclusion in sphalerite	47.64	0.23	1.98	7.34	0.98	13.40		29.28	100.85
3.	g.17/1	inclusion in sphalerite	45.32	1.47	2.44	6.55	1.12	13.45		29.21	99.56
4.	g.5/5	inclusion in pyrite	44.24	0.61	4.81	2.95	1.23	12.20	2.55	31.24	99.83
5.	g.8/2	chalcopyrite	43.83		4.43	3.32	4.07	16.89		27.25	99.79
6.	g.8/2	chalcopyrite	42.29		4.23	4.02	3.75	17.64		27.42	99.35
7.	g.8/2	veinlet in arsenopyrite	41.85		5.04	2.83	7.03	15.88		26.97	99.60
8.	g.8/2	veinlet in arsenopyrite	42.23	0.23	5.14	2.74	4.85	17.22		27.50	99.91
9.	8/15a	vein with Chpy in porous pyrite	43.74	0.41	4.15	3.23	4.74	17.10		26.10	99.47
10.	x3/3	embraces arsenopyrite	42.00	0.63	2.52	6.35	1.37	19.66		27.38	99.91
11.	x3/3	embraces arsenopyrite	43.63	0.77	2.19	6.11	1.29	19.08		26.57	99.94
12.	x3/3	sphalerite	41.55	0.28	4.29	5.15	1.23	20.10		26.84	99.75

processes is also assumed for a number of deposits in Archaean and younger terrains.

The mineral associations in the ores of Svishti Plaz 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 initially precipitated as invisible gold in arsenopyrite and pyrite. Most or all of it was later remobilized and reprecipitated with the sulphides from the second stage.

The complex bismuth mineralization, established only in the samples of one exploration mine working, significantly differs in mineralogical and chemical composition from those in main vein assemblages of the Svishti Plaz deposit. The absence of this mineralization in other mine workings suggests its connection to a different hydrothermal source. Based on spatial and geochemical proximity, we would cautiously suggest the Sredna Gora ore-forming solutions as possible such source. Probably some faults, hosting the Bi-mineralization in the Svishti Plaz deposit were open during the Late Cretaceous events, thus enabling the Sredna Gora ore-forming fluids to reach further away from the place of their origin. The superposition of Bi-mineralization on the earlier Svishti Plaz one, involving possible reheating and remobilization of ele-ments (Pb) already present in the earlier minerals, has resulted in the formation of the complex Cu-Pb-Ag-Bi assemblage (Mladenova et al., 2001). The abundant local occurrence of hematite 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.

Fluid inclusion study and sulphur isotope thermometry of the main pyrite-arsenopyrite and base metal stages in Svishti Plaz indicate a wide range of deposition temperatures, between 320 and 230°C (Bogdanov, Zairi, 1989).

Amov et al. (1981) date the granite in Teteven district at 255-245 Ma (U/Pb in zircon). Dating of the gold mineralization of the Svishti Plaz deposit is made in the same paper. The age of 270-285 Ma (Permian) based on Pb isotopes in galena is interpreted as a genetic relationship and a common endogene source of hydrothermal mineralization and granite magmatism in the region. A later article connects the mineralization of Svishti Plaz deposit with Late Cretaceous dyke magmatism without any data support (Cheshitev et al., 1995).

The new data established show that the Svishti Plaz deposit has still to be studied and modern paragenetic studies including quantitative data on all stages of mineralization, as well as comprehensive alterations study is worth. Precise geothermometric and isotopic data on distinct mineralizing events should give a whole picture of the mineralizing process.

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References

Amov, B., V. Arnaudov, M. Pavlova, P. Dragov, T. Baldjieva, S. Evstatieva. 1981. Lead isotope data on the Paleozoic granitoids and ore mineralizations from the Western Balkan Mountains and the Tran District (West Bulgaria). I. Isotopic ratios and geochronology. – *Geol. Balcanica*, **11**, 2, 3-26.

Baltov, I., L. Gizdov. 1977. Possibilities for noble metals recovery from the ore of Svishti Plaz deposit. – *Bull. NTI, Nipropuda*, **1**, 29-31 (in Bulgarian).

Barton, P. B., Jr., P.M. Bethke. 1987. Chalcopyrite disease in sphalerite: Pathology and epidemiology. - *Amer. Mineral.,* **72**, 451-467.

Bogdanov, K.B., N.M. Zairi. 1989. Mineralogical and sulphur isotope study of Svishti Plaz deposit, Balkan Mountains, Bulgaria. - *14th Congr. CBGA*, Sofia, Exten. abstr., 55-58.

Boiron, M-C., M. Chatelineau, J-J. Trescases. 1989. Conditions of gold-bearing arsenopyrite crystallization in the Villeranges Basin, Marche-

Combrailles shear zone, France: A mineralogical and fluid inclusion study. – *Econ. Geol*., **84**, 1340-1362.
Bouchot, V., Y. Gros, M. Bonnemaison. 1989. Structural controls on the auriferous shear zones of the Saint Yrieix District, Massif Central, France: Evidence from the Le Bourneix and Laurieras Gold deposit. - *Econ. Geol.,* **84**, 1315-1327.
Cassidy, K.F., D.I. Groves, N.J. McNaughton. 1998. Late-Archean granitoid-hosted lode-gold deposits, Yilgarn Craton, Western Australia: Deposit characteristic, crustal architecture and implications for ore genesis. - *Ore Geol. Rev.,* **13**, 65-102.
Cheshitev, G., V. Milanova, I. Sapunov, P. Tchoumatchenco. 1995. Explanatory note to the geological map of Bulgaria on scale 1:100000, Teteven map sheet, 94 p. (in Bulgarian).
Foster, R.P. 1990. Gold mineralization: Recent advances in predictive metallogeny. – *Terra Review*, 215-225.
Fuess., H, T. Kratz, J. Töpel-Schadt, G. Miehe, 1986. Crystal structure refinement and electron microscopy of arsenopyrite. - *Zeits. Krist.,* **179**, 347-356.
Groves, D.I., R.J. Goldfarb, M. Gebre-Mariam, S.G. Hagemann, F. Robert. 1998. Orogenic gold deposits, a proposed classification in the context of their crustal distribution and relationship to other gold deposit types. - *Ore Geol. Rev.,* **13**, 7-27.
Haydoutov, I. 1991. The Thracian Hercynian suture and the related magmatism. – *Geotect., Tectonophys., Geodynam.,* **23**, 3-25 (in Bulgarian).
Kerestedjian, T., 1997. Chemical and morphological features of arsenopyrite, concerning its use as a geothermometer. - *Mineral. Petrol.,* **60**, 231-243.
Kujkin, S.S., L.B. Milanov. 1970. Über dem Geologischenbau von einem Teil der Zlatishka Stara Planina. - *Rev. Bulg. Geol. Soc.,* **31**, 1, 120-126 (in Bulgarian).
Kujkin, S., M. Stajkova, S. Hristov. 1972. Über die Gold-Sulfid Vererzungen in Zlatica-Balkan. - *Bull. Geol. Inst.,* Ser. Mineral. Deposits, **21**, 55-68 (in Bulgarian).
Marmont, S., F. Corfu. 1989. Timing of gold introduction in the late Archaean tectonic framework of the Canadian Shield: Evidence from U-Pb Zircon Geochronology of the Abitibi Subprovince. - *Econ. Geol. Monogr.,* **6**, 101-111.
Mileva, G., K. Mileva. 1977. Paragenetical mineral association in gold ores of Svishti Plaz deposit in conection of their processing. - *Rudodobiv,* **1**, 5-8 (in Bulgarian).
Mladenova, V., T. Kerestedjian, D. Dimitrova. 2001. Ag-Cu-Pb-Bi mineralization from the Svishti Plaz gold deposit, Central Balkan Mountain, Bulgaria. – *Geochem. Mineral. Petrol.,* **38**, 55-66.
Möller, P., G. Kersten. 1994. Electrochemical accumulation of visible gold on pyrite and arsenopyrite surfaces. – *Mineral. Deposita*, **29**, 404-413.
Morimoto, N., L.A. Clark, 1961. Arsenopyrite crystal-chemical relations. - *Amer. Mineral.,* **46**, 1448-1469.
Mueller, A.G., L.B. Harris, A. Lungan. 1988. Structural control of greenstone-hosted gold mineralization by transcurrent shearing: A new interpretation of the Kalgoorlie Mining District, Western Australia. - *Ore Geol. Rev.,* **3**, 359-387.
Mumin, A.H., M.E. Fleet, S.L. Chryssoulis. 1994. Gold mineralization in As-rich mesothermal gold ores of the Bogosu-Prestea mining district of the Ashanti Gold Belt, Ghana: Remobilization of “invisible” gold. – *Mineral. Deposita*, **29**, 445-460.
Oberthür, T., T.G. Blenkinsop, U.F. Hein, M. Höppner, A. Höhndorf, T.W. Weiser. 2000. Gold mineralization in the Mazowe area, Harare-Bindura-Shamva greenstone belt, Zimbabwe: II. Genetic relationships deduced from mineralogical, fluid inclusion and stable isotope studies, and the Sm-Nd isotopic composition of scheelites. – *Mineral. Deposita,* **35**, 138-156.
Robert, F., A.C. Brown. 1986. Archean gold-bearing quartz veins at the Sigma mine, Abitibi greenstone belt, Quebec: Part I. Geologic relations and formation of the vein system. - *Econ. Geol.,* **81**, 578-592.
Touray, J.-C., E. Marcoux, P. Hubert, D. Proust. 1989. Hydrothermal processes and ore-forming fluids in the Le Bourneix gold deposit, Central France. – *Econ. Geol.,* **84**, 1328-1339.
Todorov, T., R. Jankova. 1989. Gold in the main minerals in mineralizations of different type in the West Balkanides. – In: *Geology and Ore Deposits of North-West Bulgaria.* Sofia, Technika, 153-172 (in Bulgarian).
Trashliev, S. 1961. On the genesis and age of the Kashana barite deposit, Pirdop region. - *Rev. Bulg. Geol. Soc*. **22,** 3, 245-252 (in Bulgarian).

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