Concentration of Gold From Small Deposits in Serbia

Rudolf TOMANEC[1], Marina BLAGOJEV[2]

[1] University of Belgrade, Faculty of Mining and Geology, Department of Mineral Processing; email: tomanec@rgf.bg.ac.rs
[2] University of Belgrade, Faculty of Mining and Geology, Department of Mineral Processing; email: marina.blagojev@rgf.rs

Abstract

Tests presented in this work are conducted on samples of the Pb-Zn-Fe-Au poor mineralization from the Grabova Reka deposit, Ist Serbia. The methods are described of selective separation of auriferous minerals and accessory sulphides from complex quartz veins, small gold deposits, in Blagojev Kamen area (Grabova Reka deposit) characterized by nonunion and relatively poor gold mineralization (Au, Au+Ag, electrum, Au+Fe, Au+Pb, Au+scheelite). Gold prevailing occurs in small grains (5÷10 rarely 100 μm) contained in quartz, pyrite or in galena of pinkish shade from alloying with Bi and Cu. Electrum, a natural alloy of Au and Ag varies in grain size, but generally, electrum is found in large grains (0.5 mm on average) in the form of conglomerate where electrum is cementing cataclastic grains of pyrite (or as inclusions in pyrite and in galena) and other Pb-Zn sulphides. There are many deposits, in the mentioned region, with numerous outcrops of quartz veins with the gold rates from 10 g/t to 60 g/t or even to 120 g/t on average, somewhat lower silver, and some lead and zinc (about 1%). The analysed sample was collected by chipping in places of visible sulphide mineralization from quartz vein No. 2 in plagiogranite. The purpose of this work was to accurately establish the modes of gold or auriferous mineral occurrence, for testing its selective separation. A flow-chart is given of the mineral recovery process and the mineral balance. A characterization is given of the mineralized grains in raw material which are essential for planning the technology of processing. One of the methods used, is the heavy liquid separation analysis at the density of 13.6 g/cm² .

Keywords: gold, mineral characterization, selective separation, concentration techniques

Introduction

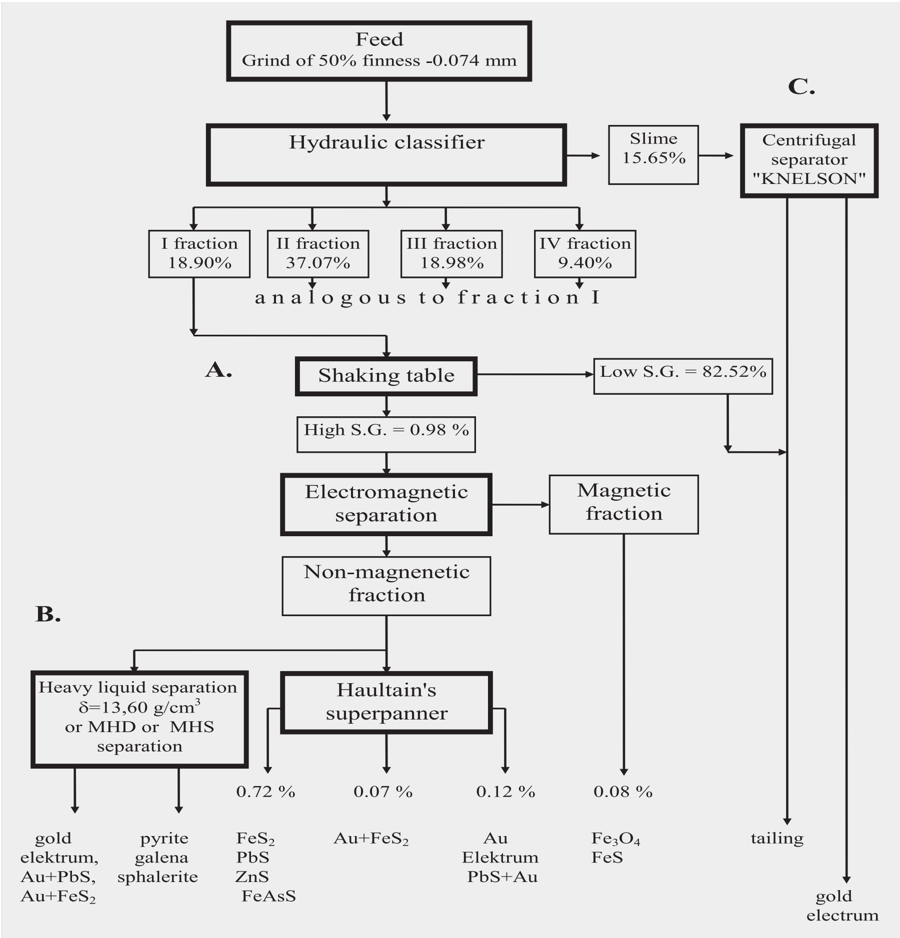
The constant depletion of cooper ore reserves and the ever lower gold concentration in ores of Bor, Majdanpek, and Veliki Krivelj (where gold production per year could be compared with the total annual recovery at Blagojev Kamen) were some of the reasons for turning to "small" gold deposits.

This part of Serbia, the Pek catchment area, is known for the numerosity of deposits and occurrences of gold mineralization (Au, Au+Ag, Au+scheelite). In a zone extending from the Danube to Debeli Lug (at Majdanpek), over 150 km in surface area, two ore fields are located: Brodica Field with the deposits Velika Albena, Keja Selsi, Ogasu Tomin, and Cubera, and Blagojev Kamen Field with the deposits Badalan, Ogasu Stanki, Zeleznik, Bosiljkovac, Sveta Barbara,and Grabova Reka. An interest in mining and processing ore from Grabova Reka deposit was provoked by the geological investigation results which confirmed the presence on many quartz vein outcrops with the average gold concentrations between 10 g/t or even 120 g/t. It has been noted with interest, and much studied lately, that plagiogranite intrusions in this area bear significant concentrations of noble metals for a massive recovery.

History of investigation

Many small deposits and numerous gold mineralization occurrences of economic value in a relatively large area, with variable concentrations of gold and associated elements, have been certainly a limiting factor through a long period of production, particularly intensive in this century. Here is a brief historical review of the recent explorations and mining of gold in the study area.

Gold production in this region dates back to the ancient Romans who panned placer material in the Pek valley and thus left traces in heaps of washed gravel, and in a numerosity of shallow (to 30 m) mine workings. Written records on gold panning in the Pek originate from Baron Herder who came in Serbia, invited by duke Milos Obrenovic, in 1835. Felix Hofman, a pioneer of Serbian mining, was first who explored and collected samples for the Paris International Exhibition in 1888. However, mining was undertaken only in 1902 by a British joint-stock company. It is believed that during fifteen years to 1918, employing one and later four dredges, the gold production amounted to about 3000 kg. In 1933, the Pek allusion was taken on lease by the King Aleksandar Karadjordjevic, until the World War II. Exploration was resumed in 1948, but dredges finally stopped excavating in 1952. Gold-bearing quartz veins in the Pek valley near Blagojev Kamen had a similar fate. According to records, the mining concession, for Sveta Barbara locality, was issued to Djordje Weifert and Felix Hoffman. Mean gold concentration was then 36.3 g/t. In 1927 and in 1929 the concession



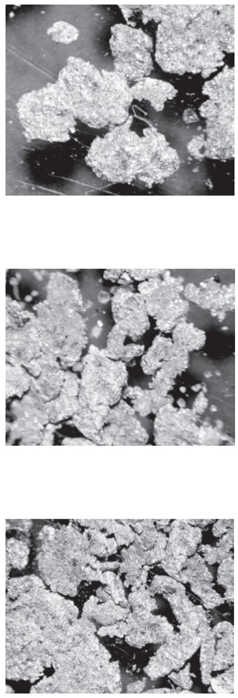


Fig. 1. Flow chart of selective mineral separation testing.
A. Shaking table as a preconcentrator. B. Option: Heavy liquids separation on 13.6 g/cm³ or magnetohydrostatic, magnetohydrodynamic separation. C. Option: For small gold particles centrifugal separator Knelson, or Humphrey's spiral concentrator

Rys. 1. Schemat testów separacji selektywnej
A. Stół koncentracyjny jako faza wstępna. B. Opcja: Rozdział w cieczy ciężkiej przy gęstości 13.6 g/cm³ lub separacja magnetohydrodynamiczna. C. Dla małych ziaren złota wirówka Knelson lub wzbogacalnik spiralny Humphreya

was given to a French stock corporation. About that time, an amalgamation plant was erected, and another, cyanidization unit built before 1937. The mines Debeli Lug, Todorova Reka, and Grabova Reka were worked simultaneously with Blagojev Kamen. Quartz vein No. 1 (Grabova Reka deposit), mined after the Second World War, and had a mean gold content of 14.25 g /t.

The deposit of Grabova Reka was most attractive in the period 1962–63, but mining was soon (in late 1964) discontinued. Explorations were resumed in 1978, and mining works reopened in Grabova Reka deposit. Quartz vein No. 2, from which a sample was taken for examination reported in this paper, was uncovered south of vein No. 1. Average gold and silver concentrations in it are 22 g/t and 18.5 g/t (besides 1% of lead and zinc).

Sample and and methods

The auriferous quartz vein No. 2 was sampled from furrows at levels 439 and 416 of the Grabova Reka deposit. The total sampling length was 60 metres. The representative composite sample from ore vein No. 2 had the following composition: SiO_2 = 77.98%, Al_2O_3 = 1.98%, CaO = 4.94%, MgO = 1.26%, K_2O = 0.254%, Na_2O = 0.22%, Fe = 3.60%, Cu = 0.58%, Zn = 0.76%, Pb = 1.25%, S = 1.98%, Cd = 0.09%, As = 0.10%, Au = 29.18 g/t, Ag = 25.30 g/t, etc. Mineral composition of the ore is complex, as showed by ore microscopy and analysis of concentration products (Bugarin, 1994; Tomanec, 1995).

Pyrite is the most significant and the highest contained mineral; it also proved to be one of main noble metal bearers in the ore. Pyrite itself is cataclasitc, its fractures filled with sulphides and

Tab. 1. Gold mineral selective recovery balance (in granodiorite)

Tab. 1. Bilans uzysku selektywnego złota (w granodiorycie)

Size fraction	Weight, %	Shaking table, fraction rate (%)	El.magnetic sep. fraction rate (%)	Haultain's table fraction rate (%)
				High S.G. fraction = 0.05
				Middling = 0.03
				Tailing = 0.32
			N.M.F. = 0.40	Feed = 0.40
			M.F. = 0.02	
		High S.G. = 0.42	Feed = 0.42	
		Middling = 0.19		
		Low S.G. = 18.29		
I	18.90	Feed = 18.90		
				High S.G. fraction = 0.06
				Middling = 0.04
				Tailing = 0.27
			N.M.F. = 0.37	Feed = 0.37
			M.F. = 0.03	
		High S.G. = 0.40	Feed = 0.40	
		Middling = 0.16		
		Low S.G. = 36.51		
II	37.07	Feed = 37.07		
				High S.G. fraction = 0.004
				Middling = 0.00
				Tailing = 0.046
			N.M.F. = 0.05	Feed = 0.050
			M.F. = 0.02	
		High S.G. = 0.07	Feed = 0.07	
		Middling = 0.25		
		Low S.G. = 18.66		
III	18.98	Feed = 18.98		
				High S.G. fraction = 0.002
				Middling = 0.00
				Tailing = 0.078
			N.M.F. = 0.08	Feed = 0.080
			M.F. = 0.01	
		High S.G. = 0.09	Feed = 0.09	
		Middling = 0.25		
		Low S.G. = 9.06		
IV	9.40	Feed = 9.40		
Slime	15.65	15.65		
Feed	100.00			

quartz of the younger generation. Fine cracks in pyrite grains of concentration products are filled with gold and electrum which replace it and eventually substitute it in most of pyrite, whilst cataclastic pyrite occurs only in relics (Tomanec et al., 1995a).

Chalcopyrite frequently occurs in the examined mineral in the form of pyrite inclusions intergrown with pyrrhotite, or in single grains, rarely in aggregates, but most often in grains and rods oriented in sphalerite as a result of exsolution. It is extremely rarely intergrown with gold or electrum.

Sphalerite is a mineral of wide distribution, but of variable or relatively low concentration. It is found in nests or irregular lenticular aggregates which may be small to rarely cm-size, it occurs in greenish yellow-greenish variety. Much of the mineral is found in direct contact with gold minerals, where together with galena it is cementing cataclastic pyrite, giving an impression of brecciated aggregates.

Galena is also one of essential constituents in the examined ore samples. It bears noble metals in the form of electrum and gold minerals as principal components. Galena is cementing cataclastic pyrite in which case it contains the highest amounts of noble metals which remained preserved from the younger silification.

Gold prevailing occurs in small grains (5–10–100 mm) contained in quartz, pyrite or in galena of pinkish shade from alloying with Bi and Cu; it also may be in middling particles of hundreds of micrometers.

Electrum is certainly the most important constituent of ore in this locality. This natural alloy of Au and Ag varies in grain size, but generally, electrum is found in large grains (0.5 mm on average) in the form of conglomerate where electrum is cementing cataclastic grains of pyrite and other

Tab. 2. Gold mineral selective recovery balance (in granodiorite) [* Humphreys spiral concentrator]

Tab. 2. Bilans uzysku selektywnego złota (w granodiorycie) [* wzbogacalnik spiralny Humphreya]

Size fraction (mm)	W_t of size fraction (%)	Shaking table (fraction rate)	**W_t (%)**	**Ag (g/t)**	$\Sigma W_t \cdot Ag$	Recovery of Ag (%)	**Au (g/t)**	$\Sigma W_t \cdot Au$	Recovery of Au (%)
I	18,90	Concentrate	0,42	106,70	44,810	49,4935	49,90	20,958	18,72
		Middling	0,19	0,05	0,009	0,0099	82,60	15,694	14,02
		Tailing	18,29	0,05	0,914	1,0095	0,05	0,914	0,82
		Size fraction	18,90	2,42	45,738	50,52	1,99	37,566	33,55
II	37,07	Concentrate	0,40	30,00	12,00	13,2542	70,00	28,00	25,00
		Middling	0,16	33,00	5,28	5,8318	0,05	0,008	0,01
		Tailing	36,51	0,05	1,8255	2,0163	0,05	1,825	1,63
		Size fraction	37,07	0,52	19,1055	21,1024	0,80	29,833	26,64
III	18,98	Concentrate	0,07	34,40	2,408	2,6596	63,90	4,473	3,99
		Middling	0,25	0,05	0,0125	0,0138	0,05	0,012	0,01
		Tailing	18,66	0,05	0,933	1,0305	0,05	0,933	0,83
		Size fraction	18,98	0,18	3,3535	3,7040	0,29	5,418	4,84
IV	9,40	Concentrate	0,09	0,05	0,0045	0,0049	52,40	4,716	4,21
		Middling	0,25	72,00	18,00	19,8814	0,05	0,012	0,01
		Tailing	9,06	0,05	0,453	0,50034	0,05	0,453	0,40
		Size fraction	9,40	1,96	18,4575	20,3867	0,55	5,181	4,63
V	15,65	Middling *	2,00	1,60	3,20	3,5344	14,60	29,20	26,08
		-	-	-	-	-	-	-	-
		Tailing *	13,65	0,05	0,6825	0,7538	0,35	4,777	4,27
		Size fraction	**15,65**	0,24	3,8825	4,2884	2,17	33,977	30,34
Feed	**100,00**	**-**	**-**	**0,91**	**90,537**	**100,00**	**1,12**	**111,975**	**100,00**

Pb-Zn sulphides. It is rarely contained in quartz, often as inclusions in pyrite, and always in galena or concentrated in galena and pyrite contacts. Magnetite occurs in small grains without any sign of oxidation Tomanec et al., 1995b.

Quartz is one of dominant ore constituents. Two generations are distinguished: the older one milky white in colour, extremely cataclastic, with cracks filled with pyrite and subordinately other sulphides, and the younger quartz deposited after the sulphide minerals, dark gray in colour (quite likely pigmented by relics of replaced sulphides). Other identified minerals had not any appreciable influence in the process of noble metal concentration. These were limonite, hydrohematite, pyrrhotite, arsenopyrite, calcite, etc.

The milling properties of ore were determined in laboratory-scale ball mill type Denver, volume 15.2 litres. A sample mass of one kilogram, upper grain size limit 2.362 mm, was ground in intervals of 10, 15, 20 and 30 minutes. Grind fineness of 50% of -0.074+0 mm was selected for further testing.

After adequate treatment of the sample, grinding to the fineness allowing ore to open and liberate gold mineral and its bearers (taking care that over grinding should not occur), liberated mineral was concentrated and individual fractions separated through various techniques (Fig. 1).

Results and discussion

One of the purposes of the narrow grind classification in a hydraulic classifier (Fahrenwaldt) was the removal of the finest size fraction (slime) with mineral clays and kaolin to obtain a narrow size class range for treatment on the shaking table. The four separated size fractions were passed on the shaking table to separate the heavy fraction as the bearer of gold mineral and light fractions with gangue.

Slime was not treated in the same way. An analysis of the obtained results (in total balance) has shown that heavy minerals were contained in the ore by 5.10%, light minerals by 51.50%, and slime amounted to 43.40% (Table 1). In the microscopic analysis of the heavy fraction, pyrite was identified in the rate of 90%, and galena, magnetite, gold (in all forms) in the order of 1.5%, 1% and 0.5%, respectively. It was also identified that quartz constituted 96% of the light fraction. Slime in the hydraulic classifier contained amounts of clay, kaolin, and other alteration minerals which filled the microfissures.

Tab. 3. Gold mineral selective recovery balance (in granodiorite)

Tab. 3. Bilans uzysku selektywnego złota (w granodiorycie)

Products	W_t (%)	**Ag (g/t)**	$\Sigma W_t \cdot Ag$	Recovery of Ag (%)	**Au (g/t)**	$\Sigma W_t \cdot Au$	Recovery of Au (%)
Concentrate	3,83	22,38	85,725	94,68	26,91	103,073	92,05
Tailing	96,17	0,05	4,809	5,32	0,09	8,902	7,95
Feed	**100,00**	**0,91**	**90,534**	**100,00**	**1,12**	**111,975**	**100,00**

The smallest grains of gold, pyrite and galena passed in a significant percent into the product. For recovery of these products - monomineral fractions, concentration in centrifugal separator will be used in Knelson type separator, which is very effective in gold recovery from this kind of feed material.

As we can see from the results of selective separation of minerals given in the table 2, content of gold in heavy fraction ranges from 14.60 g/t to 70.00 g/t, in the some quantity as in the slime, which is separated in the second size fraction. Though considering utilization of gold determined by chemical analysis and represented by the total balance of metal, gold content is the most commonly occurring in the corse size fractions.

An analysis of the obtained results (in total balance) has shown that heavy fraction minerals were contained in the ore by 3.81% (with the concentration Ag = 22.38 g/t and Au = 26.91 g/t), light fraction minerals by 96.17% and slime amounted of 15.65% (table 3).

In this product as a significant percentage we can find it in the fine particles of the gold, pyrite, magnetite, sphalerite, galena etc. Extracting these minerals of heavy fraction was done by the using Humphrey's spiral concentration. Using Humphrey's spirals as adequate substitutes for separator classifier "KNELSON" gives quite satisfactory results for this feedstock and well exploited heavy metals.

Conclusion

Analysis of the concentration product - heavy fraction, from which magnetic minerals and associated single sulphide mineral grains were separated, revealed the modes of gold and electrum occurrence: as single grains, or locked (intergrowth) with pyrite when the latter is cataclastic and gold – or electrum – cemented. Also contained was a significant amount of gold in galena, in relatively simpler forms of intergrowth that allows separation along the contact faces. The physical properties of the two minerals will permit their separation in the technological process (Tomanec et al., 1997).

The fractions of coarse galena interlocking ore minerals, pyrite bearing the same minerals (gold, electrum), and partly single fine grains of gold and electrum, separated from the heavy fraction (where from magnetite was separated) on Haultain table, are contained by 0.21% and 0.19%, respectively.

Ore from auriferous quartz veins of the Grabova Reka deposit is characterized by a high rate of clay minerals which are filling fissured and cracks. This grain size class, slime, is not considered in this paper, but it should be remembered in future investigations, because, besides clays, it contains: gold, electrum, pyrite, galena, sphalerite (all sulphides bear some gold), and its concentration in Knelson type centrifugal separator is recommended. The Humphrey's spiral concentrator gave quite satisfactory concentration results.

In this deposits, previously exploited quartz vein number 1 had a lower content of gold of 14.25 g/t; quartz vein number 2 (south of vein 1) had an average gold content of 22 g/t and silver of 18.5 g/t, and the content of lead and zinc just over 1%. Test of selective separation of auriferous minerals (Tomanec et al., 1995), on samples from quartz vein number 2 (level 439 and 416) had a 29.19 g/t of gold and 25.30 g/t of silver.

Literatura – References

1. BUGARIN, M. *Genesis of the Blagojev Kamen gold deposit.* Ph.D thesis, Faculty of Mining and Geology, Belgrade, 1994.
2. TOMANEC, R. et al., *Testing selective recovery of auriferous minerals from Grabova Reka deposit - Proceeding of the XV Yugoslav mineral processing symposium*, Smederevo, 1995: 197–204.
3. TOMANEC R. LAZIĆ P. *Particle characterization and selective separation process of complex auriferous minerals - Proceedings of the 6th International Mineral Processing Symposium,* Kusadasi, Turkey, 1996: 533–538.
4. TOMANEC R. et al. *Gold recovery from plagiogranites of the Grabova Reka evaluation. - Proceeding of the International Symposium Ore Deposits Exploration*, Faculty of Mining and Geology University of Belgrade 1997: 165–172.
5. TOMANEC R. *Laboratory Methods of raw materials investigation in mineral processing.* Faculty of Mining and Geology University of Belgrade, Belgrade, 2000.

Koncentracja złota z małych złóż w Serbii

Zaprezentowane testy w pracy zostały przeprowadzone na próbkach Pb-Zn-Fe-Au ze złoża Grabova Reka w Serbii. Metody separacji selektywnej złotonośnych minerałów oraz siarczków ze złożonych żył kwarcu zostały opisane. Małe złoża złota w rejonie Blagojev Kamen (złoże Grabova Reka) charakteryzują się relatywnie słabą i rozproszoną mineralizacją (Au, Au+Ag, elektrum, Au+Fe, Au+Pb, Au+szelit). Złoto występuje w małych ziarnach (5-10, rzadko 100 μm) zawartych w kwarcu, pirycie lub galenie o różowawym zabarwieniu ze stopów z Bi oraz Cu. Elektrum, naturalny stop Au i Ag jest zróżnicowane pod względem uziarnienia, ale zazwyczaj spotyka się je w dużych ziarnach (średnio 0.5 mm) w formie konglomeratu, gdzie elektrum zespala kataklastyczne ziarna pirytu (lub występuje jako wtrącenie w pirycie oraz w galenie) lub innych siarczków Pb-Zn. W omawianym regionie znajduje się wiele złóż, z wieloma żyłami kwarcu o średniej zawartości złota od 10 g/t do 60 g/t lub nawet 120 g/t. Ponadto zawierają one nieco mniej srebra oraz nieco cynku i ołowiu (ok. 1%). Analizowana próbka została pobrana za pomocą strugania w miejscach o widocznej mineralizacji siarczkowej w żyłach kwarcu w plagiogranicie. Celem tej pracy jest prawidłowe ustalenie występowania złota lub minerałów złotonośnych aby przetestować ich selektywną separację. Przedstawiono schemat technologiczny procesu przeróbki oraz bilans minerałów. Charakterystyka ziaren mineralnych w surowcu mineralnym została podana co jest bardzo istotne przy planowaniu technologii przeróbki. Jedną z zastosowanych metod jest rozdział w cieczach ciężkich przy gęstości 13.6 g/cm^3.

Słowa klucze: złoto, charakterystyka minerałów, separacja selektywna, techniki zagęszczania