

The Material Composition and Technological Characteristics of Ores in Chovdar Gold-Ore Deposit (Lesser Caucasus)

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The material composition and technological peculiarities of the new morphogenetic type of gold ore mineral raw materials of one of the prospective gold ore deposits of Azerbaijan have been studied in detail by the example of seven laboratory technological samples.

Two natural types of ores have been established in Chovdar gold ore deposit: oxidized and primary sulphide that are delimited by the mixed semi-oxidized ores and have been provided for development together with oxidized ores in the future. Laboratory technological samples have been taken from core material representing different areas and types of deposit's ores. Composite samples of Chovdar (with 700 kg weight) are mixture of deposit's ores taken from various points and the occurrence depths of deposit. Other six compositions of Composite A (C1, C2, C3) and Composite B (C4, C5, C6) of the core samples, with 150 kg weight of each samples, were intended to investigation of the technological features of this mineral raw materials and development of rational technological scheme of its processing. The chemical composition of ores and their total mineral composition including sulfur-containing mineral forms, mineral forms of copper, forms of separations and associations of the main ore minerals, forms of separations and associations of the precious metals have been investigated. The mineral composition of the samples' material has been studied by the QEMSCANTM operating system allowing determining their chemical composition and grain sizes along with quantitative assessment of the revealed mineral forms.

The gold is characterized by native state with a relatively small grain size, the principal amount of which (more than 80%) is closely associated with the non-metallic minerals in the oxidized ores (Composite A). Seven grains of the native gold, six of which with size - 2-8 μm , one relatively large - 30 μm have been revealed in water separation products of the heavy fraction. High-grade gold is 86.6-100.0% (average 96.7%). A significant part of the discovered grains of the silver minerals (they are 16 in all, their average size - 5 μm) includes in barite and is characterized as Ag-Cu alloy, native form, copper-containing minerals of silver sulfide – jalpaite Ag_3CuS_2 and shtromeyerite AgCuS . Nearly all these compounds as well as gold grains are closely associated and are partially covered by iron oxides.

Gold in the primary sulphide ores (Composite B) is also characterized mostly by small native grains, half of them (53%) is closely associated with sulphides of iron and copper, and the rest - with light non-metallic minerals. There have been found 21 grains of gold, one of them being relatively large (61 μm) has been presented in free state, three grains have been confined and the other 17 as small inclusions (1-8 μm) have been included in pyrite and copper sulfides (chalcopyrite, chalcocite, covellite) in the gravitational concentrated product (gold "head"/gold gravity concentrate) of this sample. The native gold in the primary ores is characterized by lower quality (average Au - 91,8%) than in the sample of the oxidized ores.

Low-sulfide quartz gold-containing ores are characterized with minimum amount of harmful impurities (As, Sb, F, Cl and Hg, C_{org} – it has been carried out by special analysis for organic carbon) at relatively high content of iron oxides.

The revealed gold speciation in primary ores suggest that the most complete extraction of this metal can be provided due to the effective recovery of iron and copper sulfides from this type of ore. The last one may be carried out by flotation method.

Key words: Chovdar deposit, gold, material composition, mineral raw material, technological sample, oxidized ore, primary sulphide ore, mineral form.

INTRODUCTION

Chovdar ore field with an area of about 350-400 km² is situated in the north-east and north flanks of the Dashkesan ore region. It is known the large Chovdar gold-sulphide deposit discovered relatively recently in the ore field where gold-contained secondary quartzites with area type of development especially “Central” area with near-surface occurrence of ore body providing its open development, hydrothermal-changed gold-bearing zones with vein and lenticular bodies, Danayerichay-Gartal Mountain – Pirinyal upstanding block with massive vein-disseminated ores of pyrite-chalcopyrite-galenite-sphalerite composition containing the precious metal within 0.2-6.0 ppm and et al. according to preliminary data are commercial. The abandoned Chovdar barite deposit is located within the ore field.

Chovdar gold-ore deposit area is composed of Upper Bajocian-Bathonian formations of Middle Jurassic which are crumpled into small isoclinal folds of the high-orders oriented in submeridional direction. The brachsynclinal and brachyantoclinal structures especially Chovdar volcanogenic brachyantoclinal have been revealed as well.

The dislocations with a break in continuity have a main role in the distribution of the deposit ore bodies. The main submeridional ore-controlling faults are located in the reduced zone with 2-3 km width and they are accompanied by a number of the parallel small disturbances and often healed with quartz, barite, quartz-calcite mineralization. The repeated tectonic activation of the area resulted in renewal of the ancient fractures and the formation of new ones predominantly north-easterly direction that provided rocks blocks movement. Therefore it has been revealed three major blocks (Shadakh-Chovdar-Chaykend, Danayerichay-Gartal Mountain-Pirinyal, Kyzylja-Laish) in the territory within which the fragments of the volcanic-tectonic structures, the areas of the consedimentary downwarping and etc. are preserved.

The material composition of the natural ores varieties of Chovdar gold ore deposit has been detail analyzed according to the results of the chemical analytical, mineralogical and other multi-method investigations of this work. The above-mentioned studies have mainly been carried out by SGS Mineral Services UK LTD (Ontario, Canada).

Two natural ores types: oxidized and primary sulphide are differentiated by complex semi-oxidized (transition zone) ores have been determined in Chovdar gold-ore deposit (Fig. 1). The investigations considered in this work have been carried out on seven technological laboratory samples taken from core material representing different areas and ores types of deposit [6, 7].

One of the samples - Chovdar Composite (with 700 kg weight) was ores mixture of deposit sampled evenly from various points and depths of the ore body occurrence (180 ordinary core samples taken from 69 drill holes) over the whole mineralized zones. The sample was intended for estimation of the crushability and grindability of the mineral raw materials. It was characterized the deposit in whole taking into consideration the ores proportionality according to lithology, texture, metasomatism and mineralization type in the ore field. The places and intervals of the material sampling (Chovdar Composite) from the core of the appropriate drill holes have been presented in Table 1 and Figure 2.

Other six compositions of the core samples, each weighing 150 kg, were intended for the technological features investigations of this mineral raw materials and development of the rational technological scheme of its processing. Moreover three samples (C1, C2, C3)

characterized the ores of the oxidation zone of the deposit in various parts and the depths of the ore body occurrence taking into account the ratios of gold and copper contents in them. Another three samples (C4, C5, C6) characterized the zone of primary sulphide ores of the deposit. They were also taken from different parts and the depths of the ore body occurrence taking into account the ratios of gold and copper contents in them. The places and intervals of the core material sampling of six technological samples taken from 234 points (intervals) of 44 drill holes have been presented in Table 2 and Figure 3.

Moreover the compositions in equal proportions: separately oxidized - Composite A (C1+C2 + C3) and primary (sulphide) - Composite B (C4+C5+C6) ores were composed of the above-mentioned six technological samples whereon state and occurrence forms of Au and Ag were studied in detail [7].

All above-mentioned samples were subjected to chemical and mineralogical analyses. These investigations results are as below.

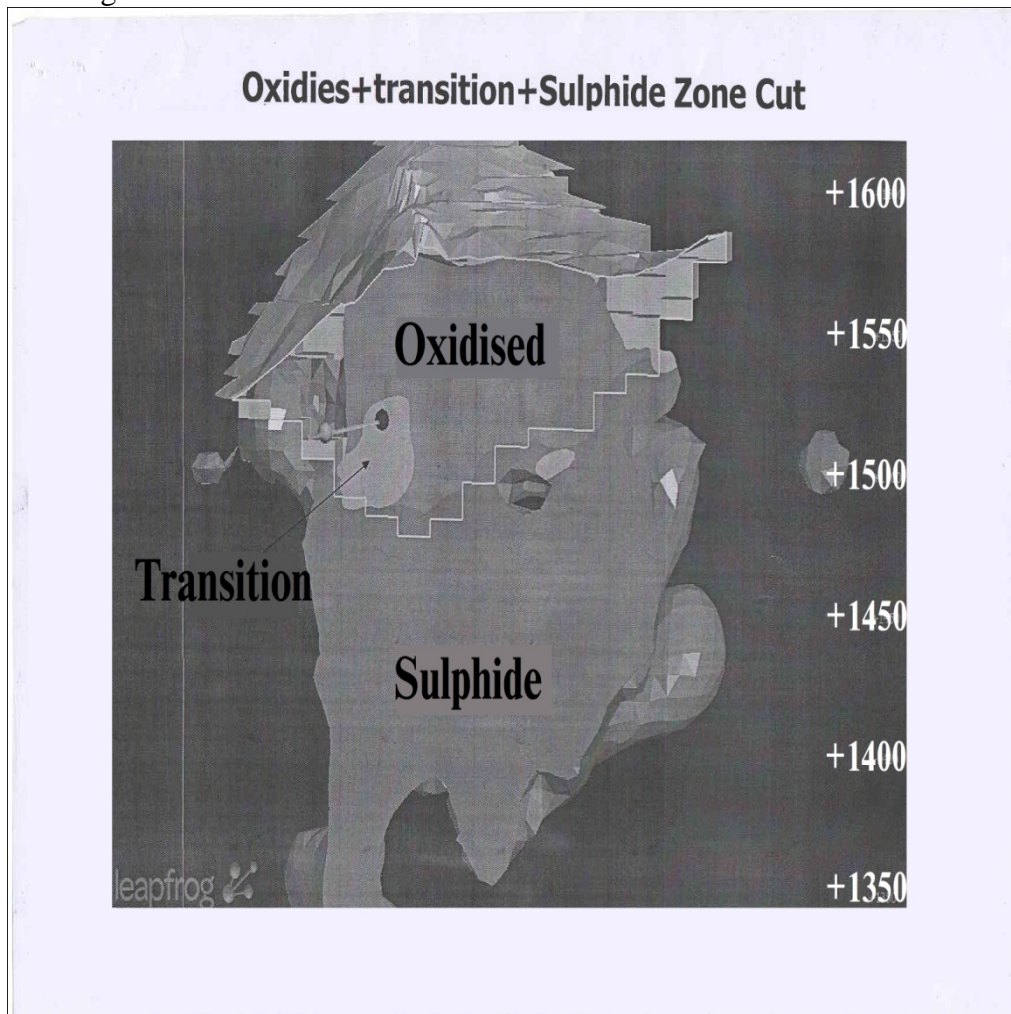


Fig. 1. Scheme of oxidized primary sulphide and mixed ores location of Chovdar field.

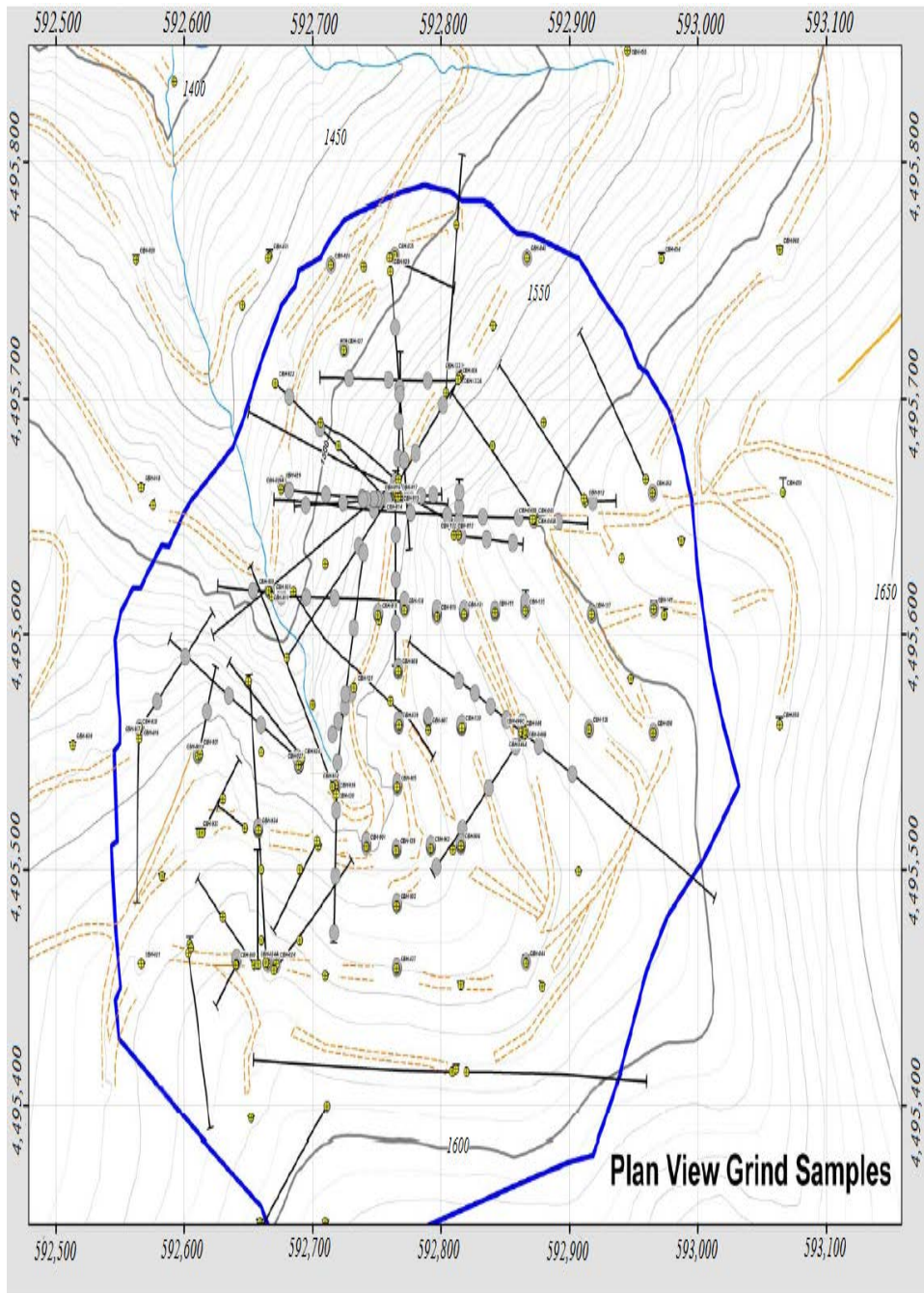


Fig. 2. Places and intervals of “Chovdar Composite” material sample taken from core of the respective drill holes

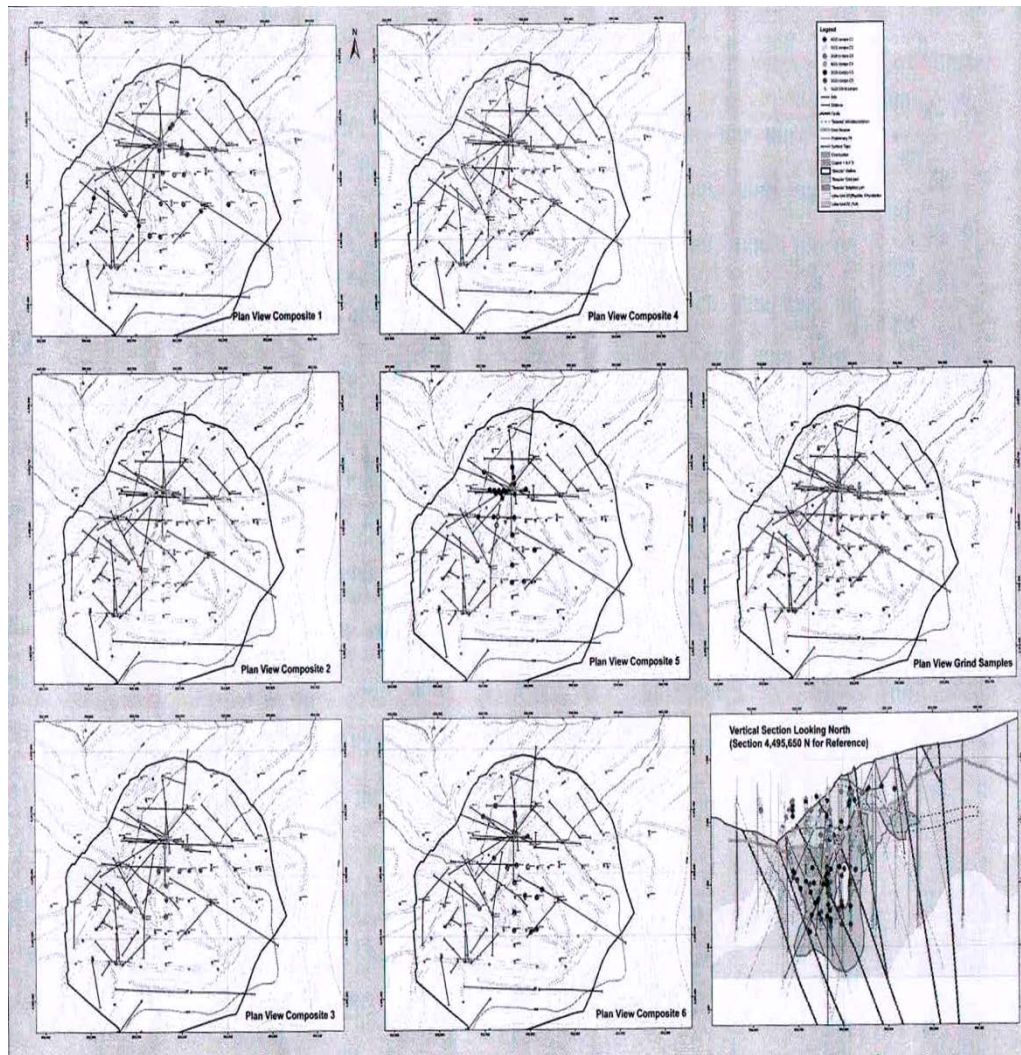


Fig. 3. Places and intervals of core material sampling of six technological samples taken from 234 points (intervals) of 44 drill holes

1. Chemical composition of the technological samples

For research of the chemical composition of the considered laboratory technological samples it was carried out complete silicate (for rock-and ore-forming compounds - oxides), elementwise analysis for a number of practically important elements and also fire assay test for gold and silver. The results of chemical composition analysis according to main elements and compounds (oxides) contained in all above-mentioned technological samples have been presented in Table 1 but the results of the elementwise analysis of six main technological samples (C1-C6) have been presented in Table 2.

According to the Tables data the gold with content ranging from 0.65 to 3.85ppm is the main commercially valuable component in all considered technological samples. Silver with contents ranging from 2.5 to 23.2ppm is of certain interest for following extraction. Moreover it should be noted that relatively high content of copper - 0.825% has been revealed in one of the samples characterizing the primary ores (C5). It allows to suggest the possibility of the following efficient extraction of the metal from the primary-sulphide ores type of the deposit.

Relatively low copper contents (in the range of 0.006-0.017%) have been revealed in the oxidized ores samples (C1 - C3). This factor indicates that the copper is no of practical importance in the oxidized ores.

Table 1

Chemical composition (in %) of the main elements and the compounds in the technological samples

Name of elements and compounds	Samples name								
	Chovdarr Composite	Oxidized			Primary sulphide			Oxidized	Primary
		C1	C2	C3	C4	C5	C6	Comp. A	Comp. B
Au, ppm ¹	1.08	0.65	2.4	3.2	1.1	3.85	1.1	1.89	2.04
Ag, ppm ¹	6.1	12.3	9.4	15.6	3.5	23.2	2.5	-	-
Cu	0.15	0.01	0.006	0.017	0.01	0.825	0.014	-	-
SiO ₂	71.9	77.6	84.7	81.0	66.0	69.4	67.7	86.9	72.3
Al ₂ O ₃	10.9	7.82	5.32	3.53	17.2	7.87	17.3	4.09	9.62
Fe ₂ O ₃	7.62	8.08	4.98	8.59	6.03	10.7	4.59	5.25	8.62
MgO	0.09	0.05	0.05	0.08	0.05	0.08	0.08	0.08	0.07
CaO	0.25	0.09	0.08	0.08	0.07	0.05	0.12	0.11	0.07
Na ₂ O	0.04	0.05	0.04	0.08	0.05	<0.01	0.03	0.05	0.02
K ₂ O	0.23	0.09	0.07	0.06	0.30	0.23	0.57	0.06	0.26
TiO ₂	0.45	0.43	0.43	0.47	0.45	0.36	0.39	0.44	0.38
P ₂ O ₅	0.07	0.09	0.05	0.05	0.09	0.03	0.08	0.05	0.05
MnO	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr ₂ O ₃	0.02	0.04	0.06	0.07	0.03	0.05	0.03	0.04	0.03
V ₂ O ₅	<0.01	0.02	0.01	<0.01	0.03	<0.01	0.03	0.01	0.01
LOI	7.56	5.18	3.41	3.95	8.97	8.40	8.33	3.19	8.02
Incl. H ₂ O ⁺ ₂		2.30	1.06	1.26	3.84	1.11	3.20	1.45	3.41
		0.07(0.01)	0.06(0.01)	0.08(0.02)	0.06(0.01)	0.06(0.01)	0.09(0.02)	0.18(0.04)	0.14(0.025)
CO ₂ (Ctotal) ³		2.81(1.12)	2.29(0.92)	2.61(1.04)	5.07(2.03)	7.23(2.89)	5.04(2.02)	1.56(0.62)	4.47(1.79)
SO ₃ (Stotal) ⁴									
∑	99.2	99.6	99.2	98.0	99.3	96.9	99.2	100.3	99.4
Ctotal ⁵								0.03	0.02
Corgan. ⁵								<0.05	<0.05

Note: ¹ – according to the results of the fire assay test;

² – the estimated content of H₂O⁺ in amount of Al₂O₃ (in clay - kaolinite and alunite according to data of the quantitative mineralogical analysis);

³ - the estimated content of CO₂ in amount of MgO and CaO (in carbonates - MgCO₃, CaCO₃);

⁴ – the estimated content of SO₃ included in the index of the LOI: SO₃ = LOI - (H₂O + CO₂)

⁵ – according to the results of special analysis for carbon.

The results of the elementwise analysis (Table 2) carried out on the emission spectroscopy with inductive plasma (ISP) indicate that besides the above-mentioned elements (Au, Ag and Cu in the primary ores) there haven't been revealed other valuable components with commercially significant contents in the investigated samples of both oxidized and primary ores.

Table 2

Elementwise chemical composition (in%) of the technological samples of Chovdar

№ S/No	Name of elements	Sample names					
		Oxidized ores			Primary–sulphide ores		
		C1	C2	C3	C4	C5	C6
1	Cu	0.01	0.006	0.017	0.01	0.825	0.014
2	Pb	0.03	0.014	0.036	0.02	0.011	0.009
3	Zn	0.003	0.003	0.003	0.002	0.025	0.002
4	As	0.0353	0.0179	0.0693	0.0211	0.0629	0.0226
5	Cd	0.0003	0.0001	0.0001	0.0001	0.0013	<0.0001
6	Ni	0.001	0.002	0.001	0.001	0.002	0.002
7	Co	0.001	0.001	0.001	0.002	0.004	0.003
8	Bi	0.0011	0.0058	0.006	0.0007	0.0008	<0.0001
9	Sb	0.0009	0.0028	0.0125	0.0001	0.0392	<0.0001
10	Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
11	Te	0.0003	<0.0001	0.0038	<0.0001	0.0126	<0.0001
12	Se	<0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001
13	F	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
14	Cl	0.04	0.05	0.03	0.03	0.02	0.02
15	Stotal	0.95	0.55	0.80	5.37	9.51	5.58
16	CO ₃	0.28	<0.01	<0.01	0.51	0.78	0.49

Assessing the chemical composition of the considered ores samples it is necessary to note a very positive factor - small content of the harmful impurities such as As, Sb, F, Cl and Hg in them which are usually negatively reflected on processing technology of such gold-contained ores. Furthermore it is also necessary to note that this harmful material contents in both types of ores are small - <0.05% according to special analysis results for the organic carbon that carried out on the mixed samples of oxidized (Comp.A) and primary (Comp.B) ores (Table 1).

As expected it has been determined relatively high contents of the total sulphur (5.4 - 9.5%) in the primary sulphide ores samples in comparison with the oxidized ores samples (0.55 - 0.95%). Moreover relatively high contents of arsenic (0.063%) and antimony (0.039%) are observed in the primary ore sample (C5) with relatively high copper content (0.825%). This factor allows to suggest the existence of some (small) quantity of arsenic and antimony-containing possibly copper sulphide minerals in the considered ores.

Estimating the results of the chemical analysis for rock-and ore-forming compounds (Table 1) it should be noted that oxide silicon is main rock-forming compound in both oxidized and primary ores samples. Thereby the quantity of the mentioned compound (77.6 - 84.7%) in the oxidized ores is slightly higher than in the primary ores (66.0 - 69.4%).

Moreover slightly high contents of the clay-forming compound- Al₂O₃ are observed in the samples of both ores types. In addition considerably higher contents of the mentioned compound have been revealed in the primary ores samples (7.9 - 17.3%). This factor can have a negative effect on the ores treatment technology.

The low contents of the carbonate-forming compounds - CaO and MgO in the considered samples are positive factor especially for hydrometallurgical treatment technology of both oxidized and primary ores types. The contents limits of last ones are only 0.05-0.12%.

Assessing the ore-forming compounds it should be noted that as one would expect the sulphur (total) contents are considerably lower in the oxidized ores samples than in the primary ores ones (see Table 2). So if sulphur contents range from 0.5 to 0.95% in the first

ones then the limits of this element contents are ten times bigger - 5.4-9.5% in the second ones. Thereby iron oxide quantities (Fe_2O_3) in the samples of both ores types are approximately identical limits: in the oxidized ores - 5.0-8.6%, and in the primary ones - 4.6-10.7% (Table 1). This factor indicates that the main iron mass has presented by its oxide minerals with small quantity of iron sulphides in the oxidized ores samples (according to Table 2 data the presence of significant sulphides contents of other metals is very limited).

In primary ores samples with relatively low contents of copper (with the exception of C5 sample) and other non-ferrous metals in them the main iron quantity has most probably been represented by its sulphides. It allows to characterize the material of these samples as the primary - sulphide ore.

The presence of titanium oxide (TiO_2) with contents ranging from 0.36 to 0.47% has also been determined in the considered samples of both ores types that is probably connected with the presence of titanite iron ore - ilmenite (FeTiO_2) and perhaps certain amount of rutile and titanomagnetite in these ores.

The mineral composition of the investigated ores samples and characteristics of the detected minerals are considered in more detail below.

2. Mineralogical and petrographic investigations

The mineral composition of the samples material has been studied by QEMSCANTM operating system. This system has been based on the quantitative estimation of matter by scanning electron microscopy of the polished sections. This system together with quantitative estimation of the revealed mineral forms allows to determine their chemical composition and grains sizes.

2.1. Total mineral composition

Total approximately quantitative mineral composition of the considered technologic samples and state (dimension) of the revealed minerals grains were studied on these samples materials which were crushed up to 2 sizes: -3.35 mm and -0.212 mm (Table 3.4).

According to the data presented in Table 3, quartz with mass fraction in the range of 74 - 88%, at average grains size - 0.22 - 0.34 mm (at the size of the investigated samples material -3.35 mm) is the main rock-forming mineral of the oxidized ores samples. On more finely crushed material (-0.212 mm) of these samples the quartz grains size is significantly decreased (up to 0.009-0.068 mm) by slight increasing this mineral mass fraction that is natural i.e. its attachments with other minerals are released and accordingly mass fraction of the analyzed mineral is more precisely characterized.

Relatively significant quantities of clay minerals (6-16%) with average grains size - 0.04-0.05mm and also slight quantities of other silicates (0.1- 0.4%), alunite (0.1- 0.7%), mica (0.05- 0.1%) and etc. including barite, jarosite, apatite, carbonates, zircon (summarily 0.4- 1.0%) have also been revealed from the rock-forming minerals in the oxidized ores samples.

According to semi-quantitative X-ray diffraction analysis (X-ray Diffraction) data the clays have mostly been represented by kaolinite (> 30 rel.%), partially dickite (10-30%) in small quantities – by illite, plagioclase, potassium feldspar (2-10 rel.%) in the considered samples.

Considering ore-forming minerals we note that they have represented in a greater degree by iron and iron-titanium oxides (summarily 3.6-6.1 abs.%) than by the sulphides of iron and copper (summarily 1-2.3 abs.%) in the samples of the oxidized ores.

This factor indicates sufficiently high degree of these ores oxidation at very low contents of copper sulphides in them (summarily 0.02-0.07 abs.%). The last ones have mainly been represented by the secondary sulphides - chalcosine, covellite, bornite. The primary sulphide-chalcopyrite quantity is only 0.02 % in all considered samples. The copper minerals discovered in the investigated ores will be considered in more detail below.

Table 3

Approximately-quantitative mineral composition (%) and grains dimensionality (µm) of the revealed minerals in the oxidized ores samples

Minerals name	Material size -3.35 mm						Material size -0.212 mm					
	C1		C2		C3		C1		C2		C3	
	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm
Pyrite	2.57	57	1.35	45	2.16	47	1.67	9-38	0.98	9-28	2.13	8-35
Chalcopyrite	0.02	16	0.01	16	0.03	20	0.02	4-7	0.02	3-8	0.02	3-9
Other Cu sulphides ¹	0.00	0	0.00	15	0.04	71	0.04	3-19	0.00	6-23	0.02	8-26
Enargite	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
Tetrahedrite	0.00	0	0.00	0	0.00	15	0.00	0	0.00	0	0.00	0
Other sulphides	0.00	16	0.05	34	0.02	16	0.02	3-8	0.02	3-8	0.11	4-8
Total: sulphides	2.59	-	1.41	-	2.25	-	1.75	-	1.02	-	2.28	-
Fe Oxides	5.40	50	1.81	49	3.40	52	4.11	8-30	2.23	6-32	4.07	7-29
Fe-Ti Oxides	1.13	21	1.23	21	1.52	21	1.95	5-13	1.37	5-12	2.09	5-12
Quartz	73.56	223	87.73	339	81.05	281	74.27	9-54	88.18	9-68	84.30	9-59
Clays	16.12	51	7.53	48	8.90	37	16.09	6-31	6.53	6-15	5.64	5-18
Others silicates	0.62	22	0.08	22	1.62	27	0.43	4-13	0.11	4-11	0.30	5-11
alunite	0.37	40	0.07	17	0.11	18	0.67	4-33	0.12	3-8	0.25	3-8
Micas	0.02	17	0.02	18	0.02	17	0.08	5-10	0.08	5-11	0.05	5-10
Others ²	0.18	27	0.13	40	1.14	74	0.65	7-37	0.38	5-28	1.00	6-39
Total	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-

Note: ¹ - other Cu sulphides include: chalcocite, covellite, bornite;

² - others include: barite, jarosite, apatite, carbonates, zircon.

Table 4

Approximately-quantitative mineral composition (%) and minerals grains dimensionality (µm) revealed in the primary sulphides ores samples

Note: ¹ - other Cu sulphides include: chalcocite, covellite, bornite;

Minerals name	Material size -3.35 mm						Material size -0.212 mm					
	C4		C5		C6		C4		C5		C6	
	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm	Quantity , %	Average size, µm
Pyrite	11.79	69	19.87	92	11.86	76	13.75	10-53	21.30	9-55	14.38	10-53
Chalcopyrite	0.01	15	1.71	45	0.06	25	0.02	3-7	2.10	6-30	0.01	3-8
Other Cu sulphides ¹	0.00	0	0.64	26	0.00	0	0.00	0	0.89	4-16	0.00	0
Enargite	0.00	0	0.01	17	0.00	0	0.00	0	0.02	4-10	0.00	0
Tetrahedrite	0.00	0	0.16	26	0.00	0	0.00	0	0.23	6-18	0.00	0
Other sulphides	0.00	17	0.04	23	0.02	21	0.04	4-7	0.28	3-7	0.03	3-7
Total: sulphides	11.80	-	22.43	-	11.94	-	13.81	-	24.82	-	14.42	-
Fe Oxides	0.34	38	0.00	16	0.00	0	0.59	5-26	0.26	6-71	0.06	4-21
Fe-Ti Oxides	1.20	21	0.93	22	0.75	23	1.18	5-12	1.01	5-12	0.77	5-12
Quartz	57.47	180	67.53	270	60.67	194	59.41	8-51	63.11	9-56	53.89	8-50
Clays	27.31	85	7.80	62	22.75	71	22.73	6-31	8.82	6-25	25.35	6-33
Others silicates	0.37	20	0.14	17	0.50	18	0.29	4-11	0.06	3-10	0.36	3-8
Alunite	0.15	16	0.16	16	0.09	16	0.39	3-7	0.65	3-7	0.39	3-7
Micas	1.27	43	1.01	43	3.02	45	1.37	5-19	0.95	6-20	4.48	5-20
Others ²	0.09	32	0.01	25	0.29	69	0.22	5-24	0.33	7-31	0.28	7-33
Total	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-	100.0	-

² - others include: barite, jarosite, apatite, carbonates, zircon.

Assessing the sulphides grains sizes we note that with size of the samples material -3.35 mm the average size of pyrite grains in them is 45-57 μm , chalcopyrite - 16-20 μm , other sulphides - 16-34 μm . With material size - 0.212mm the pyrite grains size is decreased up to 8-38 μm , chalcopyrite up to 3-9 μm and other sulphides up to 3-8 μm . This factor is indicative of some sulphides overgrinding especially chalcopyrite even during fine ores crushing.

Considering the approximately-quantitative mineral composition of the primary-sulphide ores samples (Table 4) we note that the rock-forming minerals have mainly been represented by quartz in them as well as in the oxidized ores samples. However quartz quantity in these samples (54-63%) is significantly lower (at 20-25%) than in the oxidized ores samples. Moreover significant clay contents (23-27%) have been revealed in separate samples of the primary ores (C4, C6). It should also be noted that mica contents are higher than in the oxidized ores (1.4-4.5 %). The quantities of other rock-forming minerals (silicates, alunite and etc.) are almost at the same level as in the oxidized ores samples. Thereby list and size of minerals of the mentioned mineral matters (clays, silicates and etc.) are also nearly equal.

Considerably large quantity of the ore-forming minerals, the main of which is pyrite, has been revealed in the primary ores. Thereby pyrite quantity is more than 21% in the separate sample of the mentioned ores type (C5). In the same sample it has been defined the greatest quantity of different copper sulphides (3.2 %). The copper sulphides quantity (0.01-0.02%) is of no practical importance in other two samples (C4, C6).

It should be noted that the chemical analysis results for total sulphur content (Table 2) in the considered samples of the primary ores are slightly out of keeping with assay grade of this element according to the cumulative quantity of sulphides mentioned in Table 4. In the last one sulphides quantity has probably overestimated. However it should be noted that the mineral composition of the samples presented in Table 4 is approximately-quantitative.

Relatively low contents of iron oxides and titanium (summarily 0.8-1.7%) have been determined in the samples of the considered ores types. Thereby the mass fraction of the iron oxide itself is maximum in one of the samples (C4) only 0.59% but in the other two - 0.06-0.26%. This factor confirms the primary - sulphide nature of these samples ores.

The grains size of pyrite (70-90 μm) and chalcopyrite (15-45 μm) is slightly higher in the primary ores samples than in the oxidized ores ones. During relatively fine material crushing (up to -212 mm) there are observed some overgrinding of these minerals especially chalcopyrite as well as in the oxidized ores. This factor should be taken into account during development of flotation treatment technology of this ores type.

2.2. Sulphur-containing mineral forms

The list and the quantitative relationship of sulphur-containing minerals in its are of great importance for characteristics of the ore mineral raw materials and development of its treatment technology. For this purpose sulphur-containing minerals were revealed and their quantitative relationships were defined in all six technological samples. The calculation of last ones was made according to the sulphur content in the appropriate sulphur-containing minerals at % from the total sulphur content in the analyzed sample. The results of these investigations have been presented in Table 5. The same table shows the initial sulphur contents in the analyzed sample that have been established by elementwise chemical analysis (see Table 2).

According to the presented data (Tab. 5) the main sulphur-containing mineral is pyrite in all considered samples. The largest pyrite quantity has been observed in the primary ores (90.5-98.8%).

Relatively high contents of alunite (3.1-9.9%), barite (7.3-9.9 %) and some quantity of jarosite (0.4-1.0 %) have been revealed from the sulphur-containing minerals in oxidized ores samples. The last one is usually characterized for oxidation zone ores of sulphide deposits.

The considerably lesser quantities of alunite (0.8%) and barite (0.2-0.3%) have been observed in the primary ores samples. The sulphur-containing mineral composition of these samples is generally characteristic of the primary ores of sulphide deposits. The list and quantitative relationships of copper sulphides in the samples are considered below in the appropriate section.

Table 5
The sulphur-containing minerals and their quantitative relationships
in the technological samples
(relative % from total sulphur content)

Name of the sulphur-containing minerals	Samples name					
	Oxidized ores			Primary-sulphide ores		
	C1	C2	C3	C4	C5	C6
S (total)	0.95	0.55	0.80	5.37	9.51	5.58
Pyrite	80.5	86.1	82.8	98.6	90.5	98.8
Chalcopyrite	0.4	1.0	0.7	0.1	6.0	0.0
Bornite	0.0	0.0	0.1	0.0	0.8	0.0
Chalcocine	0.7	0.1	0.1	0.0	0.7	0.0
Covellite	0.0	0.0	0.2	0.0	0.2	0.0
Enargite	0.0	0.0	0.0	0.0	0.0	0.0
Tetrahedrite	0.0	0.0	0.0	0.0	0.5	0.0
Other sulphides	0.5	1.1	2.5	0.2	0.1	0.1
Alunite	9.9	3.4	3.1	0.8	0.8	0.8
Barite	7.5	7.3	9.9	0.2	0.3	0.2
Jarosite	0.4	1.0	0.5	0.1	0.0	0.0
Others	0.2	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

2.3. The mineral forms of copper

The mineral forms of copper and their relative quantitative relationships (at % from the total content of Cu in the sample) were also estimated in all six technological samples. The results of these investigations have been presented in Table 6. The initial copper contents in the analyzed sample determined by elementwise chemical analysis have been presented in this Table. (See. Table 2).

The data presented in Table 6 indicate that the copper content almost in all the considered samples except the primary ore sample - C5 are characterized by very low values (0.006-0.017%). The relatively high content of copper in C5 (0.825%) sample allows to suggest the possible commercial value of this metal in the primary ores of deposit. Therefore it is very important to estimate the mineral forms of copper location in the considered samples

especially in the primary ores.

According to the conducted research results (Table. 6) it has been defined that the copper in the sample of C5 (at 49%) has represented by its primary sulphide - chalcopyrite and it is characterized totally almost at 45% by its secondary sulphides - chalcocite (25%), bornite (17%), and covellite (2.6%). Additionally small quantities of copper sulphides containig antimony - tetrahedrite (5.6 rel.%) and arsenic - enargite (0.5 rel.%) have been revealed in this sample. The small quantities of tetrahedrite and enargite have also been defined in other samples of the primary ores (C4, C6) characterized by low copper contents. Moreover nearly 30% of this metal has been presented by tetrahedrite in C5 sample with 0.014% copper content.

Assessing the presence of tetrahedrite and enargite in the oxidized ores samples we note that a small amount of tetrahedrite has been discovered only in one of these samples (C3).

Generally the mineral copper forms in the primary ores samples are characteristic of the mentioned natural type of the mineral raw materials of sulphide deposits. Slightly increased contents of the secondary copper sulphides (chalcocite and bornite) in C5 sample allow to suggest that probably some part of this sample has been taken from the mixed ores zone of deposit or from zone close to the oxidized ores.

Low copper contents in the considered samples of the oxidized ores don't allow to justify sufficiently convincingly the oxidation degree of these samples material according to its mineral forms.

2.4. The forms of separations and assemblages of the main ore minerals

The forms of separations and assemblages of the main ore minerals are extremely important for technological assessment of ore mineral raw materials both among themselves and with host rocks minerals at a certain size of ore grinding. This factor allows to estimate the possible degree of the appropriate mineral component extraction from ore. The operating system (QEMSCANTM) used for the considered mineralogical and petrographic investigations allows to carry out such investigations.

Table 6

The mineral forms of copper and their quantitative relationships in the technological samples (at % from total content of Cu)

Name of the copper minerals	Samples name					
	Oxidized ores			Primary–sulphide ores		
	C1	C2	C3	C4	C5	C6
Cu total	0.01	0.006	0.017	0.01	0.825	0.014
Chalcopyrite	14.5	74.6	34.7	91.1	49.2	61.6
Bornite	0.1	0.0	18.3	0.4	16.9	4.3
Chalcocite	85.4	25.4	20.6	7.7	25.2	5.2
Covellite	0.0	0.0	25.2	0.0	2.6	0.0
Enargite	0.0	0.0	0.0	0.6	0.5	0.0
Tetrahedrite	0.0	0.0	1.1	0.2	5.6	28.9
Others	0.0	0.0	0.0	0.0	0.0	0.0

Total	100.0	100.0	100.0	100.0	100.0	100.0
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The investigations considered in this section have been carried out on the samples materials with size - 0.212 mm (50% -0.075 mm). Thereby the classes -0.212 +0.025 mm and - 0.025 mm +0.0 mm obtained by screen assay of the appropriate sample were separately investigated. Then the research results of the above-mentioned classes were combined and average grade (%) of the analyzed mineral form in the ore with size -0.212 mm was estimated in accordance with their yields.

The research results of the separations forms and corresponding assemblages of copper sulphides in the combined material (with size - 0.212 mm) of the appropriate sample have been shown in Table 7 and similar investigations carried out for the iron sulphide - pyrite have been presented in Table 8. Moreover Figures 4 and 5 characterized different separations forms of copper sulphides (Figure 4) and pyrite (Figure 5) in this sample have been presented by the example of the most typical sample of the primary ore - C5 for visual estimation of this work.

Table 7

Quantitative relationships (relative %) of separation forms and assemblages of copper sulphides

Name of the copper sulphides assemblages	Samples name					
	Oxidized ores			Primary–sulphide ores		
	C1	C2	C3	C4	C5	C6
Completely free	0.3	8.5	24.3	0.0	48.0	2.4
Mainly free	2.1	7.1	0.0	0.0	26.8	1.5
in association with pyrite	0.0	1.8	2.2	11.3	6.7	5.1
--<-- with other sulphides	0.0	0.0	0.4	0.0	2.9	0.0
--<-- with quartz	0.4	3.1	3.5	0.8	2.2	1.7
--<-- with mica	0.0	0.0	0.0	0.0	0.0	3.2
--<-- with clays	0.0	0.0	0.7	4.1	1.6	8.6
--<-- with other silicates	0.0	0.0	0.0	0.0	0.0	0.0
--<-- with Fe and Ti oxides	0.2	0.0	2.0	0.0	0.0	0.0
--<-- with other minerals	2.7	3.3	0.7	3.6	0.2	0.0
--<-- complicated complexes	94.2	76.3	66.4	80.2	11.6	77.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

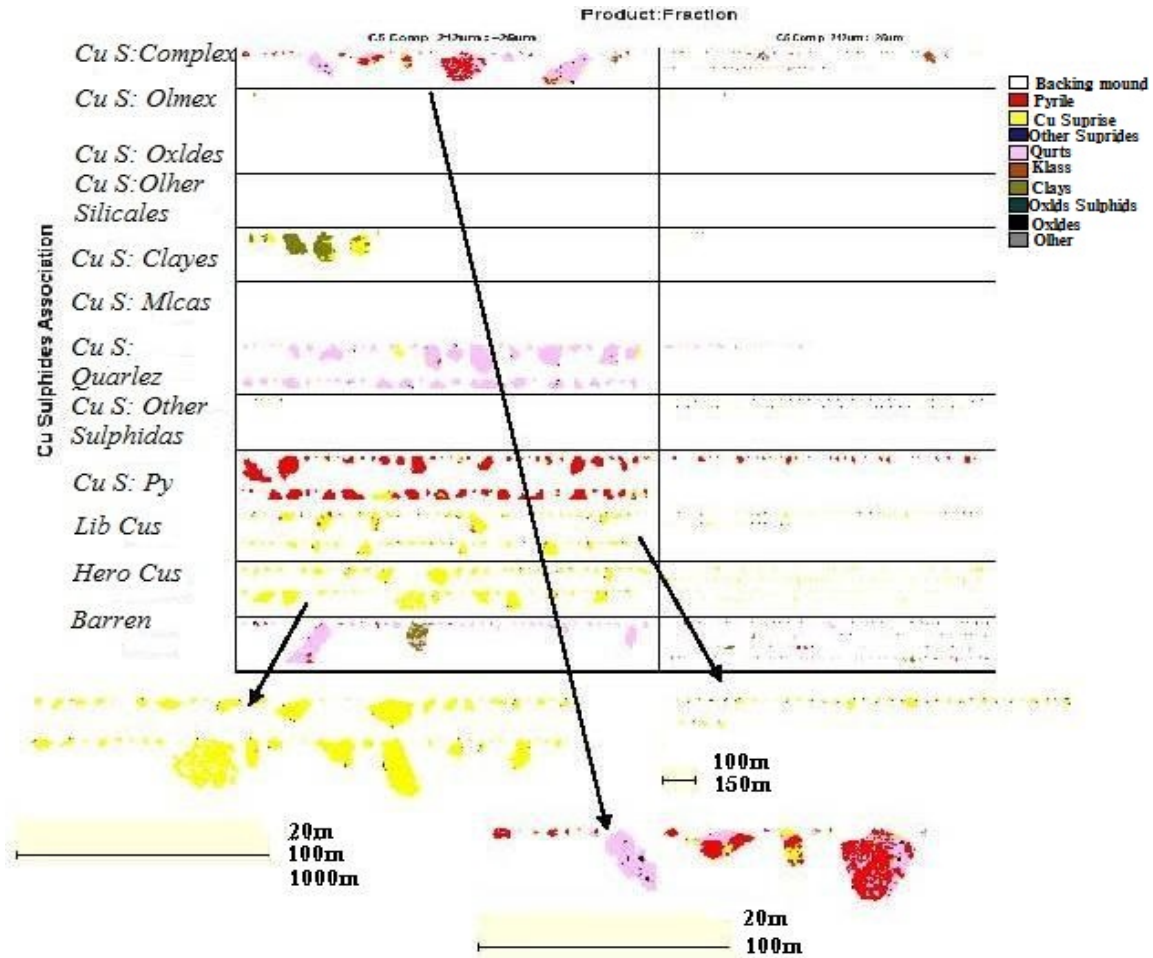


Fig. 4. The forms of copper sulphides separations in the primary ore sample – C5

The data presented in Table 7 indicate that the copper sulphides in the samples with low contents of the mentioned metal both in the oxidized (C1-C3) and in primary (C4, C6) ores have mainly been presented (at 66-94 rel.%) by finely dispersed forms in close association with the complicated (hard diagnosable) complexes. In this regard the selective separation of copper minerals from such ores varieties seems both technologically and economically unreasonable.

The copper sulphides with the above-mentioned material size have mainly been represented (at 75%) by free forms in the primary ore sample (C5) with relatively high copper content (0.825%); about 10% of the mentioned minerals are characterized as assemblages with pyrite and other sulphides. This factor allows to suggest that during some material size reduction of such ores of deposit (up to 75-80% -0.074 mm) it is technologically possible to obtain sufficiently high indices of selective separation of copper minerals from them (up to 90%).

Assessing mineralogical state of pyrite (Table 8) we note that this mineral in the samples of both ores types is mostly characterized by free form. Thereby the total quantity and mainly free pyrite grains range from 53 to 76% in the oxidized ores samples but - 80-82% in the primary ores samples. Lower quantity of relatively free pyrite grains in oxidized ores samples is caused by comparatively high quantity of this mineral being in close association with quartz (6.5-30%) and with complex (difficult diagnosable) complexes (10-33%).

Very small pyrite quantity being in close association with clays is a positive factor for both ores types (0.1-3.5%) .

Table 8

Quantitative relationships (relative %) of separation forms and assemblages of pyrite

Name of the pyrite assemblages	Samples name					
	Oxidized ores			Primary–sulphide ores		
	C1	C2	C3	C4	C5	C6
Completely free	68.5	48.1	45.4	58.3	65.6	57.9
Mainly free	7.8	11.2	7.7	22.1	16.6	22.4
in association with Cu sulphides	0.0	0.0	0.0	0.0	0.7	0.0
--<-- with other sulphides	0.0	0.0	0.0	0.0	0.0	0.0
--<-- with quartz	6.5	29.8	12.9	6.8	10.3	4.7
--<-- with mica	0.0	0.1	0.0	0.0	0.0	0.0
--<-- with clays	1.5	0.0	0.1	2.7	0.6	3.5
--<-- with other silicates	0.0	0.0	0.0	0.0	0.0	0.0
--<-- with Fe and Ti oxides	0.4	0.1	0.3	0.0	0.0	0.1
--<-- with other minerals	0.3	0.9	0.5	0.1	0.1	0.1
--<-- complicated complexes	15.0	10.0	33.1	10.0	6.2	11.2
Total	100.0	100.0	100.0	100.0	100.0	100.0

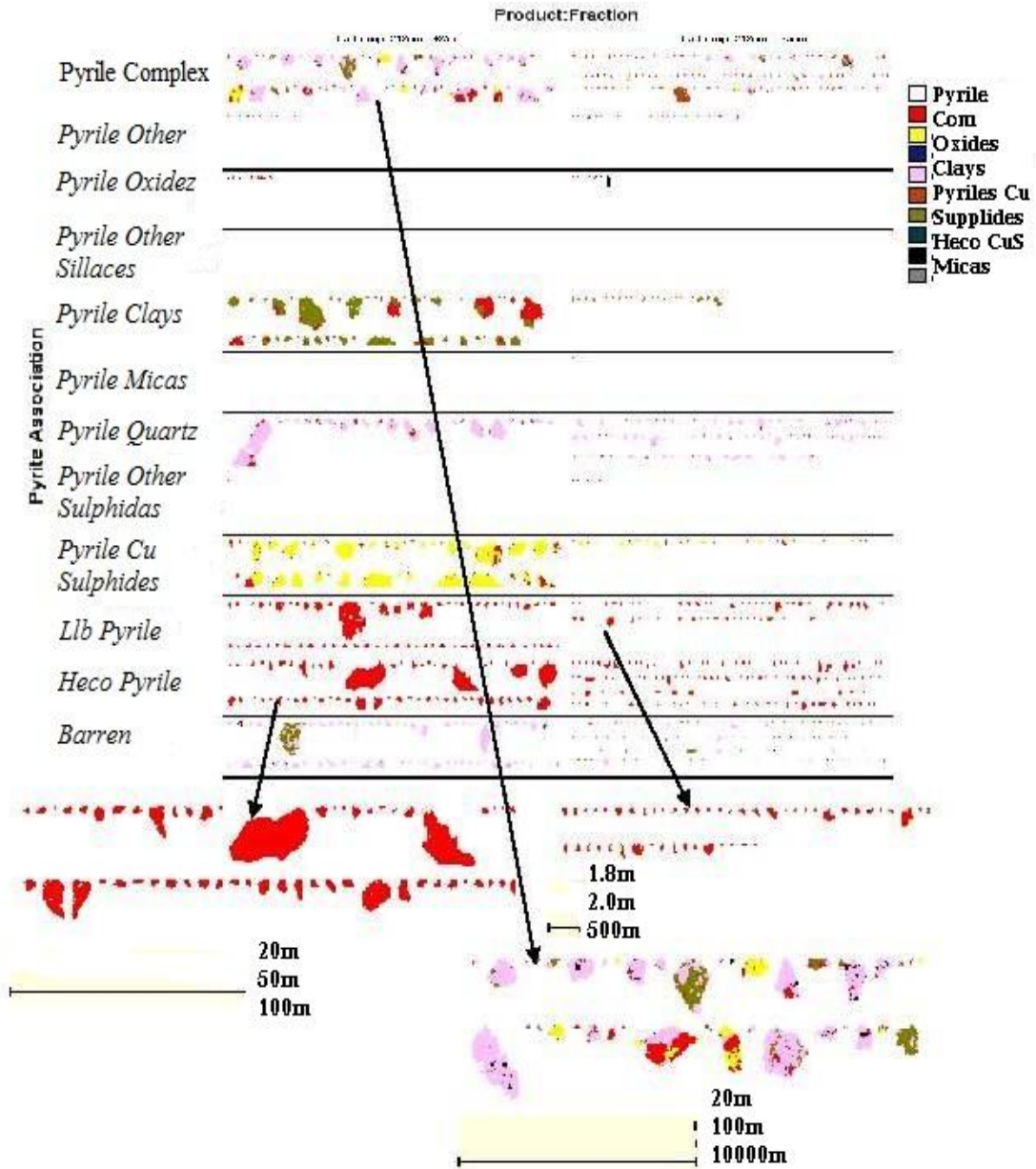


Fig. 5. The forms of pyrite separations in the primary ore sample – C5

Generally the considered forms of pyrite separation indicate the possibility of its sufficiently effective separation from the primary ores of deposit (85%) by flotation enrichment method. Taking into account that the gold part in these ores can be closely associated with pyrite, this factor should be considered positive.

3. The forms of separations and assemblages of the precious metals

3.1. Material composition of the mixed samples of the oxidized and primary ores

As previously stated the investigations considered in this section were carried out on two compositions (mixtures) of the estimated technological samples one of which was composed of the oxidized ores samples (C1 + C2 + C2 - Composite A) and the other one of the primary ores

samples (C4 + C5 + C6 - Composite B).

According to the fire assay test results the gold content in the mentioned mixed samples was: Composite A - 1.89 ppm; Composite B - 2.04 ppm. The complete chemical composition of the samples according to the rock- and ore-forming chemical compounds has been presented in above-mentioned Table 1.

The semi-quantitative X-ray diffraction (XRD) mineralogical analysis was carried out on these materials of the mixed samples. Its preliminary results have been presented in Table 9 and approximately estimated contents of all revealed minerals have been shown in Table 10.

Table 9

Approximate results of the semi-quantitative X-ray diffraction (XRD) mineralogical analysis of the mixed samples

Samples name	Content, %			
	Main (>30 rel.%)	Moderate (10-30 rel.%)	Small (2-10 rel.%)	Slight (<2 rel.%)
Composite A	Quartz	Dickite	Goethite, barite	Pyrite, magnetite, hematite, rutile, zircon, jarosite
Composite B	Quartz	Dickite	Pyrite	Goethite, rutile, jarosite, potassium feldspar, zircon

According to the conducted investigations results (Table 9, 10) the mineral composition of both mixed samples is mainly equal. As expected the difference is only in that the pyrite quantity is considerably larger in primary ores sample (Comp. B) than in the oxidized ores sample (Comp. A). Conversely, the hydroxides and iron oxides (goethite, magnetite, hematite) and barite are relatively larger in the last one.

Generally the mineral compositions of the mixed samples - Comp.A and Comp.B are separately characteristic of the oxidized and primary ores of the moderately sulphide deposits. At the same time we note that the primary ores of Chovdar are excessively enriched by clay mineral - dickite (mineral with kaolinite composition - $Al_2Si_2O_5(OH)_4$).

Table 10

Approximately-estimated results of the semi-quantitative X-ray diffraction (XRD) mineralogical analysis of the mixed samples

Minerals	Content, %	
	Comp. A	Comp. B
Quartz	79.7	62.0
Dickite	10.4	23.4
Pyrite	1.0	9.9
Goethite	2.7	1.3
Magnetite	1.0	-
Hematite	0.8	-
Jarosite	0.9	0.8
Rutile	0.5	0.5
Barite	2.0	-
Potassium feldspar	-	1.9
Zircon	0.9	0.1
Calcite	-	0.2

Total	99.9	100.0
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3.2. Scheme of the mixed samples preparation for mineralogical investigations

The investigations according to Au and Ag occurrence forms in the considered mixed samples A and B were carried out on the material of these samples (with 1.0 kg weight) crushed up to size -0.15 mm (80% -100 mesh). The samples preparation for mineralogical investigations was carried out according to the scheme (Fig. 6) including the preliminary separation of the crushed material (-0.15mm) of the appropriate sample (about 0.45 kg) in the heavy liquid with a specific gravity of 3.1g/cm³. Then for separation of the potentially free gold particles the obtained heavy fraction containing mainly the sulphides, iron oxides and heavy silicate minerals were subjected to thorough washing (separation) in the special pan with separation of 3 products: gold-containing “head”; iron oxides product; tailings separation sequentially for the sample the oxidized ore (A). 4 products: gold-containing “head”; sulphides product; product of the demolish minerals/(secondary); tailings of separation were distinguished in this operation for sulphide ore sample (B).

From all separation products (including ones from the light fraction due to heavy liquid separation) 13 polished sections, 7 of which presented the sample A and 6 - sample B were prepared and studied under an electron microscope. Moreover all separation products were subjected to gold assay test and it was estimated the distribution of this metal in them. The part of the separation products was also subjected to chemical analysis for Ag, Fe, As and S (Table 11).

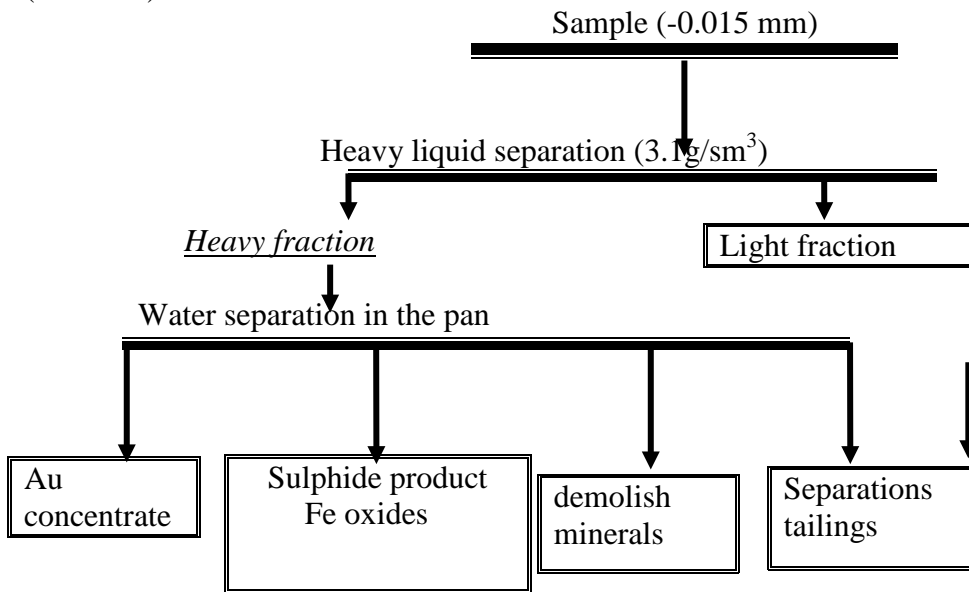


Fig. 6. Scheme of samples preparation for mineralogical investigations on gold

Research results (Table 11) carried out on the oxide ore sample (Comp.A) show that only about 16 % of the gold contained in the sample is distributed in the heavy fraction. During following water separation of this fraction in the pan only about 3% of mentioned ore metal is separated in so-called “gold head” (Au concentrate) with potentially possible presence of free grains of gold particles and about 11% of this metal is separated in Fe-Ti oxides product. These factors allow to suggest that the main quantity of the gold in the oxidized ores of deposit has been represented by small – fine-dispersed forms that can be closely associated with light non-metallic minerals. A small part of gold is closely associated with Fe-Ti oxides.

The investigations on the primary ore sample (Comp.B) have showed that more than 53% of the gold contained in the sample is distributed in the heavy fraction (with material yield – about 11%). The following water separation of the heavy fraction in the pan has

allowed to receive “gold head” (Au concentrate with potentially possible presence of free gold grains) with distribution of only 3.5% of the mentioned metal in its. Moreover there was also obtained product of nearly pure iron sulphides (S-44.3%, Fe-40.9%) with extraction of gold (up to 43%) of this ore sample from its. These factors allow to suggest that the main quantity of the gold has been presented by small - fine-dispersed forms both in the primary ores of deposit and in the oxidized ores thereby almost half of them are closely associated with iron sulphides and the other half - with light non-metallic minerals.

Table 11

The gold distribution over separation products of the oxidized (Comp.A) and primary (Comp.B) ores samples (see Fig. 6)

Samples name	Separation products	Yield, %	Content, ppm, %					Distribution Au, %
			Au, ppm	Ag, ppm	Fe, %	As, %	S, %	
Oxidized Composite A	Au concentrate	0.15	35.3	-	-	-	-	2.8
	Fe-Ti oxides products	3.22	6.23	-	25.6	0.31	5.35	10.6
	Water separation tailings	0.72	6.23	-	-	-	-	2.4
	Total heavy fraction	4.09	7.30	-	-	-	-	15.8
	Light fraction	95.91	1.66	9.6	2.67	0.03	0.58	84.2
	Initial ore sample	100.0	1.89	-	-	-	-	100.0
Primary Composite B	Au concentrate	0.16	44.6	-	-	-	-	3.5
	Sulphides product	8.34	10.5	-	40.9	0.19	44.3	42.9
	Product of the demolish minerals	1.64	8.0	-	24.5	0.16	-	6.4
	Water separations tailings	0.80	1.07	-	-	-	-	0.4
	Total heavy fraction	10.94	9.93	-	-	-	-	53.3
	Light fraction	9.06	1.07	5.0	2.45	0.019	2.57	46.7
	Initial ore sample	100.0	2.07	-	-	-	-	100.0

3.3. Mineralogical research of the polished sections

As it was noted for the assessment of Au and Ag occurrence forms in the considered mixed samples from all obtained separation products (see Fig. 6) 13 polished sections including 7 from the oxidized sample (Comp.A) and 6 from the primary ores sample (Comp.B) were prepared and examined under an electron microscope. At the same time it was carried out scanning and it was examined the revealed grains states of Au and Ag minerals including their sizes (length, width, surface area, estimated diameter), forms of the associations with other minerals (free, confined or enclosed inside the respective mineral) and also their chemical composition (spectral sounding) allowing to determine variety of the evaluated mineral compound.

3.3.1. Oxidized ores sample – Composite A

Only 7 signs (grains) of gold and 16 silver signs and its minerals were revealed in the mentioned material of the oxidized ores sample (Comp.A). Locations (names of ore concentration products), sizes and assemblages forms of the detected gold grains are shown in

Table 12 but their chemical composition (on Au and Ag) – in Table 13. Similar data on silver are presented in Tables 14 and 15. Moreover microphotographs (optical image) detected in the considered gold grains sample are shown in Fig. 7 and 8 but Ag minerals - in Fig. 9.

Table 12

The sizes and forms of the gold assemblages in the oxidized ores sample

№ grains	Product of Au grain detection	Grains sizes of Au, μm				Assemblages forms
		Length	Width	Area, μm ²	Estimated diameter of grain	
1	Fe oxides	12	5	60	8	Free
2	Fe oxides	12	6	72	8	Confined to chalcopyrite/covellite
3	Fe oxides	3	3	9	3	Enclosed in goethite
4	Water separation tailings	30	30	900	30	Free
5	Light fraction	7	2	14	4	Confined to undetermined mineral
6	Light fraction	2	2	4	2	--<--
7	Light fraction	2	2	4	2	Enclosed in the undetermined mineral/limonite
Limits of the estimated diameter of grains					2-30	
Average diameter of all grains					8	

The presented results of electron microscopy (Table 12) confirm previously stated suggestions concerning presence of the fine gold in the considered ores type. From 7 detected grains of the metal only one grain can be characterized as relatively large with the estimated diameter of 30 μm (0.03 mm). Moreover this grain is porous (Fig. 7a) and probably fine – “floating” because i.e. it has been discovered in the water separation tailings from ore heavy fraction. The rest of the grains are characterized by rather small forms with size of 2-8 μm. A part of very small almost dispersed grains (2-3 μm) is covered (enclosed) by iron oxides (Fig. 8, c).

Spectral sounding of the revealed gold grains (Table 13) has showed that according to the chemical composition (semi-quantitative analysis) all 7 grains are mainly characterized as high-standard native gold with basic metal contents in the range of 86.6 - 100.0%, on average - 96.7%. The grains numbers presented in Table 13 correspond to the above-mentioned ones in Table 12.

Table 13

The spectral zoning results of the revealed grains Au (Comp.A)

№ grains	Content, %			Compound name
	Au	Ag	Total	

1	100.0	-	100.0	Native Au
2	100.0	-	100.0	Native Au
3	87.7	12.3	100.0	Native Au
4	93.4	6.6	100.0	Native Au
5	100.0	-	100.0	Native Au
6	99.6	0.4	100.0	Native Au
7	86.6	13.4	100.0	Native Au
On average	96.7	3.3	100.0	Native Au

Table 14

The sizes and forms of the silver assemblages in the oxidized ores sample

№ grains	Product of Ag grain detection	Grains sizes of Ag minerals, μm				Assemblages forms	Mineral name
		Length	Width	Area, μm^2	Estimated diameter of grain		
1	Fe oxides	12	2	24	5	Enclosed in barite	Cu-Ag mineral
2	Fe oxides	10	4	40	6	Enclosed in barite	Cu-Ag mineral
3	Fe oxides	14	3	42	6	Enclosed in barite	Cu-Ag mineral
4	--«--	15	4	60	8	Enclosed in barite	Cu-Ag mineral
5	--«--	10	2	20	4	Enclosed in barite	Cu-Ag mineral
6	--«--	7	2	14	4	Enclosed in barite	Cu-Ag mineral
7	--«--	4	2	8	3	Enclosed in barite	Cu-Ag mineral
8	--«--	4	0.5	2	1	Enclosed in barite	Cu-Ag mineral
9	--«--	10	2	20	4	Enclosed in barite	Cu-Ag mineral
10	--«--	4	2	8	3	Enclosed in barite	Cu-Ag mineral
11	--«--	8	3	24	5	Enclosed in barite	Jalpaite- Ag_3CuS_2
12	--«--	2	1	2	1	Enclosed in barite	Jalpaite - Ag_3CuS_2
13	--«--	8	3	24	5	Enclosed in barite	Cu-Ag mineral
14	Light fraction	8	6	48	7	Enclosed in barite	Native. Ag
15	Light fraction	12	3	36	6	Enclosed in barite	Native Ag
16	Light fraction	16	2	12	3	Enclosed in barite	Cu-Ag mineral

Limits of the estimated diameter of grains	1-8	
Average diameter of all grains	5	

Estimating occurrence forms the silver minerals in the oxidized ores sample (Table 14, Fig. 9) we note that all revealed grains of these minerals are characterized by rather small (1-8 μm) almost dispersed forms included in barite. According to the chemical composition (Table 15) determined by the spectral sounding the main quantity of these grains (7 signs) are characterized by Ag-Cu alloy, 2 grains – by native form of Ag, 2 more grains with copper-containing silver sulphide - jalpaite (Ag₃CuS₂) and also one grain – by copper-containing sulphide mineral- by stromeyerite (AgCuS).

Table 15

Resulting data of the spectral zoning of the detected Ag minerals grains in the oxidized ores (Comp.A)

Grains quantity	Elements contents, %					Ag minerals name
	Ag		Cu		S	
	Limits	Average value	Limits	Average value		
2	84.1-96.7	90.4	3.3-15.9	9.6	-	Native Ag
7	41.3-73.8	62.0	26.0-58.7	37.8	-	Ag - Cu alloy
2	49.7-61.9	55.7	26.6-32.9	29.7	14.5	Jalpaite – Ag ₃ CuS ₂
1	55.1		28.6		16.33	Stromeyerite - AgCuS

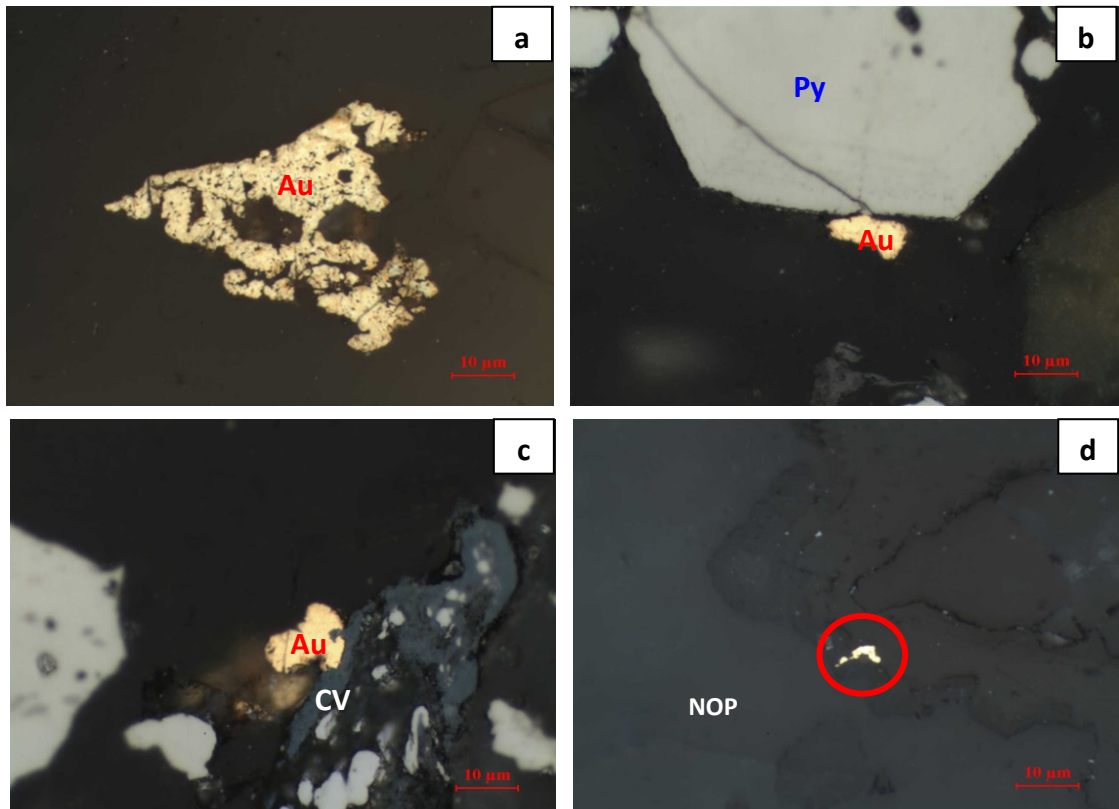


Fig.7 Photographies of gold grains (yellow) in the oxidized ore sample (**Comp.A**)
 a) – big free and partially porous grain; b) – free grain near pyrite (Pv); c) – confined to covellite (CV) and to dark (undetermined) minerals (NOP);
 d) – free (outlined by red), confined to dark (undetermined) minerals.

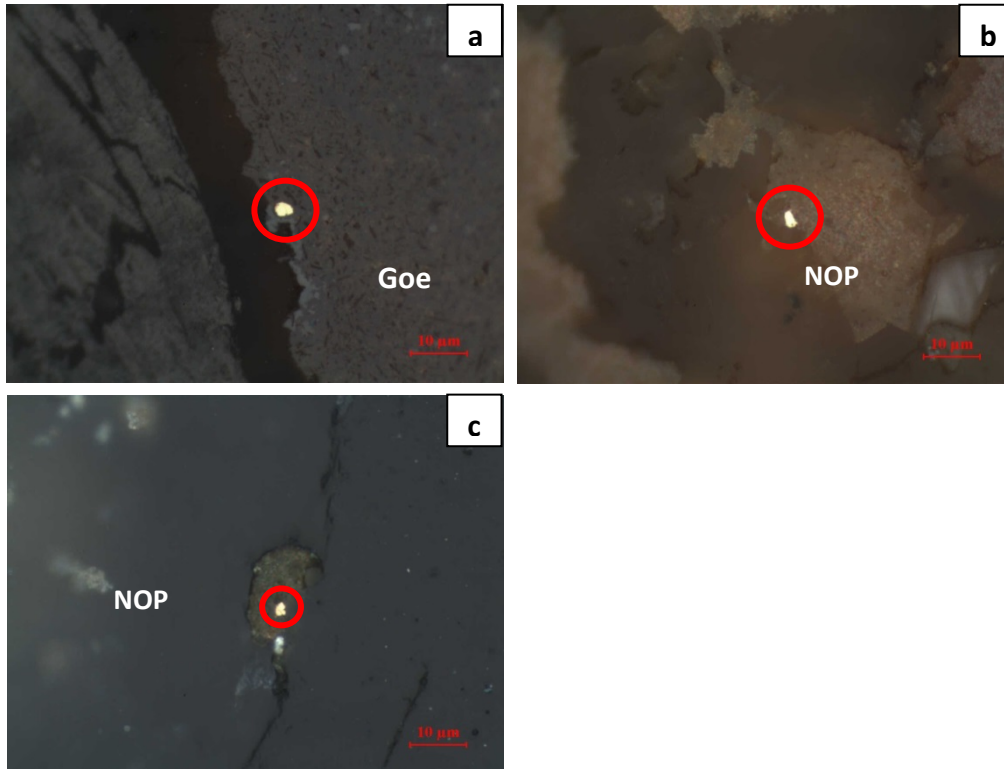


Fig.8. Photographies of small gold grains (outlined by red) in the oxidized ores sample (**Comp.A**)
 a and c) – enclosed in goethite; b) – enclosed in dark (undetermined) mineral (NOP)

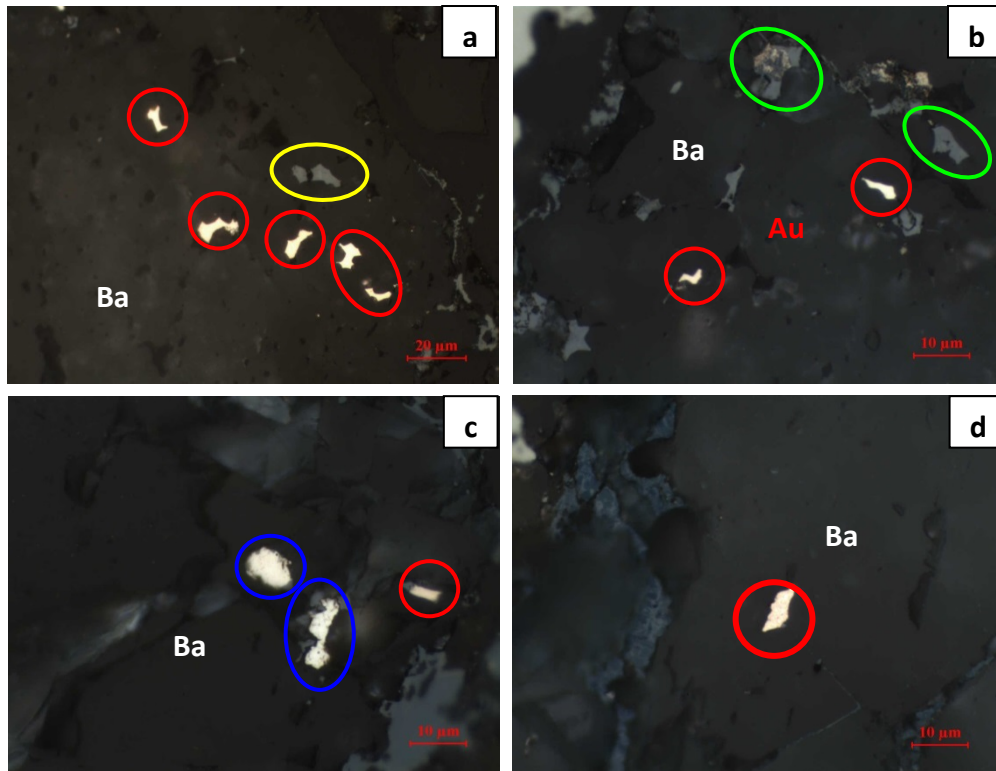


Fig. 9. Photographies of Ag minerals grains in the oxidized ores sample (Comp.A)

All minerals enclosed in barite:

- a) – Cu-Ag alloy (outlined by red) and stromeyerite -AgCuS (outlined by yellow);
- b) – Cu-Ag alloy (outlined by red) and jalpaite Ag_3CuS_2 (outlined by green);
- c) – Cu-Ag alloy (outlined by red) and native silver (outlined by blue);
- d) – Cu-Ag alloy (outlined by red).

3.3.2. The primary ores sample - Composite B

21 gold grains were revealed during microscopic investigations of six polished sections of the sample (Comp.B). All of them were found in the previously enriched sample material - Au concentrate. Locations (name of ore concentration product), the sizes and assemblages forms of the detected gold grains have been presented in Table 16 but their chemical composition (according to microspectral sounding data on Au and Ag) - in Table 17. In addition the microphotographs (optical image) of some revealed gold grains in the considered sample have been shown in Fig. 10.

Table 16

The sizes and forms of the gold assemblages in the primary ores sample (Comp.B)

№ grains	Product of Au grain detection	Au grains sizes, μm				Assemblages forms
		Length	Width	Area, μm^2	Estimated diameter of grain	
1	Au concentrate	2	1	2	1	Enclosed in pyrite
2	Au concentrate	1	1	1	1	Enclosed in pyrite
3	Au concentrate	2	1	2	1	--«--
4	Au concentrate	6	2	12	3	--«--
5	Au concentrate	1	1	1	1	--«--
6	Au concentrate	7	4	28	5	Confined to pyrite

7	Au concentrate	3	1	3	2	Enclosed in bornite/ Chalcocite/covellite
8	--«--	2	2	4	2	--«--
9	--«--	2	1	2	1	--«--
10	--«--	5	2	10	3	--«--
11	--«--	2	2	4	2	--«--
12	--«--	1	1	1	1	--«--
13	--«--	2	1	2	1	--«--
14	--«--	5	4	20	4	--«--
15	--«--	6	4	24	5	--«--
16	--«--	2	1	2	1	--«--
17	--«--	3	3	9	3	--«--
18	--«--	7	3	21	5	--«--
19	--«--	10	8	80	9	Confided to in bornite/chalcocite/ covellite
20	--«--	4	3	12	3	--«--
21	--«--	75	50	3750	61	Free
Limits of the estimated diameter of grains					1 - 61	
Average diameter of all grains					6	

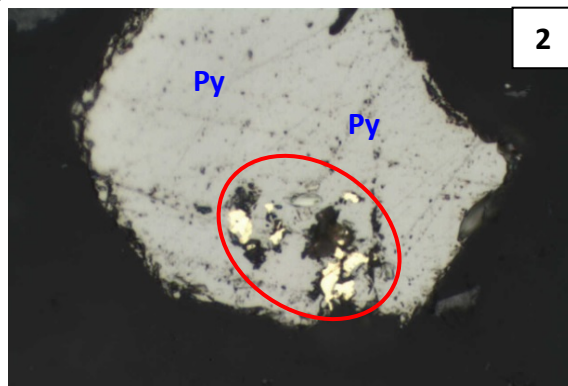
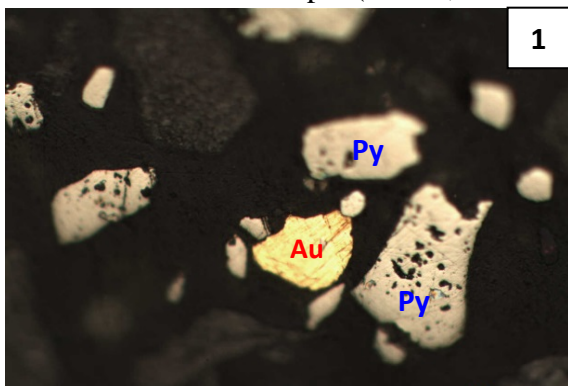
Table 17

**Resulting data of spectral sounding of some revealed gold grains
in the primary ores (Comp.B)**

Grains quantity	Elements content, %				Compounds name
	Au		Ag		
	Limits	Average value	Limits	Average value	
3	85.7-95.3	91.8	4.7-14.3	8.2	Native Au

According to the carried out research results (Table 16) the main quantity of gold grains detected in this ores sample are characterized by very small, almost dispersed forms included in iron sulphides (pyrite) and copper (chalcopyrite, covellite, chalcocite). Only one grain from 21 discovered grains is characterized as relatively large (61 μm) - free (Fig. 9, 1), three grains (with grain size of 3-9 μm) are evaluated as confided to the sulphides of copper and iron but the rest - 17 signs are presented by very small forms (mainly 1-3 μm) included (covered) in the mentioned sulphides.

According to microspectral sounding results of 3 gold grains (Table 17) they are classified as native gold. The content of the base metal in them ranges between 85.7 - 95.3 %, on average - 91.8%. It should be noted that this index of gold fineness is slightly lower than in the oxidized ores sample (96.7%, Table 13).



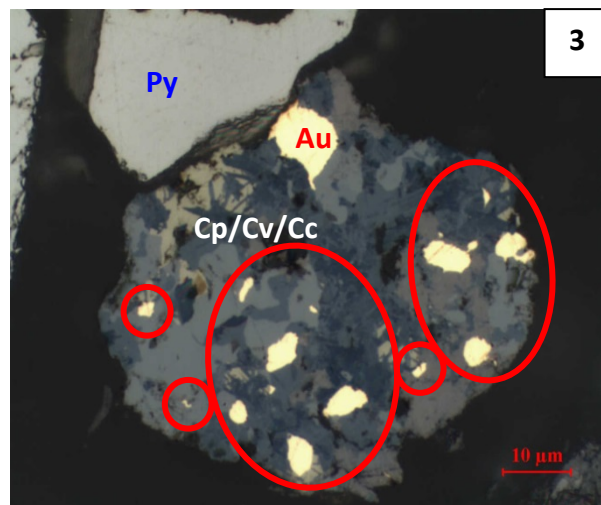


Fig. 10. Photographies of gold grains (yellow and outlined in red) in the primary ores sample (Comp.B) 1) - free; 2) - enclosed in pyrite (Py); 3) - enclosed in chalcopyrite/covellite/chalcocite (Cp/Cv/Cc)

CONCLUSION

Generally according to the mineralogical and petrographic investigations results of the mixed samples of the oxidized (Composite A) and primary sulphide ores (Composite B) can make the following conclusions.

The oxidized ores sample (Composite A)

1. The sample material is mainly presented by quartz (~ 80%), some quantity of the clay mineral - dickite (10%), iron oxide (5.5%) and by titanium (0.5%), barite (2%) and in small amount – by pyrite (1%).
2. Gold is characterized by the native state with a relatively small grains size in the sample material. Their main quantity (80%) is closely associated with light - non-metallic minerals (Table 11, the light fraction from separation of the sample material in heavy liquid).
3. 7 signs (grains) of native gold have been revealed in the water separation products of the heavy fraction, 6 of which are characterized by size in the range of 2-8 μm and one relatively large - 30 μm with a very porous structure.
4. According to assemblages forms two detected relatively large gold grains (8 and 30 μm) have been presented in free condition but the rest of them are in close assemblages and are partially covered (enclosed) by iron oxides.
5. According to microspectral sounding results almost all revealed native gold grains are characterized as high-standard ones with the base metal contents within 86.6-100.0% (on average 96.8 %).
6. 16 small grains of silver minerals (on average 5 μm) enclosed in barite have been discovered in the material of sample. The considerable part of these grains are characterized as Ag-Cu alloy, 2 grains - native form, 3 grains - copper-containing

minerals of silver sulphide: jalpaite and stromeyerite.

7. The determined Au and Ag occurrence forms allow to suggest with great probability that the most complete separation of gold from the oxidized ores can be provided only with relatively fine comminution of these ores (in the range of 80 - 90% -75 μm). In this regard the use of heap leaching method for this mineral raw material seems ineffective and unpractical. As for silver that the effective separation of this metal is unlikely.

The primary sulphide ores sample of (Composite B)

1. The mineral composition of the sample is mainly identical with the oxidized ores sample (Comp.A) at considerably higher content of pyrite (10%) and slight presence of iron oxides (1.3%) which allows characterizing it's as primary sulphide ore. It should be noted higher content of clay mineral - dickite (23%) in this sample.
2. Gold in the sample is also characterized mainly by small native grains, half of them (53%) is closely associated with iron sulphides and copper but the others - with light - non-metallic minerals.
3. 21 signs (grains) of gold have been detected in the gravity concentration product (gold "head") of the sample. Only one relatively large (61 μm) is presented in free state, 3 grains are confined and other 17 in the form of small inclusions are enclosed (1- 8 μm) in pyrite and copper sulphides (chalcopyrite, chalcocite, covellite).
4. According to microspectral sounding results of 3 grains the native gold is characterized by lower quality (on average Au - 91.8%) in the primary ores than in the oxidized ores sample (96.8%).
5. The detected occurrence forms of Au in the primary ores allow to suggest that the most complete extraction of this metal can be provided due to the effective separation of the iron sulphides and copper from this ores type. The last one can be carried out by flotation method of concentration. Moreover it should be noted that relatively large free grain of Au detected in the considered ores allows to suggest the possibility of their separation by gravitational methods of concentration before sulphides flotation.

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