Extraction of Gold from Sulfide and Sulfide-Polymetallic Ores from the Lok-Garabagh Structural-Formational Zone of the Lesser Caucasus

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Abstract

As a result of studying the size of gold particles, it was found that the ores of the Gedabek deposit contain both finely dispersed and coarser gold. Finely dispersed gold is extracted from ores by heap leaching, and coarser gold by flatation. When studying polished sections, it was found that free and bound gold is associated with the surrounding sulfide minerals - pyrite, chalcopyrite, arsenopyrite. In the Gyzylbulag deposit, the size of gold is larger - 0.015-0.02 mm. Such gold is extracted from ores by the method of flatation and gravity. The deposit contains quartz-pyrite-chalcopyrite, quartz-chalcopyrite and chalcopyrite-sphalerite mineral associations. Of these, quartz-chalcopyrite is more productive for gold. The Goshinsky gold deposit is usually found in early pyrite in a finely dispersed state (0.001-0.1 mm) and is extracted from ores by agitation cyanidation. Dagkesaman deposit gold size varies within 0.001-0.025 mm extraction of gold from pyrite-polymetallic ores by gravity.

Key words: pyrites, gold, native gold, flotation, granulometric composition.

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Lok-Qarabağ struktur-formasion zonasında olan kolçedan və kolçedan-polimetal yataqlarının filizlərindən qızılın ayrılması

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Annotasiya

Qızıl hissəciklərinin ölçülərinin öyrənilməsi nəticəsində müəyyən edilmişdir ki, Gədəbəy yatağının filizlərində həm incə dispers, həm də daha iri dənəli qızıl zərrəcikləri mövcuddur. İncə dispers qızılın filizdən ayrılmasında topa aşınma üsulundan istifadə olunur. Cilalanmış anşlifləri öyrənərkən müəyyən edilmişdir ki, sərbəst və əlaqəli qızıl sulfid mineralları - pirit, xalkopirit, arsenopirit ilə assosiasiyada olur. Qızılbulaq yatağında qızılın ölçüsü daha böyükdür - 0,015-0,02 mm. Qeyd edilən yatağın filizindən qızılın filizdən ayrılmasından flotasiya və qravitasiya üsulu ilə filizdən ayrılır. Yataqda kvars-pirit-xalkopirit, kvars-xalkopirit və xalkopirit-sfalerit mineral assosiasiyaları ayrılmışdır. Bu assosiasiyalardan qızıl üçün kvars-xalkopirit daha məhsuldar hesab olunur. Qoşa yatağında qızıl adətən ilkin piritdə incə dispers halında (0,001-0,1 mm) olduğundan filizdən sianitləşmə üsulu ilə çıxarılır. Dağkəsəmən yatağının qızılının ölçüsü 0,001-0,025 mm daxilində dəyişir, kolçedan-polimetal filizindən qızılın çıxarılması qravitasiya üsulu ilə həyata keçirilir.

Açar sözlər: kolçedan, qızıl, sərbəst qızıl, flotasiya, qranulometrik tərkib.

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Извлечение золота из руд колчеданных и колчеданно-полиметаллических месторождений Лок-Гарабахской структурно-формационной зоны Малого Кавказа

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Аннотация

В результате изучения размеров частиц золота установлено, что в рудах Гедабекского месторождения присутствует как тонкодисперсное, так и более крупное золото. Тонкодисперсное золото извлекается из руд методом кучного выщелачивания о более крупное методом флотации. При изучении аншлифов установлено, что свободное и связанное золото ассоциируется с окружающими сульфидными минералами – пиритом, халькопиритом, арсенопиритом. В Гызылбулагском месторождении размеры золота более крупные – 0,015-0,02 мм. Такое золото извлекается из руд методом флотации и гравитации. На месторождении имеются кварц-пирит-халькопиритовая, кварц-халькопиритовая и халькопирит-сфалеритовая минеральные ассоциации. Из них более продуктивная на золото кварц-халкопиритовая. На Гошинском месторождением золото обычно находится в раннем пирите в тонкодисперсном состоянии (0,001-0,1 мм) и извлекается из руд методом агитационного цианирования. Размеры золота Дагкесаманского месторождения варьируют в пределах 0,001-0,025 мм, извлечение золота из колчеданно-полиметаллических руд происходит методом гравитации.

Ключевые слова: колчедан, золота, самородного золота, флотация, гранулометрический состав.

Introduction

The Lok-Garabagh structural-formational zone (SFZ) occupies the northeastern part of the Lesser Caucasus and covers certain ore regions in the territory of Azerbaijan, where a number of gold-bearing deposits of pyrite formations - Gedabek, Gyzylbulag, Gosha and Dagkesaman are located.

As it is known, the effective extraction of gold from gold-bearing pyrite deposits of significant change depends on a number of its typological and morphological features, including the size of gold particles (granulometric composition), gold-bearing mineral associations and occurrence forms.

Taking into account the above, based on our own factual materials and mineralogical studies the granulometric composition and gold-bearing mineral associations, have been studied which are of great practical importance in the extraction of gold from the ores of the described deposits. The results obtained give us the opportunity to choose the right technological scheme for the extraction of gold from ores of pyrite and pyrite-polymetallic deposits of this structural-formational zone.

As it is known, the particle size of gold in ores varies from fractions of a millimeter to tens, rarely larger. Its size depends on a number of factors: the amount of gold carried by gold-bearing solutions to the place of their discharge, the composition of solutions, the physicochemical conditions of gold deposits, etc.

At the Gedabek deposit, it has been found out that the size of gold varies over a wide range from finely dispersed to coarser. Finely dispersed gold, having a dimension of 0.01-0.005 mm, is not captured under a microscope, even in an electron microscope with its maximum magnification, its determination is difficult. Only analytical studies allowed to reveal its presence in quartz-pyrite types of ores. Currently, gold is extracted from the named ores of the Gedabek deposit using the heap leaching method.

Larger gold is noted in the pyrite-chalcopyrite-sphalerite association, which is productive for gold. The sizes of native gold here are variable and range from 0.01-0.3 mm. This is probably due to the redeposition and enlargement of fine and finely dispersed gold found in ores of the early quartz–pyrite association [2]. Native gold of this size (0.01-0.3 mm) is easily captured by gravity and flotation.

Gold taken from samples of various types of ores is characterized by larger segregations (0.01-2.5 mm, in some cases up to 3.0 mm).

Thus, as a result of studying the size of gold particles, it has been determined that both finely dispersed and relatively coarse gold are present in the ores of the Gedabek deposit. This is, apparently, explained by the non-simultaneous formation of the main masses of gold particles and its participation in various mineral parageneses [4]. These large segregations of gold are extracted from various types of ores by the flotation method.

Gold-bearing mineral associations. The study of the mineral association of gold with the surrounding sulfide minerals is of great practical importance when extracting it from gold-bearing sulfide ores, and is also important for developing search criteria for these deposits. As it is known [4], the dominant mineral associations of gold in all genetic types are associated with sulfides and quartz, where gold is usually xenomorphic.

When studying polished sections made from primary and oxidized ores, it was determined that free and bound gold associates with the surrounding sulfide minerals - pyrite, chalcopyrite, arsenopyrite, chalcocite.

The data obtained are also confirmed as a result of rational analysis.

Thus, as a result of this analysis, it was found out in the ores of the Gedabek deposit, the predominant amount of gold is in the free state (43.0%) and in intergrowths with late sulfide minerals (pyrite, chalcopyrite) 45.3%. The content of gold in iron hydroxides and sulfide minerals is low (4.8 and 6.6%, respectively), and in quartz - 0.3% (Table 1).

Table 1 – Results of phase analysis of noble metals (according to A.Z. Akhmedov, A.V. Shibaeva 2015)

№	Forms of finding precious metals	Absolute content, g/t		Distribution in ore, %	
		Au	Ag	Au	Ag
1	Free with clean surface	4,25	2,52	43,0	8,3
2	In intergrautes with an open surface	4,48	3,32	45,3	10,9
3	Contained in iron hydroxides and carbonates	0,47	18,85	4,8	62,0
4	Contained in sulfide minerals	0,65	5,08	6,6	16,7
5	Contained in quartz	0,03	0,64	0,3	2,1
Total:		9,88	30,41	100	100

The studied ore, after the removal of free gold from it by gravity processes (settlement, enrichment at locks), can be directed to flotation enrichment. Since the ore contains gold embedded in sulfides (about 6.6%), flotation allows such sulfides to be extracted into a concentrate. For the processing of tailings of gravity and flotation concentration of gold ores, well-known methods of heap leaching can be used.

In general, considering the high content of cyanidable gold, it can be assumed that the most effective technological method for its extraction is agitation leaching with weak solutions of cyanide salt.

Granulometric composition of gold of the Gyzylbulag deposit. The sizes of gold grains from the ores of the Gyzylbulag deposit have been studied from observations in polished sections and the largest weight from samples of crushed ores. It has been determined established that in polished sections the dimension of gold ranges from 0.015 mm to 0.02 mm. Considering that the probability of detecting large particles in polished sections is low, it can be assumed that the given sizes deviate from the average ones to a smaller side and the average statistical sizes of gold are actually 0.04-0.05 mm (taking into account the data obtained from the samples). The particle size of gold extracted from ore samples ranges from 0.1 to 2.0 mm or more. These dimensions, of course, are not fully representative, since the smallest particles are not removed during crushing and washing.

The obtained results on the granulometric composition of native gold can be used when choosing a technological scheme for extracting gold from the gold-bearing ores of the Gyzylbulag deposit.

Gold-bearing mineral associations. In the composition of the ores of gold and gold deposits, mineral communities of different times (paragenesis) are established, representing equilibrium groups of minerals that arise under certain narrow physicochemical conditions of an intermittent staged process of ore deposition [3].

The Gyzylbulag deposit has the following stages of mineralization: quartz-pyrite-chalcopyrite, quartz-chalcopyrite and chalcopyrite-sphalerite. All named mineral associations are gold-bearing. However, the degree of gold content is different, more productive for gold is quartz-chalcopyrite. As a result of mineralogical studies, it was determined that at this stage of mineralization, gold is located inside chalcopyrite, as well as in intergrowths with basic sulfide minerals.

Table 2 - The results of the phase analysis of the of the Gyzylbulagskoe deposits ores (according to A.Z. Akhmedov and I.I. Rychkov, 1988)

№	The form of finding gold and silver	Distribution in % rel.		True content, g/t	
		Au	Ag	Au	Ag
1	Free gold with clean surface	17,2	1,8	0,78	0,12
2	Inter growth of gold, silver sulfides	67,2	28,6	3,05	1,87
3	Gold and silver in iron hydroxides	7,0	4,3	0,32	0,28
4	Gold and silver embedded in sulfide minerals	5,1	62,1	0,23	4,07
5	Gold and silver in silicates and quartz	3,5	3,2	0,16	0,21
Total:		100,0	100,0	4,54	6,55

As at can be seen from the table, according to the phase analysis with sulfides, there is about 67% of gold, 17.2% is free gold, extracted by amalgamation 7.0% in iron hydroxides, 5.1% is contained in sulfide minerals, only 3.5% of gold It is enclosed in silicates and quartz and is not opened when the ore is crushed to 0.074 mm.

It should be mentioned that in the Gyzylbulag deposit, a small part of gold may be in a finely dispersed form, or partially in a chemically bound state in chalcopyrite. As is known, early generation is constantly present in pyrite deposits, represented by fine particles dispersed in pyrite and arsenopyrite.

The granulometric composition of native gold from the Goshinsky deposit was studied using sieve analysis and in polished sections made from primary and oxidized ores, as well as from the oxidation zone.

As it a result of sieve analysis, it was found that in the ores of the Gosha deposit, the granulometric composition of native gold is very variable (0.05-0.2 mm) in both primary and oxidized ores enriched in gold.

In quartz-pyrite ores of this deposit, gold is usually found in early pyrite in a finely dispersed state (0.001-0.01 mm), which is easily involved in the cycles of chemical dissolution, migration and redeposition in ores and rocks. Relatively large segregation of gold is noted in quartz-gold-telluride types of ores (from 0.001-0.03 mm), where gold is closely associated with late sulfides, including hessite. Gold, in the oxidation zone, is characterized by relatively large sizes (0.01-0.065 mm). The enlargement of gold grains may be due to the redeposition of finely dispersed gold from sulfides of the early association.

According to the researchers [5], mechanical enrichment methods can be quite effectively used for the primary ores of this deposit and the larger gold associated with late sulfides is easily captured during gravity enrichment, and combined technologies, including, along with mechanical, hydrometallurgical methods of opening raw materials should be used for oxidized ores, which are hard-to-enrich mineral raw materials.

Gold-bearing mineral associations. One of the important factors for the technological evaluation of gold ores is the location and nature of the association of gold with various sulfide minerals that make up these ores.

The locations of gold in the described deposit are different: finely dispersed, free, bound (in aggregates). As noted above, it is impossible to detect finely dispersed gold in pyrite from quartz-pyrite types of ores under a microscope. However, semi-quantitative spectral analysis in the monomineral fraction of pyrite revealed the presence of gold from 0.8 to 2.0 g/t. At the same time, individual samples are characterized by higher contents (10.0-12.0 g/t). Apparently, this is due to the presence of later superimposed gold in some pyrite crystals. The results obtained suggest that early pyrite contains gold and it is in a finely dispersed state.

The studies carried out made it possible to obtain new objective data confirming the idea that submicroscopic gold is found in pyrite in a finely dispersed state. The results of technological research can be of great practical importance for the development of new rational schemes for the extraction of dispersed gold from quartz-pyrite concentrates. The results of the conducted studies suggest that gold in this fuld was deposited as part of mineral associations of all stages of mineralization, and its largest amount is related to with the initial stages of ore formation. Here, finely dispersed and binely visible gold was deposited during pyrite crystallization. Gold of the late association has a sharply subordinate significance and is accompanied by hessite-petzite aggregates. The data obtained are consistent with the results of phase analysis of the ores of the Gosha deposit. Thus, according to the data of phase analysis [14], 59.7% of gold in the ores of this deposit, is in easily accessible aggregates, 11.9% in iron hydroxides (goethite, hydrogoethite), and a small amount (6.0%) in sulfide minerals and 4.5% in quartz (Table 3). Table. 3 indicates that gold in the primary ores of this deposit is largely represented by easily accessible forms, which make it possible to ensure relatively high rates of their extraction by mechanical enrichment methods. Thus, the nature of the ores, the intergrowth of gold with late sulfides, and the occurrence of microcracks in quartz and pyrite testify to the superposition and later manifestation of gold mineralization in the Gosha deposit.

Table 3 - Results of phase analysis of gold and silver of Gosha deposits (according to A.Z. Akhmedov et al., 2002)

№	Form of finding gold and silver	Distribution in % rel.		True content in g/m	
		Au	Ag	Au	Ag
1.	Free with a clean surface	17,9	23,7	2,4	9,2
2.	Growth gold, silver sulfides	59,7	51,5	8,0	20,0
3.	Gold and silver in iron hydroxides	11,9	6,7	1,6	2,6
4.	Gold and silver enclosed in sulfide minerals	6,0	11,9	0,8	4,6
5.	Gold and silver in silicates and quartz	4,5	6,2	0,6	2,4
TOTAL:		100	100	13,4	38,8

Granulometric composition of native gold of the Dagkesaman deposit. It is known that the size of gold is one of the main factors determining the technological scheme for processing gold-bearing ore. Therefore, the study of the granulometric composition of native gold is of great practical importance. Thus, relatively large gold is released from other minerals during ore grinding, and the resulting free gold particles are easily captured during gravitational enrichment. Fine free gold floats well and quickly dissolves during cyanidation, but is almost not recovered during gravity enrichment. Finely dispersed gold, associated in most cases with sulfides, is only slightly revealed during ore grinding. Therefore, its bulk remains in mineral carriers, most often in pyrite and arsenopyrite. Ores containing such gold, as noted above, belong to the category of refractory and are processed by special methods [4].

When studying the granulometric composition of native gold, polished thin sections, as well as primary and oxidized ores (from sample mills) were used. It has been established that gold in primary ores is very fine. Its dimensions vary within 0.001-0.025 mm. In comparison with the latter, the gold grains found in the ore crushing sample are larger - 0.01-0.3 mm, less often up to 1.0 mm.

As it is known [1], in gold-polymetallic deposits, gold has later segregations and is intergrown with the main late sulfide minerals and less often with quartz, and also observed in cracks among previously formed minerals along the surface of their crystals and intergranular spaces. So, during the mineralogical study of the ores of this deposit, it was found that gold is also intergrown with sphalerite and quartz.

Gold is intergrown with galena and sphalerite in chalcopyrite. The results obtained showed that a large amount of gold was released from solutions in the form of free and bound (in intergrowths with late sulfide minerals) in the Dagkesaman deposit. These data are consistent with the results of phase analysis [6].

Table 4 - The results of the phase analysis of finding gold in the average sample (according to S.S. Aktaeva, 1984)

Forms of finding gold	Distribution, Au, Ag %		Au content, Ag g/t	
	Au	Ag	Au	Ag
Gold-free, amalmatable	36,2	39,3	3,4	0,22
Gold intergrown with sulfides and quartz-cyanided	51,0	48,5	4,6	3,7
Gold intergrown with sulfides and quartz, coated with films in Fe and Mn hydroxides	12,8	12,2	1,2	0,18
TOTAL:	100	100	9,2	4,1

Table 5 - Granulometric composition and gold-bearing associations of native gold

Gold-copper-pyrite	Gold-quartz-copper-pyrite	Gold pyrites	Gold pyrite polymetallic
Place of Birth			
Gedabek	Gizilbulag	Gosha	Dagkesaman
Granulometric composition, mm			
In polished sections: 0.001-0.03, In samples-milled ores: 0.01-2.0. Finely dispersed gold dominates	In polished sections: 0.14-0.2. In samples-milled ores: 0.08-2.0. Fine and fine gold predominates	In polished sections: 0.001-0.01 In samples-mills of ores: 0.1-0.063. Pulverized-finely dispersed gold dominates	In polished sections: 0.01-0.05 In samples-mills of ores: 0.01-0.25; less than 2.5. Powdered gold
Gold-bearing mineral associations			
The main one is pyrite-chalcopyrite sphalerite. Minor-quartz-pyrite-pyrite with fine gold	The main-quartz-chalcopyrite - sphalerite. Unproductive - quartz-pyrite with finely dispersed Gold	The main one is quartz-gold-telluride and quartz-gold-goethite-hydrogoethite. Unproductive-quartz-pyrite with fine gold	The main one is sulfide-polymetallic with galena. Unproductive - quartz-pyrite with finely dispersed gold

The table shows that in the analyzed sample, free gold is 36.2%, and gold in easily accessible aggregates is 51.0%, while the rest, approximately 12.8%, are in hard-to-reach sulfides (in pyrite, arsenopyrite) and quartz.

As it is presenteoit in Table 5, the granulometric composition of native gold in the ores of the described deposit is very variable 0.001-0.2 mm.

The typomorphic features of native gold determened, which are characteristic of ores of pyrite and pyrite-polymetallic deposits of this region, make it possible to evaluate and determine the most rational technological schemes for their processing, which, of course, will be of great practical importance in the industrial development of these deposits.

It is known, that effective extraction of gold from gold-bearing mineral raw materials largely depends on a number of its typomorphic features, including: the size of gold particles and forms of occurrence (free-visible, fine, dispersed enclosed in sulfides, various associations of intergrowths with other minerals, etc.).

According to a number of researchers [5], the size of native gold and the forms of its intergrowths with surrounding minerals are a very significant factor for determining the technological properties of gold-bearing mineral raw materials.

Large gold, being released from intergrowths during ore grinding, is easily captured during gravity enrichment, but it is difficult to float (due to its high specific gravity) and slowly dissolves when leaching with cyanide solutions.

Within the Lok-Garabag structural-formational zone of the Lesser Caucasus, there are a number of gold-bearing deposits of pyrite formation (Gedabek, Gyzylbulag, Gosh, Dagkesaman). At the same time, native gold in them has different typomorphic characteristics (Table 6). In this regard, the considered deposits of gold-bearing ores in this region are characterized by various technological methods for their processing (Table 6).

Fine gold in crushed ore is partly free and partly intergrown with other sulfide minerals. Free fine gold floats well, quickly dissolves during cyanidation, but is hard-to extract by gravity methods. Fine gold in intergrowths with an open surface is also successfully dissolved during cyanidation, and the flotation efficiency of such gold particles is determined by the flotation ability of the mineral associated with them. Some of these minerals can be characterized as practically non-floatable, which causes, accordingly, certain losses of gold with tailings (waste) enrichment.

Another important factor determining the technology for processing gold-bearing minerals is the degree of ore oxidation. This factor is usually established by the degree of oxidation of the sulfides contained in them. On this basis, ores are divided into primary, oxidized and mixed (semi-oxidized). Gold in the oxidized ores of the Gedabek and Gosha deposits is present in a finely dispersed state, which makes it necessary to extract it by agitation leaching (cyanidation) of finely divided material.

Technological types and methods of processing gold-bearing sulfide and sulfide polymetallic deposits of the Lok-Garabag structural-formational zone of the Lesser Caucasus are given in Table 6.

It should be noted that only Gedabek of the deposits considered in Table 6, is currently being industrialized. The oxidized ores of the Gedabek deposit are processed by heap cyanide leaching. For primary ores, the method of flotation enrichment is adopted to obtain copper and gold-bearing flotation concentrate. The latter is processed by vat agitation cyanidation.

Table 6 - Technological types and methods of processing gold-bearing ores of the Lok-Garabag structural-formational zone of the Lesser Caucasus.

№	Name of fields	Types ores	Mineral composition ores	Character-istics of gold	Mineral associations tions of gold	Technological ores features	
						Technolog ical type	Schems enrichment
1	Gedabek	Gold-copper-pyrites	Pyrite chalcopyrit sphalerite native gold	Small and fine dis-pers	Pyrite-chalcopyrit Spalerimerchandise	Gold Silver Copper	Heap and vat, propaganda leaching (cyaniing). Flotation
2	Gyzylbulag	Gold-quartz-copper-pyrite	Chalcopyrit Pyrite Quartz	Small and fine dispers	Quartz-chalcopyrhytes	Gold Silver Copper	Flotation Gravity
3	Gosha	Gold pyrite	Pyrite Extinguishes Petzit	Pulverized-new and fine dis-pers	Quartz Gold-Telluride	Gold Silver Kolchedan	Flotation propaganda cyanoing sulfide concentrate
4	Dagkesa-man	Gold-quartz-polyme-tallic	Galena Sphalerite	Pulverizedew and fine	Quartz-galena-sphalerite	Gold Silver Sphalerite Galena	Travitine Flotation

To extract gold in the deposit, a plant was built for processing complex ores using the heap leaching method, as a result of which, the extraction of gold from complex ores amounted to up to 70%. In order to reduce the loss of valuable components, a tank leaching plant was also built, which significantly increased the production of precious metals. The vat leaching technology has made it possible to recover more than 90% of the gold contained in the ore.

In the future, it is planned to build a gold processing plant in Azerbaijan, which will allow the production of pure gold of Azerbaijani production. At present, after the primary processing of ore mined from the Gedabek deposit, the resulting concentrate is sent to Switzerland to obtain refining gold.

The construction of such a plant in Azerbaijan will justify the investment, since the geological service of the Ministry of Ecology and Natural Resources of Azerbaijan has discovered, along with many already known, new deposits with unique gold reserves in Nakhichevan, Goygol, Dashkesan and other regions of the republic. This confirms the production potential and value of the country in the future as the owner of one of the main natural resources.

The technology for processing primary gold-copper ores of the Gyzylbulag deposit has been tested in semi-industrial conditions. Based on the results of these tests, a combined gravity-flotation technology was recommended with the production of high-quality gold flotation concentrate and gold-bearing copper concentrate, recommended for processing at a copper smelter with selective extraction of gold and copper from it.

The technology of other deposits (Gosha, Dagkesaman) has been tested and recommended based on the results of laboratory studies.

Conflict of Interests

The authors declare there is no conflict of interests related to the publication of this article.

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