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Metallurgy

Research and development of gold ore processing technology

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ABSTRACT
This paper presents the results of technological studies of two samples of gold-bearing ore from the gold-bearing deposit of Kazakhstan deposits 1 and 2. A comprehensive analysis of ore samples by X-ray fluorescence, X-ray phase, chemical, and mineralogical methods was carried out. The calculated initial gold content was determined, and X-ray fluorescence analysis showed that the main elements that make up the ore are oxygen up to 51% and silicon up to 33%. X-ray phase analysis showed the presence of more than 95% quartz and muscovite in the samples. The form of finding gold in the ore, according to the results of mineralogical analysis, is defined as free gold and gold in iron hydroxide. Silver is present in the studied samples in the form of various types of halides. An ore beneficiation scheme has been developed and presented, including gravity and flotation. Gravity enrichment was carried out in two stages, with the production of concentrate and tailings, with the maximum recovery of gold in concentrate up to 91%, flotation enrichment using butyl xanthate reagents and a blowing agent, was carried out in two stages with the production of main and control concentrates and final flotation tailings. The subsequent hydrometallurgical study of the ore was carried out to assess the effect of sodium cyanide on the extraction of gold, tests were performed on the leaching of the initial samples of the ore and the obtained flotation and gravity concentrates in the agitation mode, it was found that cyanide leaching is an effective method for processing the mineral raw materials of the gold-bearing deposit of Kazakhstan, and the obtained flotation concentrates, with the recovery of gold into solution under optimal conditions up to 98%. The results obtained make it possible to predict the effectiveness of the main technological stages in the ore processing scheme, technology optimization, and maximum gold recovery.

Keywords: mineralogical analysis, gold, ore, concentrate, gravity, flotation, cyanidation.

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Introduction

Enhanced environmental requirements and the task of increasing the complexity of the use of raw materials modify the assessment and reassessment of new gold fields and operated ones, respectively. Gold ores are usually characterized by a significant variety of material composition, which implies the use of a larger number of processes, schemes, and options to process them. The technology for processing of gold ores is complex and specific, and differences in the material composition, processing properties, and technological category of ores determine the methods of concentration and extraction, as well as the possibility of processing according to a single process scheme.

In connection with the depletion of reserves of free-milling and high-grade ores, new deposits with a low content of valuable components, a complex or variable mineral composition, and technologically refractory ores are put into operation. The complex, heterogeneous, and variable composition of ores within a single deposit complicates the processing scheme and causes the need to adjust technological modes, and sometimes it requires processing ores according to various process schemes [[1], [2], [3], [4], [5]]. Depending on enrichability, gold fields are classified as: - placer; - silica gold vein; - primary quartz carbonate-sulphide; - sulfide; - carbonaceous shales. Placer and silica gold vein fields are free-milling. Gold is extracted from solid sulfide ores as a by-product. When producing concentrates of non-ferrous metals such as copper, zinc, lead, and molybdenum, the technology for the concentration of gold-bearing carbonaceous shales has not been developed [[6], [7], [8], [9], [10]].

Primary quartz-sulfide deposits are the most common deposits of gold-bearing ores. These ores are divided into free-milling and refractory ones. When processing refractory ores by direct cyanidation or a combined method, including the stage of ore pretreatment and concentration by flotation, less than 60-75% of gold is extracted, while when enriching free-milling ores, more than 90% is extracted [[11], [12], [13], [14]].

Moreover, the qualitative and quantitative composition differs within the perimeter of one deposit; therefore, research on improving the efficiency of gold extraction, flotation concentration of crude minerals containing fine gold, and the use of gravity concentration methods are relevant.

Features of refractory ores are the presence of fine gold which is usually embedded in pyrite or other sulfides and is found in an unreleased form inside mineral particles of sulfides. The particle size of gold in such ores is usually less than 20 μm [[15], [16], [17], [18], [19], [20], [21], [22]].

Experimental part

Materials and basic methods. In this research, we used modern research and analytical equipment such as Optima 2000 DV atomic emission spectrometer (United States); D8 ADVANCE X-ray diffractometer; Thermo Nicolet Avatar 370 FTIR spectrometer; Venus 200 X-ray fluorescence spectrometer (PA Nalyical B.V., Holland), and AxioScope A1 optical microscope. MShL-22k ball mill (Russia) was also used;

Main results and analysis. The material composition of the base ore was studied and technological regimes were worked out for dressing and hydrometallurgical processing by cyanidation in order to extract gold into a productive solution.

To determine the material composition of the ore for the content of S_{total}, $S_{sulfate}$, $S_{sulfide}$, Au, Ag, CaO, and SiO_2 and for further research, ore pretreatment was carried out. The samples received were subjected to pretreatment operations such as averaging and quartering. The selected averaged samples were received for chemical, fluorescent, phase, and mineralogical analyses. The sample processing scheme is compiled for each deposit and each type of ore, taking into account the characteristics of the mineral and the size of the initial samples.

Table 1 – Results of X-ray fluorescence analysis of ore samples of gold-bearing deposits of Kazakhstan 1 and 2

Element	Content, %	Element	Content, %	Element	Content, %	Element	Content, %
Dep 1 (Deposit 1)							
O	51.59	S	0.357	Cu	0.023	P	0.031
Na	0.022	K	0.405	Zn	0.005	Fe	1.969
Mg	0.151	Ca	0.056	Rb	0.007	Pb	0.092
Al	1.658	Ti	0.082	Zr	0.002	Bi	0.003
Si	33.557	Mn	0.010	Mo	0.011		
Dep 2 (deposit 2)							
O	49.344	P	0.037	Mn	0.031	Zr	0.05
Na	0.087	S	**0.295**	Fe	**4.715**	Mo	0.009
Mg	0.270	K	0.494	Cu	0.079	Pb	0.092
Al	2.591	Ca	0.192	Zn	0.007	Ni	0.007
Si	29.566	Ti	0.117	Rb	0.010	Sr	0.004

In preparation for the research, the sample were mixed and reduced in accordance with the standard procedure with the allocation of weighed quantities for technological research and the study of the material composition.

Technological experiments including various methods of studying the material composition of the feedstock and microscopic studies provide data for characterizing the morphology of gold and the degree of its association with ore components. The detailed elemental composition of the base ore samples of gold-bearing deposits of Kazakhstan 1 and 2 (Table 1) was determined by fluorescence analysis which allows to capture of the spectra of elements from beryllium to uranium. The results are shown in Table 1.

According to the results of the analysis, we can conclude that the studied samples contain oxygen (O) at 51.59% for Dep 1 and 49.34% for Dep 2, and silicon (Si) at 33.55% for PK1 and 29.56% for Dep 2. The sulfur content (S) is low and amounts to 0.36% for Dep 1 and 0.29% for Dep 2. The content of Al is 1.65 and 2.59%, respectively.

The main composition of the rock-forming components was determined by X-ray phase analysis. The survey was carried out using the D8 Advance (Bruker) apparatus (α-Cu, tube voltage 40 kV, current 40 mA). Processing of the obtained data of diffraction patterns and calculation of interplanar distances were carried out using the EVA software. Sample decoding and phase search were performed using the Search/match program with the use of the 2020 PDF-2 powder diffractometric database. The results of the X-ray phase analysis are shown in Table 2.

According to the research results, the crystalline part of the image studied consists of quartz (Dep 1 97.3% and Dep 2 95.9%) and muscovite. The research data give grounds to assume that the technological type of ore under study is silica gold.

The subsequent mineralogical analysis made it possible to establish the main forms of finding gold in the rocks of mineral raw materials.

To establish forms of gold deportment, ore samples of gold-bearing deposits of Kazakhstan 1 and 2 were mineralogically analyzed. A polished section (∅ = 25 mm, weight = 10-15 grams) formed from this material was studied under an optical microscope AxioScope A1.

Mineralogical analysis of ore samples with a size of up to 0.1 mm in order to study the ore mineral composition and forms of gold deportment. The study was carried out using an OLYMPUS-BX 51m microscope in reflected light, and mineralogical analysis was carried out using an electron probe microanalyzer.

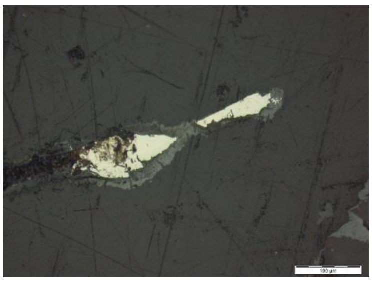
To perform the analysis, the sample was divided into heavy and light fractions. According to the method, heavy fractions were isolated in a heavy liquid with a specific gravity of 2.9 g/cm^3 with the subsequent production of polished artificial briquettes.

Mineralogical analysis in reflected light. Examination of Dep 1 sample. According to the results of the study, non-metallic minerals that make up more than 95% of the area of the polished section 1 were determined as quartz grains of grayish-milky-white color and mica, which was confirmed by X-ray analysis (quartz 97.3% and muscovite 2.7%). The copper mineralization of the secondary sulfide enrichment zone is represented by pyrite. In this sample, iron-containing minerals and oxidized minerals account for about 2-3% of the area of the polished section. Under the reflected light microscope, pyrite occurs in the oxidation zone of iron oxides. The inclusion of large sizes up to 2 mm is shown in Figure 3. Pyrite is white with a brass-yellow tinge and shows high reflectivity. Iron hydroxides are often found to be light gray, have brown internal reflexes, and be isotropic (Figure 1).

Table 2 – Results of X-ray phase analysis of the initial sample of gold-bearing deposits of Kazakhstan 1 and 2

Range	Name	Formula	Content, %
Dep 1			
PDF 01-085-0865	Quartz	SiO_2	97.3%
PDF 00-003-0849	Muscovite	H4K2(Al,Fe)6Si6O24	2.7%
Dep 2			
PDF 01-085-0865	Quartz	SiO_2	95.9 %
PDF 00-003-0849	Muscovite	H4K2(Al,Fe)6Si6O24	4.1 %

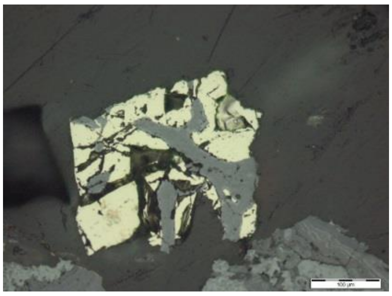
This figure shows the collomorphic structure of limonite. The size reaches up to 1.5-2 mm. There are also grains that are non-metallic and impregnated with iron oxides. Perhaps this is a clayey substance or fine sedimentary rocks (Figure 1). 1000x magnification found no visible gold grains.



Relic of pyrite in iron hydroxides. 200x magnification

Figure 1 – Mineralogical analysis in reflected light

Examination of Dep 2 sample. X-ray phase analysis showed the content of the crystalline phase: quartz 95.9% and muscovite 4.1%. The sample is similar to the Dep 1 one. In this polished section, the grains are larger and have a collomorphic structure, iron hydroxides are larger in % content, and the grain size reaches up to 3 mm. Both free single grains of pyrite and iron hydroxides were found (Figure 2).

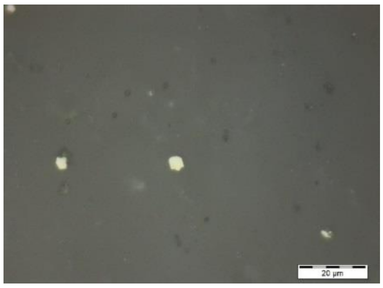


Relic of pyrite in iron hydroxides.200x magnification

Figure 2 – Mineralogical analysis in reflected light

Mineralogical analysis using an electron probe microanalyzer. The polished section is made of heavy fractions. The sample mainly consists of fragments of iron hydroxides such as goethite, limonite, and rarely hematite. There are single grains of pyrite which are usually found in the form of relics in iron oxides and hydroxides, less often in the form of free grains (Figure 3). Thorough scanning of the briquettes under a conventional microscope at 200x magnification revealed no gold; at 1000x magnification, gold was found. To confirm the presence of gold in the sample, the surface of the briquette was studied by X-ray spectral microanalysis using the Superprobe 733electron probe microanalyzer (JEOL, Japan). Analyses of the elemental composition of minerals (microinclusions) and photographs of various types of radiation were performed using an energy-dispersion spectrometer manufactured by OXFORD INSTRUMENTS (England).

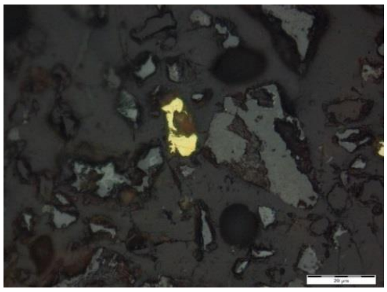
Scanning the briquette found two grains of gold in iron hydroxides (Figure 4) with a % content of Fe 3.98; Ag 0.15; Au 95.87, and the second point with a content of Fe 11.61; Ag 0.08; Au 88.31.



Free grain of pyrite. 1000x magnification

Figure 3 – Mineralogical analysis using an electron probe microanalyzer.

The gold-bearing deposit of Kazakhstan 2 (Dep 2) sample is similar in mineral composition to the Dep 1 sample. The inclusions are dominated by hydroxides and iron oxides. Free grains of pyrite are also present in a small amount (Figure 4); it is mainly found as relics in iron hydroxides.



Pyrite in iron hydroxide. 1000x magnification

Figure 4 – Mineralogical analysis using an electron probe microanalyzer

Study of the material composition of the initial samples (Dep 1 and Dep 2). The ground material of two initial samples of gold-bearing deposits of Kazakhstan 1 and 2 was received for the study of the material composition. In order to concentrate useful and accompanying ore minerals from samples in a heavy liquid with a specific gravity of 2.9g/cm^3, heavy fractions were isolated with subsequent production of polished artificial sections (briquettes). The briquettes were scanned, and hydroxides and oxides of iron predominated therein. Free grains of pyrite were found in a small amount, mainly as relics in iron hydroxides (Table 3).

Table 3 – Gold deportment in the initial samples of gold-bearing deposits of Kazakhstan 1 and 2

Deportment and content of Au, g/t					
Au_{free}, oxidized minerals.	Au is bound by a crystal lattice of minerals (iron oxides and hydroxides)*	Au with sulfide minerals	Au in quartz veins	ΣAu	Au_{total}
Base ore of gold-bearing deposit of Kazakhstan 1					
ND	3.15	<0.1	<0.01	3.25	3.25
Base ore of gold-bearing deposit of Kazakhstan 2					
<0.1	4.0	<0.05	<0.01	4.15	4.15

* Almost all of the gold in Dep 1 and Dep 2 is located in the nodes of the crystal lattices of minerals, represented mainly by oxide and hydroxide compounds of iron.

Gold-bearing deposit of Kazakhstan 1 sample. Scanning the briquette surface by X-ray spectral microanalysis found two gold crystals in iron hydroxides. Grain sizes are 0.003-0.005 mm. The first gold grain point contains Au 95.87%, and the second gold grain point contains Au 88.31%. Along with gold, several grains of silver halides such as Ag, Br, Ag, and J were found (Figure 5). All grains are in the form of inclusions in iron hydroxides.

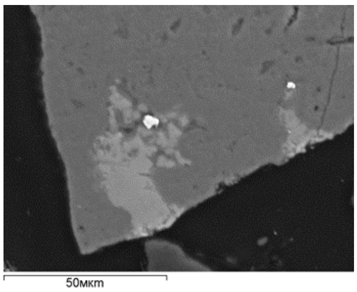
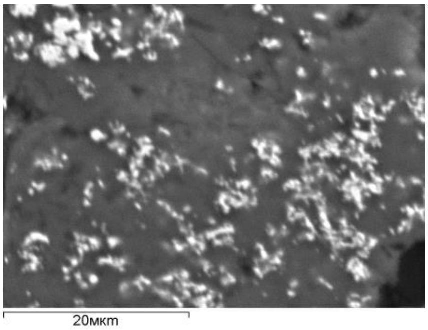


Figure 5 – X-ray spectral microanalysis of the Prirechnoye 1 sample. Gold grains in iron hydroxides

At the same time, silver which is part of the Dep 1 and Dep 2 samples, was found in compounds represented by various types of halides. Deportment of silver compounds, %: Cl 11.86; Br 9.94; Ag 76.79; I 1.42.

Gold-bearing deposit of Kazakhstan 2 sample. The mineral composition of the sample is close to the one described above. The briquette was scanned, and grains of iron hydroxides with fine dispersion inclusiveness were found therein, which, according to the analysis, is represented by gold (Figure 6). Gold is found in iron oxides in the form of tiny grains with a size of less than 1 µ.



Inclusions of the smallest grains of gold in iron hydroxide

Figure 6 – X-ray spectral microanalysis of the gold-bearing deposit of Kazakhstan 2 sample

Thus, Figure 6 shows the facts of the occurrence of inclusions of gold particles with thin inclusions in iron hydroxides. The shape of the goldenrods is diverse and can be spherical, rounded, monolithic, hooked, elongated, or incorrect. The surface of Au grains is both smooth with clear contours, and rough, relief.

Discussion of the results

Gravity concentration was studied using the base ore ground to 98% content of 0-0.071 mm fraction on a 3-inch Knelson KC-MD3 3 centrifugal concentrator with continuous unloading. This concentrator contains a rotating cone-shaped rotor with two grooves in the upper part with clamping valves installed along the circumference. At the bottom of the grooves, there are holes for fluidizing water. During operation, the heavy fraction accumulates in the grooves, and the valves are periodically opened to discharge the accumulated concentrate. The concentrate output varies depending on the frequency and duration of opening of the clamping valves.

The raw material in the form of pulp is fed into the rotor through a feeding pipe on the bottom of the cone. Under the action of centrifugal forces, the pulp is thrown against the wall of the cone and, moving to the threshold, stratified. Heavy minerals settle on the inner surface of the cone, slide to the gap and get inside the shell. Under the action of water supplied from the pipe, they are washed out through the threshold into the heavy fraction collector. The light fraction goes through the threshold into the receiver. The inner diameter of the threshold may be equal to, or less than, the inner diameter of the threshold. It depends on the location of the rotor axis, the magnitude of centrifugal forces, as well as on the mineral composition of the raw material. The output of the heavy fraction at a fixed value of the internal diameter of the threshold is controlled by the supply of water through the channels.

Research conditions: The diameter of the concentrator cone is 7.5 cm, the water flow is 3.5 L/min, the pressure is 25 kPa, and the acceleration of the gravitational fall is 60 g. Table 4 presents the results of gravity concentration.

Table 4 – Results of two-stage gravity concentration of Dep 1 and Dep 2 samples of the gold-bearing deposit of Kazakhstan

Product	Weight, g	Weight output, %	Au, g/t	E_{Au}, %
Dep-1				
Rougher concentrate	158.3	5.3	23.5	44.16
Scavenger concentrate 1	155.9	5.2	14.6	27.02
Scavenger concentrate 2	144.9	4.8	11.5	19.78
Final concentrate	**459.1**	**15.3**	**16.7**	**91.0**
Tailings	2540.9	84.7	0.3	9.0
Total	3000.0	100.00	2.81	100.00
Dep-2				
Rougher concentrate	144.8	4.8	39.25	47.61
Scavenger concentrate 1	142.3	4.7	19.7	23.48
Scavenger concentrate 2	141.5	4.7	15.3	18.14
Final concentrate	428.6	14.3	24.9	89.2
Tailings	2571.4	85.7	0.5	10.8
Total	3000.0	100.00	3.98	100.00

Before gravity concentration, Dep 1, and Dep 2 samples were ground in a ball mill to 90 % content of 0-0.071 mm fraction. The enrichment was carried out in one stage with the production of two main products, gravity concentrate and tailings. The obtained concentrates and tailings after drying were analyzed for the content of valuable components, and the concentrates of Dep 1 and Dep 2 samples were also used in further leaching experiments. The concentrates of the two stages were combined. The calculation of the balance of gravity concentration products showed that the estimated initial gold content in Dep 1 and Dep 2 is 2.81 g/t and 3.98 g/t, respectively. Thus, the discrepancy with the results of the analysis of the gold content in the initial PK 1 sample (3.21 g/t) is 12.5% (Discrepancy = (2.81/3.21 – 1.0) ×100%). In the Dep 2 sample with a gold content of 4.12 g/t, the difference in the enrichment balance was 3.4%.

Technological studies of flotation concentration were carried out with ground base ore of gold-bearing deposits of Kazakhstan 1 and 2. For flotation concentration experiments, Dep 1 and Dep 2 samples were ground in a ball mill to 90 % content of 0-0.071 mm fraction. Laboratory studies were carried out on standard laboratory flotation machines of the Mechanobr type with a chamber volume of 3.0 L. Flotation was performed at a ratio of solid particles in the pulp equal to 33%. Flotation concentration was carried out in two stages with the production of the main and Scavenger concentrates, as well as the final tailings of flotation.

During flotation studies, reagent regimes were carried out using the following reagents: For rougher flotation: pH 9.0; butyl xanthogenate 120 g/t; foamer C7 60 g/t; duration 10 min; for scavenger flotation: pH 9.0, butyl xanthogenate 60 g/t; foamer C7 30 g/t; duration 5 min. All the obtained concentrates and flotation tailings were dried for further analysis. Dep 1 and Dep 2 concentrates were used in subsequent gold leaching experiments.

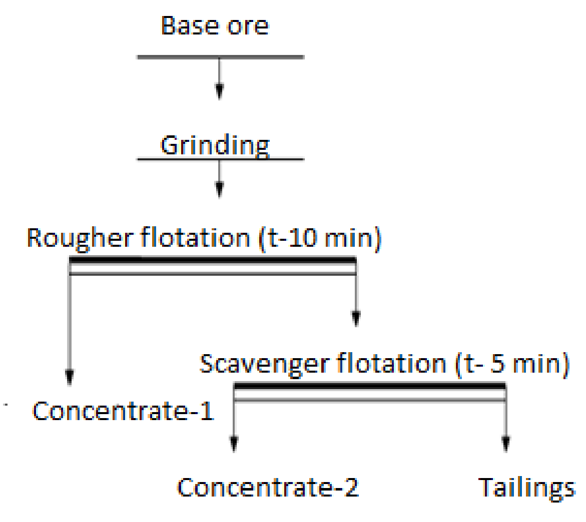


Figure 7 – Studies of flotation concentration; flotation scheme (gold-bearing deposit of Kazakhstan (1 and 2 deposits)

Figure 7 shows an experimental scheme for determining the optimal fineness of the floated material. The results of flotation concentration experiments are presented in Table 5.

Table 5 – Results of flotation of Dep 1 and Dep 2 samples ground to 90 % content of 0-0.071 mm fraction

Product	Weight, g	Weight output, %	Au, g/t	E_{Au}, %
Dep-1				
Rougher concentrate	215.6	10.8	29.0	83.64
Scavenger concentrate 1	139.7	7.0	4.2	7.85
Scavenger concentrate 2	75.4	3.8	2.2	2.22
Final concentrate	**430.7**	**21.5**	**16.3**	**93.7**
Tailings	1569.3	78.5	0.3	6.30
Total	2000.0	100.00	3.74	100.00
Dep-2				
Rougher concentrate	291.0	14.6	13.32	49.96
Scavenger concentrate 1	235.0	11.8	11.5	34.83
Scavenger concentrate 2	112.4	5.6	5.65	8.19
Final concentrate	**638.4**	**31.9**	**11.3**	**93.0**
Tailings	1361.6	68.1	0.4	7.0
Total	2000.0	100.00	3.88	100.00

The calculation of the balance of flotation concentration products showed that the estimated initial gold content in Dep 1 and Dep 2 is 3.74 g/t and 3.88 g/t, respectively.

Thus, the discrepancy with the results of the analysis of the gold content in the initial Dep 1 sample (3.21 g/t) is +16.5% When calculating the experimental error and estimated data, the discrepancy was (3.74/3.21 – 1.0) ×100%). In the Dep 2 sample with a gold content of 4.12 g/t, the difference in the enrichment balance was 5.83 %.

Hydrometallurgical studies of ore samples from the gold-bearing deposit of Kazakhstan (Dep1 and Dep 2) were carried out using samples ground to 80 % content of 0-0.071 mm fraction.

To assess the effectiveness of cyanide leaching for extracting gold from the raw materials of the Prirechnoye deposit, tests were performed on the leaching of base ore samples, gravity, and flotation concentrates. The study of the leaching process was carried out by tank leaching method with stirring activation [[18], [19]]. The data is presented in Table 6.

Leaching process mode. Cyanide (NaCN) concentration is 0.2%; duration of cyanidation is 24 h; pulp density during cyanidation is 30% solid; pH 10.5. The test sample was ground to 80 % content of 0-0.071 mm fraction, then pulped and tested in agitation mode, while controlling the alkalinity pH at 10.5. To ensure an initial pH value of 10.5, alkali NaOH was added to the sodium cyanide solution. Upon completion of cyanide leaching, the pulp was filtered, and the solid precipitate (cake) was analyzed for gold content.

Table 6 – Results of agitated cyanide leaching of gold-bearing deposit of Kazakhstan 1 and 2 samples

Option/conditions	Initial Au, g/t	$Cake_{Au}$, g/t	E_{Au}, %
Dep 1 base ore	3.21	0.08	97.51
Dep 2 base ore	4.12	0.13	96.84
Dep 1 rougher concentrate, gravity	23.5	3.83	83.70
Dep 2 rougher concentrate, gravity	39.25	20.0	49.04
Dep 1 rougher concentrate, flotation	29.0	0.54	98.14
Dep 2 rougher concentrate, flotation	13.32	0.61	95.42

The results of the studies show that during cyanide leaching of ground base ore of gold-bearing deposits of Kazakhstan 1 and 2, gold extraction in optimal modes is 97.51% and 96.84%, respectively. Gold extraction was calculated by the residual content in the cake.

Thus, the extraction of gold in optimal modes is in %:

- gravity concentration of gold-bearing deposit of Kazakhstan 1 and 2 ore: 91.0 and 89.2, respectively;
- gravity concentration of Dep 1 and Dep 2 ore followed by cyanidation of gravity concentrate: 83.70 and 49.04;
- flotation concentration of Dep 1 and Dep 2 ore: 93.7 and 93.0;
- flotation concentration of Dep 1 and Dep 2 ore followed by cyanidation of flotation concentrate: 98.14 and 95.42, respectively.

It follows from the data in Table 6 that the base ore of the gold-bearing deposit of Kazakhstan 1 and 2 and the flotation concentrates of the gold-bearing deposit of Kazakhstan 1 and 2 are well cyanized. Gravity concentrate of Dep 1 and Dep 2 is cyanidated slightly worse.

Conclusions

The technology for processing gold ores is specific and complex. For the complete recovery of the precious metal, a combination of various processing methods such as concentration and hydrometallurgical wats is used. The complex material composition, the scale of deposits, and environmental requirements require a comprehensive study of raw materials, analyses, and technological experiments. The ultimate goal of the research is to develop a technology with maximum recovery of the target metal. We carried out a technological assessment of ore from the gold-bearing deposit of Kazakhstan deposit (Dep 1 and Dep 2 samples), studied the material composition, and tested ore for the enrichment and efficiency of hydrometallurgical recovery of gold by agitated cyanide leaching. It has been confirmed that silica gold vein is the technological type of ore. Based on the study of the material composition and deportment of gold and associated minerals, it was proposed to conduct technological studies on gravity and flotation concentration, where greater efficiency and selectivity were shown in the flotation cycle; according to the results of the analysis, 93.7 % and 93.0 % passed into the scavenger concentrate for Dep 1 and Dep 2 samples, respectively. Gravity concentration has a lower efficiency in relation to this ore (91.0 % and 89.2 %) due to the loss of fine gold during the release of mineral grains. The proposed technology of ore processing of the gold-bearing deposit of Kazakhstan includes ore preparation (grinding to 80 % content of 0-0.071 mm fraction, flotation with a reagent composition: pH 9.0; butyl xanthogenate 120 g/t; foamer C7 60 g/t, with further agitated cyanide leaching by tank leaching method at a concentration of cyanide (NaCN) of 0.2; pulp density of 30% solid and alkalinity pH of 10.5). Further recovery of gold from the productive solution is possible by electrolysis after concentration by the ion exchange method.

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Алтын кенін өңдеу технологиясын зерттеу және дамыту

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ТҮЙІНДЕМЕ
Бұл жұмыста Қазақстандағы құрамында алтыны бар кен орындарының екі үлгісін –Кенорын 1 және Кенорын 2 үлгілерінің технологиялық зерттеулерінің нәтижелері берілген. Рентгендік флуоресценция, рентгендік фазалық, химиялық және минералогиялық әдістермен кен үлгілерін кешенді талдау жүзеге асырылды. Есептелген бастапқы алтын құрамы анықталып, рентгендік флуоресценциялық талдау кенді құрайтын негізгі элементтер ретінде 51%-ға дейін оттегі және 33%-ға дейін кремний болатынын көрсетті. Рентгендік фазалық талдау үлгілерде 95%-дан астам кварц пен мусковиттің барын көрсетті. Минералогиялық талдау нәтижелері бойынша кендегі алтын бос алтын және теміргидроксидіндегі алтын түрінде болатыны анықталды. Зерттелетін үлгілерде күміс әр түрлі галогенидтер түрінде кездеседі. Гравитациядан және флотациядан тұратын кенді байыту схемасы әзірленді және ұсынылды. Гравитациялық байыту концентратпен қалды өндірумен, концентраттағы алтынның максималды алынуы 91%-ға дейін, бутилксантогенатыре агентін және көбіктендіргішті пайдалана отырып флотациялық байытумен, негізгі және бақылау концентраттары және соңғы флотациялық қалдықтар алынатын, екі кезеңде жүзеге асырылды. Натрий цианидінің алтынды өндіруге әсерін бағалау үшін кеннің гидрометаллургиялық зерттеулері жүргізілді. Кеннің бастапқы үлгілерін және алынған флотациялық және гравитациялық концентраттарды араластыру режимінде шаймалау бойынша сынақтар жүргізілді. Цианидті шаймалау Қазақстандағы құрамында алтыны бар кен орнының минералдық шикізатын және одан алынатын флотациялық концентраттарды өңдеудің тиімді әдісі болып табылатынын және оңтайлы жағдайда 98%-ға дейін алтынды ерітіндіге қайтару мүмкін болатыны анықталды. Алынған нәтижелер кенді өңдеусыз басындағы негізгі технологиялық кезеңдердің тиімділігін, технологияны оңтайландыруды және алтынның максималды алынуын болжауға мүмкіндік береді.

Түйін сөздер: минералогиялық талдау, алтын, кен, концентрат, гравитация, флотация, цианидтеу.

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Исследование и разработка технологии переработки золотосодержащей руды

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АННОТАЦИЯ

В данной работе представлены результаты технологических исследований двух образцов проб золотосодержащей руды месторождения Казахстана– месторождения 1 и 2. Проведен комплексный анализ образцов руды рентгенофлуоресцентным, рентгенофазовым, химическим и минералогическим методами. Определено расчетное исходное содержание золота, так же, рентгенофлуоресцентныманализом показано, что основными элементами, составляющими руду, являются кислород до 51% и кремний до 33%. Рентгенофазовый анализ показал присутствие в пробах кварца, более, чем 95% и мусковита. Форма нахождения золота в руде, по результатам минералогического анализа, определена, как свободное золото и золото в гидроокисле железа. Серебро присутствует в исследуемых образцах в форме галогенидов различного типа. Разработана и представлена схема обогащения руды, включающая гравитацию и флотацию. Гравитационное обогащение проводилось в две стадии, с получением концентрата и хвостов, максимальное извлечение золота в концентрат до 91%, флотационное обогащение с использованием реагентов бутилового ксантогената и вспенивателя, проводилось в две стадии с получением основного и контрольного концентратов и итоговых хвостов флотации. Последующее гидрометаллургическое исследование руды проводилось для оценки влияния цианида натрия на извлечение золота, выполнены тесты по выщелачиванию исходных проб руды и полученных флотационных и гравитационных концентратов в агитационном режиме, установлено, что цианидное выщелачивание является эффективным способом для переработки минерального сырья золотосодержащего месторождения Казахстана, и полученных флотационных концентратов, с извлечением золота в раствор при оптимальных условиях до 98%. Полученные результаты позволяют прогнозировать эффективность основных технологических этапов в схеме переработки руды, оптимизации технологии и максимального извлечения золота.

Ключевые слова: минералогический анализ, золото, руда, концентрат, гравитация, флотация, цианирование.

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