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DETERMINATION OF SUBSTANTIAL COMPOSITION OF GOLD-BEARING RAW MATERIAL AND DEVELOPMENT OF TECHNOLOGY FOR ITS PROCESSING

Abstract: The studies to determine material composition of ore and develop the procedure for processing of oxidized ore from the western flank of Karyernoye deposit with complex mineral and phase composition and low gold content were conducted. Urgency of these studies is determined by difficulty of this type of crude ore processing, wherein basic metal - gold is scattered throughout various phases, its content is low, and its recovery is very complicated at processing the same raw materials at plants. The representative technological sample (TS-3) of initial ore, related to the oxidized type due to low content of sulfide sulfur, was taken. Based on substantial composition, it represents hydrothermally altered sandstone, silty sandstone and siltstone with veinlets of quartz or carbonate-quartz composition, and is characterized by gold-sulfide-quartz formation of the impregnated type. Phase and elemental compositions, forms of gold existence and nature of its bond with ore constituents were examined by chemical, X-ray phase, X-ray fluorescence, rational, and assay methods of analysis. Ore mineralization is pyrite, gold content in the sample is 0.44 g/t. Basic mineral constituents are quartz (45.0 %) and albite (3.5 %), whereas pyrite content is 1.4 %. According to the results of the rational analysis, gold is found in all four phases and mainly (72.4 %) presented in rock-forming minerals in the form of fine-grained gold, significant amount of gold (24.1 %) - in the form associated with crystal lattices of mineral carrier, and small amounts of gold occur in the form of native and quartz-covered. Three-stage ore gravity benefication was carried out, and maximum gold recovery to concentrate was 47.2%. Closed-cycle flotation benefication (3 times re-cleaning) allows recovery 64.7 % of gold into concentrate. Direct cyanide leaching of initial ore milled to –0.071 mm grain size class (80 % and 90 %) allowed converting from 86.3 % up to 90.9 % of gold into solution.

Key words: oxidized gold-bearing ore, flotation, gravitation, gravity concentrate, flotation concentrate, cyanidation

Introduction. So far, reserves of rich ores are practically depleted, thus requiring involvement of substandard raw materials with low content of valuable components into the production field. The known methods and techniques of processing of gold-bearing ores are not always justified in respect of these raw materials.

Quality of mineral raw materials from fields mined and prepared for development is continuously reduced throughout the world. Ores with low contents of useful components (poor, very poor, non-commercial), complex material composition and fine dispersion degree (complex or refractory) are gaining increasingly greater specific gravity. Use of traditional procedures for processing of these ores is hardly efficient, thus reducing investment attractiveness of facilities and restraining development thereof [1-4].

The traditional method of gold recovery from ores lies in flotation benefication, roasting and further cyanidation of cinder. Albion, Leachox, Nitrox, Arseno and other processes are applied to a lesser extent. Perspective methods of processing of gold-bearing rock include various types of hydrochlorination [5-7].

Most gold recovery plants (GRP) currently process ores which contain sulfide minerals. Gold in these ores is partially associated with sulfides, and partially present in a free state. In most cases, ores of this type belong to the category of refractory ones. These ores are usually beneficiated by flotation at modern gold recovery plants. Suffice it to say that the fraction of enterprises applying flotation comprises almost 90 %. Features of flotation as the gold recovery method is the possibility to recover gold in concentrate, not only free gold, but also that having close association with sulfides. Different gold recovery methods are used for processing of ledge gold-bearing ores, though the main one is cyanidation. Use of cyanides in gold mining is based on their unique property which consists in dissolution of this precious metal in presence of oxygen with formation of the complex compound being stable in the alkaline medium [8-11].

The purpose of this study is to examine material composition of feedstock with low gold content and develop the efficient method of gold recovery from the abovementioned type of gold-bearing ore.

Experimental part and discussion of results. The representative sample, i.e. technological sample (TS-3), was collected from the western flank of Karyernoye field for the purpose of studies. In terms of material composition it was oxidized ore which represented hydrothermally altered sandstone (quartz-carbonate), silty sandstone and siltstone with veinlets of quartz or carbonate-quartz composition having scattered pyrite impregnation. The ore under study is characterized by gold-sulfide-quartz formation of the impregnated type. Ore mineralization produces pyrite. When preparing for studies, the entire sample was crushed stage by stage to -0.071+0 mm grain size, divided, intermixed and reduced in accordance with the standard procedure, along with collection of samples (subsamples) for process studies and examination of chemical composition.

Individual samples were collected from ore crushed and milled to 80 % of -0.071 mm and 90 % of -0.071 mm grain size classes in order to perform chemical, assay, X-ray phase, X-ray fluorescence, and rational analyses. The following analysis methods were also used to determine chemical composition: atomic absorption and assay gravimetric ones. Chemical composition of the TS-3 is as follows, % wt: Fe_2O_3 – 2.65; $Fe_{ox.}$ – 1.28; SO_4 – 0.13; $S^{2+}_{(sulfate)}$ – 0.043; $S^{2-}_{(sulfide)}$ – 0.287; C_{total} – 0.4; $C_{organic}$ < 0.1.

According to the results of the TS-3 sample assay analysis, content of Au is 0.44 g/t.

Moreover, phase and elemental compositions were examined using X-ray phase and X-ray fluorescence analysis methods. The results are given in Tables 1 and 2

Table 1 – Phase composition of initial ore

Name	Formula	S-Q, %
Quartz, syn	SiO_2	45.0
Albite	$Na(AlSi_3O_8)$	3.5
Muscovite-2M1	$(K, Na)(Al, Mg, Fe)2(Si_{3.1}Al_{0.9})O_{10}(OH)_2$	2.4
Calcite	$Ca(CO_3)$	2.1
Iron oxide	Fe_3O_4	1.5
Pyrite	$Fe_{0.98}7S_2$	1.4
Gypsum	$Ca(SO_4)(H_2O)_2$	1.1

Basic phase mineral constituents are quartz and albite. Their mass fractions in samples are 45 % and 3.5 % respectively. Pyrite content in the sample is 1.4 %. It can be mentioned according to the results of the phase analysis that the basic component (gold) is associated with silicon-containing mineral such as quartz, and occurs in sulfide minerals such as pyrite and arsenic pyrite, which in their turn represent gold-bearing minerals.

Results of the X-ray fluorescence analysis of initial ore are given in Table 2.

Table 2 – Element composition of initial ore

Name of elements	Content in samples, %	Name of elements	Content in samples, %
O	52.3	V	0.01
Ti	0.23	Cr	0.01
Na	**1.46**	Mn	0.03
Mg	0.45	Fe	1.89
Al	**5.57**	Cu	0.005
Si	**30.3**	Zn	0.007
P	0.07	As	0.03
S	**0.33**	Rb	0.005
Cl	0.01	Sr	0.007
K	1.62	Zr	0.01
Ca	1.37		

Results of the rational (phase) analysis for gold of milled ore (TS-3 sample) with 90 % of -0.071 mm grain size are given in Table 3. These data show forms of gold existence in the mineral and nature of its bond with components of ore

Table 3 – Results of the rational (phase) analysis for gold

Forms of gold existence in the mineral and nature of its bond with components of ore	Gold distribution	
	Initial ore	
	g/t	%
fine-grained in rock-forming minerals	0.42	72.4
visible native	<0.01	1.75
associated with crystal lattice of mineral carrier	0.14	24.1
quartz-covered	<0.01	1.75
total in ore (according to the balance)	0.58	100

It was established as a result of the rational (phase) analysis that gold was found in all four phases. It is mainly present in rock-forming minerals in the form of fine-grained (72.4 %) gold, significant amount of gold (24.1 %) is in the form associated with crystal lattices of mineral carrier, and small amounts thereof occur in the form of native and quartz-covered gold.

Tests for gravity benefication, flotation benefication, and direct cyanidation of initial ore were carried out for the purpose of development of the efficient method of ore processing at the western flank of Karyernoye field (TS-3 sample).

Gravity benefication was performed using Knelson KC-MD3 3-inch centrifugal concentrator. Experiment conditions: concentrator cone diameter is 7.5 cm, water velocity is 3.5 dm^3/min, pressure is 15 kPa, and gravitational acceleration is 60 G. The three-stage benefication mode was developed to establish the most efficient gravity benefication.

Table 4 – Results of three-stage gravity benefication

Sample	Fraction	Name	Weight, kg	Yield, %	Au, g/t	Recovery of Au, %
TS-3 initial ore	90-100 %, -1.7 mm	First concentrate	3.2	12.8	0.47	13.8
	90-100 %, -0.5 mm	Second concentrate	1.56	6.24	1.88	26.7
	90-100 %, -0.071 mm	Third concentrate	1.52	6.08	0.48	6.7
	Combined concentrate		6.28	25.12	0.94	47.2
	Tails after three stages		18.72	74.88	0.31	52.8
Total			25.0	100.0	0.44	100.0

The data given in Table 4 show that 47.2 % of gold reacted to form concentrates of all three stages as a result of reduction to -0.071 mm during three-stage gravity benefication of initial (quarry) ore; gold content in combined concentrate comprised 0.94 g/t. The predominant portion of TS-3 initial ore gold is contained in crystal structures of light and organic minerals which do not concentrate in the bowl cone and are expelled by heavier minerals with insignificant gold content. The gravity benefication method is hardly efficient in this case.

Flotation benefication of the sample was then carried out to determine optimal parameters of gold recovery.

Ore reduction to -0.071 mm class was performed using the laboratory mill. The results of experiments on determination of amount of -0.071 mm class depending on reduction duration are given on Figure 1.

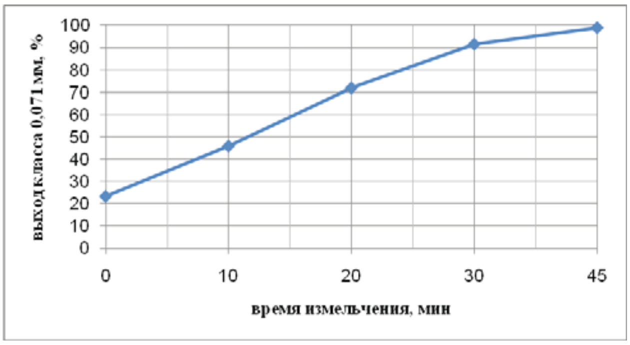

Figure 1 – Dependence of yield of -0.071 mm grain size class on grinding time

Laboratory studies were carried out using standard Mekhanobr laboratory flotation machines with chamber volume of 1.5; 0.75; and 0.5 dm^3. Flotation was performed in the following reagent scheme: butyl xanthate – collecting agent, activity according to the certificate – 84.5 %; T-80 – foaming agent, activity – 100 %; copper sulfate – activating agent, activity – 65 %; sodium sulfide – activating agent, activity – 100 %. Flotation was performed in main water with pH of 7-7.5 and pulp density of 30 %. Closed-cycle ore flotation experiments were carried out in the optimal mode on the basis of the study results obtained when determining the flotation and reagent schemes. The scheme of initial ore flotation in the closed cycle is

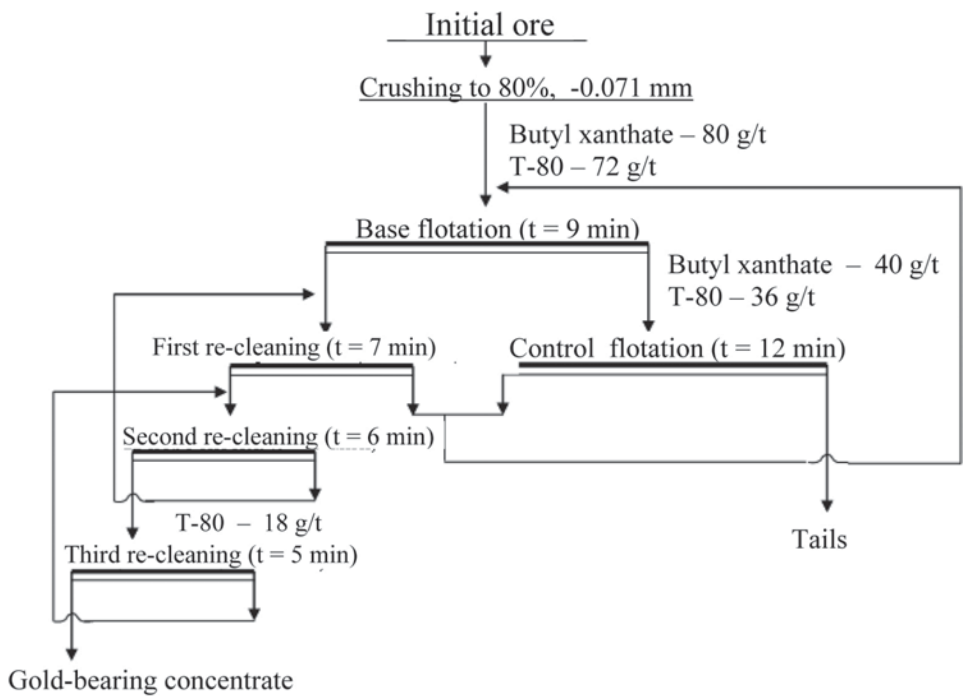

Figure 2 – Scheme of closed-cycle ore flotation

given on Figure 2.

According to the results of scheme experiments in the closed cycle given in Table 5, yield of gold-bearing concentrate was 3.54 % with gold content of 4.57 g/t and gold recovery to concentrate of 64.71 %.

Table 5 – Results of closed-cycle flotation experiments

Name of products	Yield, %	Content, g/t Au	Recovery, % Au
Concentrate	3.54	4.57	64.71
Tails	96.46	0.09	35.29
Ore	100	0.44	100.00

In order to study efficiency of gold leaching from initial ore, as well as to select the optimal cyanide leaching mode, agitation tests were performed by means of mechanical mixers and forced aeration using ore milled to -0.071 mm with different concentrations of cyanic solution. Results of cyanidation tests to determine impact of grain size of milled ore for indicators of TS-3 sample cyanidation, as well as 80 % of -0.071 mm and 90 % of -0.071 mm grain size classes are given in Table 6.

Table 6 – Results of cyanidation tests of TS-3 sample

Process conditions and results	Indicators			
	80 %, -0.071 mm		90 %, -0.071 mm	
	Test 1	Test 2	Test 1	Test 2
Sample weight, g	100	100	100	100
Solution volume, ml	400	400	400	400
NaCN concentration, %	0.05	0.1	0.05	0.1
pH	11.3	11.03	11.2	11.4
Duration, hours	24	24	24	24
With air supply	+	+	+	+
Content of Au in initial ore according to assay analysis, g/t	0.44	0.44	0.44	0.44
Content of Au in cake after leaching, g/t	0.05	0.06	0.04	0.04
Recovery degree of Au by cake, %	88.6	86.3	90.9	90.9

As can be seen from Table 6 data 88.6-90.9 % of gold is recovered during cyanidation of TS-3 initial ore sample, thus indicating that grain size of TS-3 ore reduction has impact on cyanidation indicators. The degree of recovery of gold from ore with 80 % of -0.071 mm grain size class comprises 88.6 %, and from ore with 90 % of -0.071 mm grain size class – 90.9 %.

Conclusions. Substantial composition of the technological sample was studied. Chemical, X-ray phase, X-ray fluorescence, rational, and assay analyses of initial ore were performed.

Methods of gravity, flotation benefication and direct cyanidation were used for the purpose of determination of the recovery degree of all gold phases.

Maximum gold recovery in concentrate under conditions of gravity benefication was 47.2 % with low quality of concentrates, whereas gold recovery under conditions of flotation benefication was 64.7 % after multi-stage re-cleaning, thus complicating the process.

This ore sample taken from oxidized zones of the field is easily cyanidable. Direct leaching of the TS-3 sample allowed converting from 86.3 up to 90.9 % of gold into solution.

Based on results of completed studies, it is recommended to process gold-bearing rock by direct cyanide leaching of initial ore milled up to 90 % of -0.071 mm grain size class.

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ТҮЙІНДЕМЕ

Карьерное кен орнының Батыс флангінің тотыққан кеніне өңдеу технологиясы бойынша зерттеулер жүргізілді, кендердің құрамында алтынның көрсеткіші төмен минералогиялық және фазалық құрамды күрделі. Зерттеудің өзектілігі зерттеліп отырған тау-кен шикізатын өңдеуге арналған жер қыртысының шөгінділерімен салыстырмалы түрде айқындалады, мұнда негізгі металл алттын көптеген фазалар бойынша алтын орналасқан , оны алу үшін зауыттардағы ұқсас шикізаттарды қайта өңдеу қиындайды. Сульфидті күкірт құрамының аздығынан тотыққан түрге жататын бастапқы кеннің өкілдік технологиялық үлгісі (ТП-3) таңдалады. Материалдың құрамы бойынша гидротермальды түрде өзгертілген құмтас, алеврогенді тастар және кварцтың, карбонат-кварц құрамы бар силтстондар болып табылады және таратылған түрдегі алтын-сульфид-кварцтың қалыптасуы. Фазалық және элементтік композициялар, алтын іздеу формалары және оның руда компоненттерімен байланысы химиялық, рентген фазасы, рентгендік флуоресцентті, рационалды және анализ әдісімен зерттеледі. Кенді минералдау - бұл пирит, ал алтын сынамадағы құрам - 0,44 г / т. Кварцтық минералдардың негізгі құрамдас бөлігі 45,0 % және альбит 3,5 %, пирит құрамының 1,4 %. Рационалды талдаулардың қорытындысы бойынша, алтынның барлық төрт фазасында табылғаны және негізінен (72,4 %) тау жыныстаушы минералдарда ұсақ дисперсті алтын түрінде табылған, ол минералдың минералының кристалдық торымен байланысты аз мөлшерде едәуір мөлшерде (24,1 %) кездеседі. табиғи және кварцпен жабылған. Рудалардың үш сатылы гравитациялық байытуы жүзеге асырылды, концентраттағы алтынның ең көп алынуы 47,2 % құрады. Флотация кезінде тұйық циклде байыту (3 тазарту операциясы) кезінде концентраттағы алтынның қалпына келуі 64,7 % құрады. -0,071 мм (80 % және 90 %) астық мөлшеріне ұсақталған түпнұсқа рудасын цианидпен шаймалау ерітіндіге 86,3-тен 90,9 % -ға дейінгі алтынның конвертациясына мүмкіндік берді.

Түйін сөздер: алтын кені, флотация, гравитация, гравиоконцентрат, флотациялық концентрат, цианидтеу

РЕЗЮМЕ

Проведены исследования с целью определения вещественного состава руды и разработки технологии переработки окисленной руды Западного фланга месторождения Карьерное сложного минералогического и фазового состава с низким содержанием золота. Актуальность исследований определяется сложностью переработки данного вида рудного сырья, где основной металл - золото, рассеян по многим фазам и содержания его низкие, извлечение его представляет трудности при переработке аналогичного сырья на фабриках. Отобрана представительная технологическая проба (ТП-3) исходной руды, которая относится к окисленному типу из-за низкого содержания сульфидной серы. По вещественному составу она представляет собой гидротермально измененные песчаники, алевропесчаники и алевролиты с прожилками кварцевого, карбонат-кварцевого состава и характеризуется золото-сульфидно-кварцевой формацией вкрапленного типа. Фазовый и элементный составы, формы нахождения золота и характер его связи с рудными компонентами изучены химическим, рентгенофазовым, рентгенофлуоресцентным, рациональным и пробирным методами анализа. Рудная минерализация – пирит, содержание в пробе золота 0,44 г/т. Основные составляющие минералы кварц - 45,0 % и альбит - 3,5 %, содержание пирита - 1,4 мас. %. По результатам рационального анализа золото обнаружено во всех четырех фазах и в основном (72,4 %) находится в породообразующих минералах в виде тонкодисперсного золота, значительное количество (24,1 %) в виде, связанном с кристаллическими решетками минерала носителя, в небольших количествах в виде

самородного и покрытого кварцем. Проведено трехстадиальное гравитационное обогащение руды, максимальное извлечение золота в концентрат составило 47,2 %. При флотационном обогащении в замкнутом цикле (3 перечистки) извлечение золота в концентрат составило 64,7 %. Прямое цианидное выщелачивание исходной руды, измельченной до крупности класса –0,071 мм (80 % и 90 %), позволило перевести в раствор от 86,3 до 90,9 % золота.

Ключевые слова: окисленная золотосодержащая руда, флотация, гравитация, гравиоконцентрат, флотоконцентрат, цианирование

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ПЕРСПЕКТИВЫ ИЗВЛЕЧЕНИЯ РЕНИЯ ИЗ ВУЛКАНИЧЕСКИХ ГАЗОВ. ОБЗОР

Резюме: В статье рассмотрены проблемы извлечения рения и других редких металлов из фумарольных газов вулкана Кудрявый на острове Итуруп. Дан обзор разработанных и запатентованных технологий извлечения ReS_2 из высокотемпературных вулканических газов, а также описано первое в мире месторождение рения, представленное фумарольным полем с действующими источниками глубинных флюидов. На основе комплексных физико-химических исследований газовых струй вулкана показан их стационарный характер, дана характеристика фумарольных кор, описан и подтвержден состав первого собственного минерала рения – рениита, дана оценка выноса металлов вулканическими газами, который может достигать 20-36 т/год. Основной вклад в валовый расход газов на вулкане составляет эмиссия с парящих площадок, достигающая 20000 – 30000 т/сут. при скорости 0,12–0,7 м/с, в то время как скорости газов мощных фумарол 8–120 м/с. Приведен обзор сорбционного метода выделения рения из сернокислых растворов ионитами различных марок. Сделан вывод о целесообразности извлечения рения, индия, германия и других металлов из единственного в России и мире месторождения, а фумарольные парогазовые выбросы вулкана можно рассматривать как новый тип уникального комплексного минерального сырья. Причем объем извлеченного рения может полностью удовлетворить потребности страны и исключить зависимость ее промышленности от импорта. Получать рений в промышленных масштабах планируется в 2020 году. Риски вложений в производство редкометалльного концентрата из газов экспертами считаются оправданными.

Ключевые слова: рений, фумарольные газы, улавливание, извлечение, сорбция, иониты, вулкан Кудрявый, остров Итуруп

Введение. Высокотемпературная редкометалльная парогазовая система вулкана Кудрявый на острове Итуруп уже четверть века привлекает внимание исследователей, с момента обнаружения в продуктах фумарол редкометалльной минерализации. Крупнейший специалист в области редких тугоплавких металлов Е.М. Савицкий писал: «Многие редкие элементы пока еще мало применяются в промышленности из-за недостаточного знания их свойств. У рения же открыто так много положительных качеств, что он стал остродефицитным металлом. Любые его количества будут поглощены промышленностью. Рений – это надежность, прочность, качество» [1]. С развитием высокотехнологичных отраслей промышленности рений все больше используется в электронике и электротехнике, авиакосмической и ракетной технике, химической промышленности.

В связи с развитием ракетной техники на гиперзвуковых скоростях возможно использование рения как одного из конструкционных материалов для покрытий и создания жаропрочных и жаростойких сплавов. Хорошо известно, что в нашей стране и других наиболее развитых странах мира, идут интенсивные работы над созданием гиперзвуковых летательных аппаратов (ГЗЛА), развивающих скорость до 2 км/с в плотных слоях атмосферы, в связи с чем температура на обтекателях может достигать нескольких тысяч градусов. В ядерных боевых блоках, атакующих цели из космоса, эта проблема решается путем абляции или испарения «жертвенного слоя», о чём говорил Генеральный конструктор АО «ВПК НПО машиностроения» Г.А. Ефремов [2]. Но управляемые ГЗЛА должны сохранять аэродинамическую форму. Нельзя «затуплять» изделие, чтобы у него