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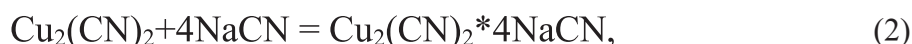
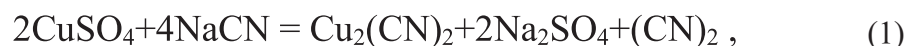
D. B. Kassymova¹, *R. V. Sapinov², N. A. Kulenova³, M. A. Adilkanova⁴^{1,3,4}D. Serikbayev EKTU, Republic of Kazakhstan, Ust-Kamenogorsk²Toraighyrov University, Republic of Kazakhstan, Pavlodar¹ORCID: <https://orcid.org/0009-0005-0937-8477>²ORCID: <https://orcid.org/0000-0001-9334-5806>³ORCID: <https://orcid.org/0000-0002-7063-4899>⁴ORCID: <https://orcid.org/0000-0002-8193-116X>*e-mail: sapinov.r@teachers.tou.edu.kz**STUDY OF THE MATERIAL COMPOSITION OF GOLD-COPPER ORES FROM KAZAKHSTANI DEPOSITS**

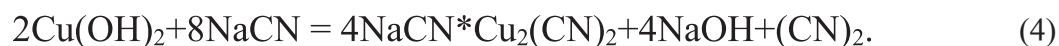
Copper in such gold-copper ores is both a valuable component and a detrimental impurity that complicates the processing of gold by cyanidation. As cyanidation is the primary process in gold recovery technology, ores or concentrates that for one reason or another are difficult to cyanide are classified as difficult to enrich. The degree of resistance of gold ores to cyanidation is determined by a number of factors that relate to the combination of gold particles with minerals and rocks, as well as natural minerals and natural substances that retard gold dissolution and increase cyanide uptake, and permanent sorbents in the ore. These resistances may include physical and chemical suppression as well as sorption activity of minerals present in the ore. Thus, the stage of determining the material composition and characterization of gold-copper ores is important, as the further strategy for selecting a cyanide leaching technology depends on it. As a result of the conducted research it was found out that in the composition of the ore gold content in the sample amounted to – 1.2 g/t. Silver content also amounted to – 1.2g/t. The total amount of copper amounted to 0.15%. The iron content amounted to 5.10 %. The total amount of sulfur was 0.34%.

Keywords: gold-copper ore, primary ore minerals, pyrite, rational analysis, cyanidation.

Introduction

Cyanide leaching is the most common method of processing gold-bearing ores. Currently, most deposits contain copper and other elements in addition to gold [1]. Copper is highly detrimental to the cyanidation process. The following reactions occur when copper compounds are exposed to cyanide solutions:





Among the copper complex compounds formed, $4\text{NaCN} \cdot \text{Cu}_2(\text{CN})_2$ is the most common [2]. There are a number of methods for the separation of gold and copper in the processing of gold-bearing and gold-copper ores [3;4]. These methods involve both selective separation of metals (gold and copper) already at the leaching stage by using different solvents, and their separation after collective cyanide leaching by precipitation of copper with different reagents and by changing the pH [5;6;7]. In conditions of sodium cyanide deficiency it is also important to pay attention to the fact that already dissolved gold can interact with copper-bearing minerals by the following reactions and then be lost with leach tailings [8;9;10].

Based on all of the above, one of the most important stages of processing gold-copper ores is to determine the presence and amount of copper. This determines the development of the technological process of processing with the choice of a method to neutralize the effect of copper on cyanide leaching of gold-copper ores. This article presents a study of the material composition and gold-copper ores of deposits in Kazakhstan, with recommendations for subsequent hydrometallurgical processing.

Materials and methods

All experiments were carried out in NAO «East Kazakhstan Technical University named after D. Serikbayev» () and «Eastern Mining and Metallurgical Research Institute of Nonferrous Metals ‘VNIItsvetmet’ () located in the Republic of Kazakhstan in Ust-Kazakhstan. D. Serikbayev» (<https://www.ektu.kz/>) and ‘Eastern Mining and Metallurgical Research Institute of Nonferrous Metals «VNIItsvetmet» (<http://vcm.ukg.kz>), located in the Republic of Kazakhstan, in the city of Ust-Kamenogorsk. The object of the study - gold-copper ores of the deposit of Kazakhstan (250 kg). Mass-spectrometer ICP-MS 7500cx of «Agilent technologies» (USA) was used to study the chemical composition of raw materials. To study the material composition of the material under study, X-ray diffractometer BRUKERD8 ADVANCE was also used to analyze the X-ray diffractometer, which is a common method for determining the qualitative composition of the material. Thermogravimetric analysis was carried out on a METTLERTOLEDO synchronous thermal analysis instrument. The experiments were carried out at maximum temperature heating up to 1050 °C at a rate of 15 deg/min in the air flow. During the heating process, the thermal effects on the DSC curve and changes in the sample mass on the TGA curve were recorded in parallel. In order to achieve the objectives of the study, the chemical and phase chemical compositions of the incoming sample were determined. Further to study the material composition of the investigated material, XRD was also carried out. TGA and DSC and rational analysis. In addition, a rational analysis was carried out to determine the forms of gold content in gold-copper ore. Suspension -1 kg of initial coarseness of 90 % grade minus 0.074 mm by standard methodology. The following forms of gold were determined: in aggregates (cyanidizable), extracted by cyanidation after treatment in hydrochloric and nitric acids, as well as thinly disseminated in rock-forming minerals.

Results and discussion

The initial particle size distribution of the incoming sample is presented in Table 1.

Table 1 – Initial granulometric composition of the studied gold-copper ore sample

Size class, mm	Yield, %
+100	2.9
-100+50	42.1
-50+30	25.4
-30+20	12.7
-20+10	6.3
-10+5	2.7
-5+2	6.4
-2	1.5
Total	100.0

The content of the main components in the sample of gold-bearing ore is shown in Table 2. As can be seen from the given chemical composition the content of gold in the sample amounted to – 1.2 g/t. The content of silver also amounted to – 1.2g/t. The total amount of copper amounted to 0.15 %. Iron content amounted to 5.10 %. The total amount of sulfur was 0.34 %.

Table 2 – Results of chemical analysis of the investigated gold-copper ore sample

Chemical element	Quantity, %	Chemical element	Quantity, %
Au, g/t	1.2	Zn	<0.02
Ag, g/t	1.2	Pb	<0.02
Cu	0.15	Mn	0.093
Fe	5.10	K	0.78
C _{tot.}	1.16	Na	2.68
C _{CO₃}	1.08	Sn	0.0006
S _{tot.}	0.34	Cr	0.012
S _{sulfate.}	0.1	Cd	<0.04
As	0.029	Cl	0.03
Sb	<0.003	Ni	0.0061
SiO ₂	58.82	Co	0.0030
Al	5.84	TiO ₂	0.92
Ca	3.35	Mg	2.00

The phase chemical composition of gold-copper ore was studied. As can be seen from the Cu in the ore is in the form of primary and secondary sulphides in the amount of 60 and 33% respectively (table 3). Oxygen-containing compounds copper is represented by 6.7%.

Table 3 – Copper content (XRF) in the tested ore

Forms of copper	Content, %	
	absolute	relatively
Sulfates	<0.01	0
Oxygen-containing compounds	0.01	6.7
Secondary sulfides	0.05	33.3
Primary sulfides	0.09	60.0
Total:	0.15	100.0

The main ore mineral in the sample is magnetite. Secondary ore minerals are pyrite, chalcopyrite, single grains of bornite, chalcocite, covellite.

Magnetite is represented by irregularly shaped grains. In the sample it makes 53.3 % (from 100% of all ore minerals), free grains make 38.0 %, 15.3 % are aggregates with other minerals (with non-metallic substance – 14.5 %, with pyrite – 0.8 %). Grain size is from 2 microns to 44 microns, with 10–44 microns prevailing. It forms aggregates with pyrite and non-metallic matter.

Chalcopyrite is represented by amoeba-shaped, irregularly shaped grains. In the sample it makes 10.2 % (from 100 % of all ore minerals), free grains make 7.7 %, 2.5 % – aggregates with other minerals (with bornite – 0.2 %, with pyrite – 0.1 %, with chalcopyrite – 0.1 %, with non-metallic matter – 2.1 %). Grain size from 1 micron to 44 microns, prevailing 10-44 microns. Forms aggregates with pyrite, bornite and chalcocite.

Pyrite is represented by irregularly shaped grains. In the sample it makes up 27.9 % (from 100 % of all ore minerals), free grains make up 27.5 %, 0.4 – aggregates with other minerals (with chalcopyrite - 0.1%, with magnetite - 0.3%). Grain size is from 3 μm to 50 μm , with 10-44 μm prevailing. It forms aggregates with chalcopyrite and magnetite.

Bornite is represented by single grains of irregular shape. In the sample it makes up 4.8 % (from 100 % of all ore minerals), free grains make up 4.6 %, aggregates with other minerals – 0.2 %. It forms aggregates with chalcopyrite.

Chalcocite is represented by single grains, in the sample it constitutes 1.5 % (of 100 % of all ore minerals). It occurs in intergrowths with chalcopyrite, sometimes covellite develops on it.

Microscopic images of the surface of outcrops of ore from the Yubileynoye deposit are shown in Figures 1a and 1b.

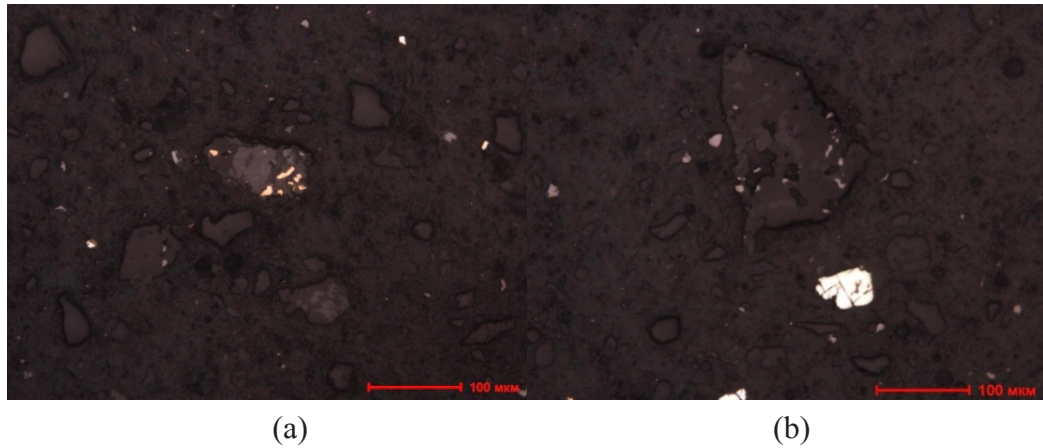


Figure 1 – Anschliff (Eq. 20x10). Free grains of pyrite and magnetite, in the center of the photo is an intergrowth of chalcopyrite with non-metallic material (a), free grains of pyrite, magnetite in the form of free grains and in the form of intergrowths in the grain of non-metallic material (b).

The results of studying the material composition of the studied material by means of X-ray diffraction analysis are presented in Figure 2. The following non-metallic minerals were identified in the sample: quartz, albite, magnetite, clinocllore, orthoclase and calcite.

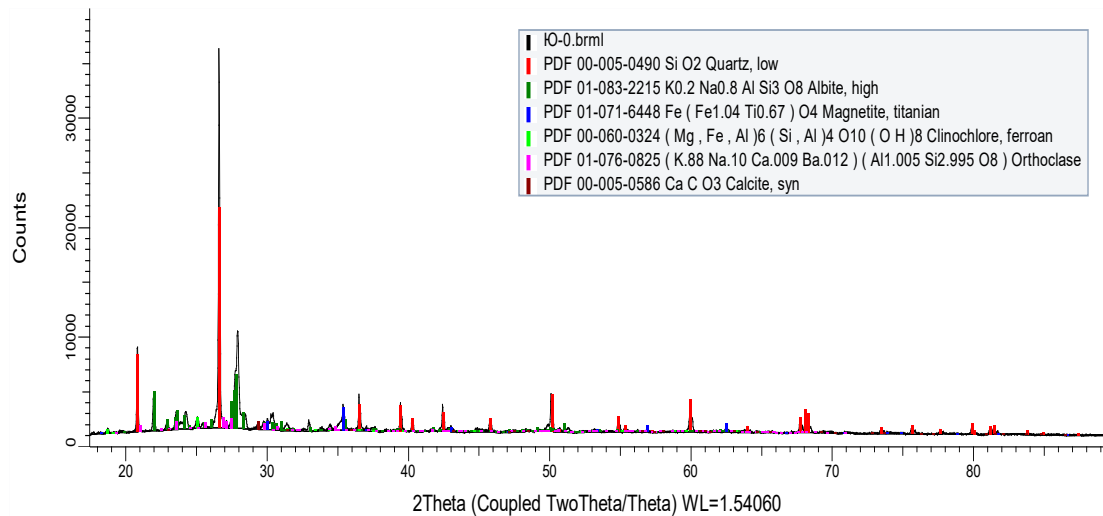


Figure 2 – XRF analysis of the sample composition of the investigated gold-copper ore sample

Figure 3 shows the results of the thermogravimetric study. The following thermal effects can be observed on the given results of the study. In the temperature range 239–259 °C there is a small endothermic effect - removal of molecular water (weight loss–0,61%). In the temperature range 438–498 °C there is an exothermic

effect, probably, there is an oxidation process (weight gain – 0.12 %). There is a small endothermic effect from 564 to 586°C, characteristic for the removal of constitutional water from rock-forming minerals (weight loss 0.75%). In the temperature range of 775-810°C there is a double exothermic peak - formation of new phases.

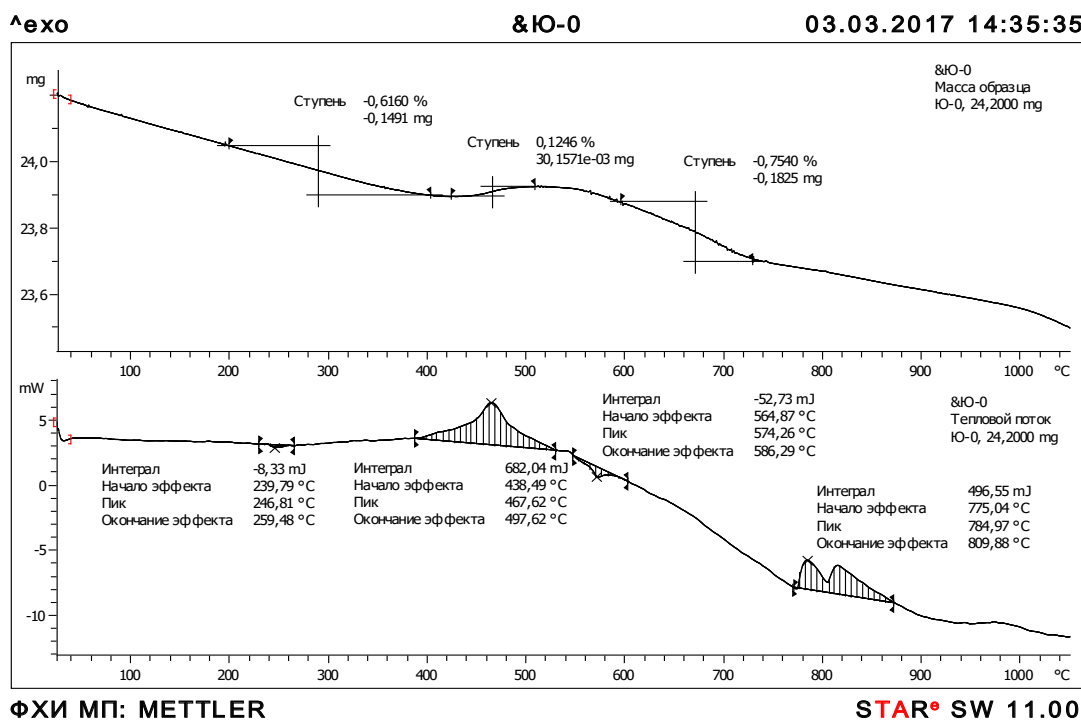


Figure 3 – Thermal effects of ore sample heating

Thus rational analysis showed the presence of gold in free form equal to 93.4 %, grade minus 0.071 mm is 47.50 % (relative), of which 45.00 % (relative) is represented by gold pellets with a clean surface and 2.50 % (relative) - gold pellets covered with oxide films (table 4). The gold content in aggregates is 40.84 % (relative). 8.33 % (relative) of gold is associated with sulfide minerals and 3.33 % (relative) with waste rock. The free silver content in the ore sample is 50.00 % (relative), in aggregates - 28.34 % (relative). 14.16 % (relative) silver is associated with sulphide minerals and 7.50 % (relative) with waste rock.

Table 4 – Forms of gold in the raw material presented

item	Main forms	Content				The morphology of the goldenrod	The size of the gilding, mm
		Au		Ag			
		g/t	%	g/t	%		
1	2	3	4	5	6	7	8
1	Ore deposit						
a)	Free: with clean surface	0.54	45	0.38	31.67	Octahedrons and their clusters, dendritic	0.025 to 0.675
b)	oxide coated	0.03	2.50	0.22	18.33	Dendritic	0.025 to 0.225
2	In a conglomerate:						
a)	with clean surface	0.47	39.1	0.26	21.67		
b)	oxide coated	0.02	1.67	0.08	6.67		
3	Assoc.:						
a)	with sulfide minerals.	0.10	8.33	0.17	14.16		
b)	With rock	0.04	3.33	0.09	7.50		
4	Initial grade, g/t	1.20	100	1.20	100.0		
5	Grade content - 0.071 mm, %		93.4				
	Grade content - 0.045 mm, %		79.0				
6							

Figure 4 shows a photograph of the clean-surface golds of the two types. Figure 4 a shows free gold with a clean surface. The shape of the goldines is dendritic. Eq. 20x1. Figure 4b shows free gold with clean surface. The shape of the gold specimens is dendritic, octahedron clusters. Eq. 20x10.

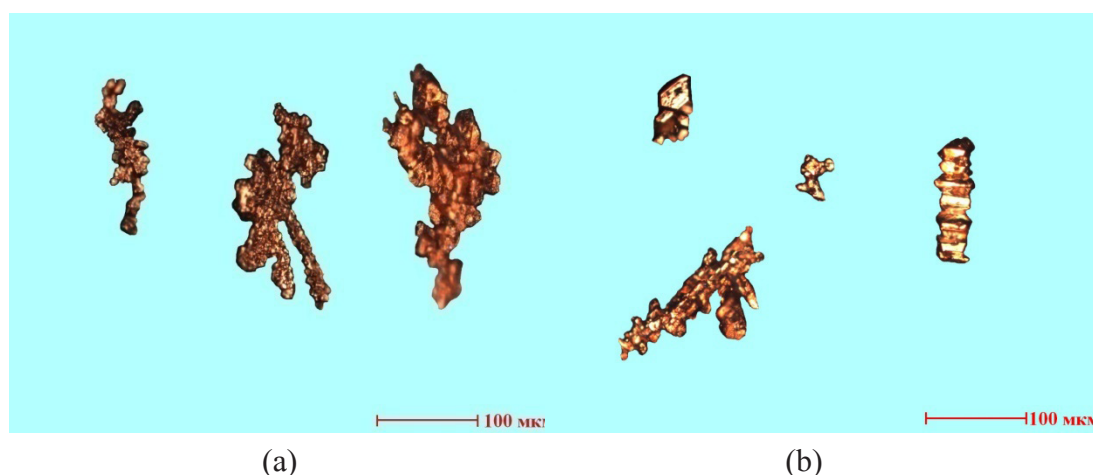


Figure 4 – Photographs of golds from a clean surface (Eq. 20x10). Free gold with a clean surface. The shape of the goldotines is dendritic (a). Free gold with a clean surface. Figure 4b shows the forms of ashlar also occurring in the ore (b)

Conclusions

Investigations revealed the presence of: magnetite (primary ore mineral), as well as pyrite, chalcopryrite, bornite, chalcosine and covellite and non-metallic minerals: quartz, albite, magnetite, clinocllore, orthoclase and calcite. Gold content in the sample amounted to 1.2 g/t. The content of other major components is, in %: SiO_2 – 58.82; As – 0.029; S total – 0.34; Fe – 5.10; Mg – 2.00; Stotal. – 1.16; Ca – 3.35; Al – 5.84. Since the ore contains copper in the amount of $\approx 0.15\%$, which is up to 1.5 kg of copper per ton of ore, to improve the economic efficiency of processing it is necessary to include the regeneration of cyanide solution and copper recovery in the form of finished commercial products. It is necessary to compare methods of copper precipitation with and without the introduction of various sulfidizers into the spent solution in order to select the optimal method.

Obtaining mathematical models to optimize and approximate the processes of cyanide leaching of gold from gold-copper ore, and copper precipitation from spent cyanide processing solutions will also be an integral part of this work.

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ҚАЗАҚСТАНДЫҚ КЕН ОРЫНДАРЫНЫҢ АЛТЫН-МЫС КЕНДЕРІНІҢ ЗАТТЫҚ ҚҰРАМЫН ЗЕРТТЕУ

Қазіргі уақытта құрамында мыс бар алтын кендерін қайта өңдеу мәселесі ең өзекті мәселелердің бірі болып табылады, өйткені алтын кендеріндегі мыс құнды құрамдас және зиянды қоспа болып табылады, бұл алтын өндіру процесін қиындатады. Біріншіден, бұл цианидтеуге қатысты-алтын рудасының шикізатын металлургиялық өңдеу процесіндегі негізгі операциялардың бірі. Цианидтеу алтынды қалпына келтіру технологиясының негізгі процесі болғандықтан, қандай да бір себептермен цианидтеу арқылы өңдеу қиын болатын алтын кендері немесе концентраттары отқа төзімді болып жіктеледі. Алтын кендерінің цианид процесіне қатысты тұрақтылығы бірнеше критерийлермен сипатталады, олар алтын бөлшектерінің кендегі минералдармен және тау жыныстарымен байланысының сипатымен,

кендегі минералдар мен заттардың болуымен анықталады. алтынның еру жылдамдығын бәсеңдететін және цианидті тұтынудың артуына, кендегі табиғи сорбенттердің болуына себепші болады. Алтын кендерінің тұрақтылық критерийлеріне физикалық депрессия, химиялық депрессия, сондай-ақ кендегі минералдардың сорбциялық белсенділігі жатады. Осылайша, материалдың құрамын және алтын-мыс кендерін анықтау кезеңі жауапты кезеңдердің бірі болып табылады, өйткені ол алтын-мыс кендерін цианидті сілтілендіруді өңдеу технологиясын анықтаудың *delnejshey* стратегиясына байланысты. Жүргізілген зерттеулер нәтижесінде кеннің құрамында сынамадағы алтынның мөлшері - 1,2 г/т құрайтыны анықталды. Күмістің құрамы да - 1,2 г/т. мыстың жалпы мөлшері 0,15% құрады. Темірдің мөлшері 5,10% құрады. Күкірттің жалпы мөлшері 0,34% құрады.

Кілтті сөздер: алтын-мыс кені, бастапқы кен минералдары, пирит, рационалды талдау, циандау.

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ИЗУЧЕНИЕ ВЕЩЕСТВЕННОГО СОСТАВА ЗОЛОТО-МЕДНЫХ РУД КАЗАХСТАНСКИХ МЕСТОРОЖДЕНИЙ

В настоящее время проблема переработки золотосодержащих руд является одной из самых актуальных, поскольку медь в золотых рудах - это одновременно и ценный компонент, и вредная примесь, осложняющая процесс извлечения золота. Прежде всего, это касается цианирования - одной из основных операций в процессе металлургической переработки золоторудного сырья. Поскольку цианирование является основным процессом технологии извлечения золота, золотые руды или концентраты, которые по тем или иным причинам трудно поддаются цианированию, относят к категории тугоплавких. Устойчивость золотых руд по отношению к цианистому процессу характеризуется несколькими критериями, которые определяются характером связи частиц золота с минералами и породой в руде, наличием в руде минералов и веществ, замедляющих скорость растворения золота и вызывающих повышенный расход цианида, наличием в руде природных сорбентов. К критериям упорности золотых руд относятся физическая депрессия, химическая депрессия, а также сорбционная активность минералов, присутствующих в руде. Таким образом, этап определения вещественного состава золотомедных руд является одним из ответственных, так как от него зависит стратегия выбора этапов технологии переработки золотомедных руд цианидным выщелачиванием. В результате проведенных исследований было установлено, что в составе руды содержание золота в пробе составило

– 1,2 г/т. Содержание серебра также составило - 1,2 г/т. Общее количество меди составило 0,15 %. Содержание железа составило 5,10%. Общее количество серы составило 0,34 %.

Ключевые слова: золото-медная руда, первичные рудные минералы, пирит, рациональный анализ, цианирование.

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