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Study of the material composition of refractory gold-bearing ore from the Aktobe deposit

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ABSTRACT
The study of the material composition of gold-bearing ores includes the determination of quantitative chemical and mineral composition, forms of noble metals, granulometric composition, and physical and mechanical properties to choose the direction for the development of an effective technology of their complex enrichment. This work is devoted to the study of the material composition of refractory gold-bearing ore of Aktobe deposit. It was determined that the content of gold is 1.55-1.6 g/t, the mass fraction of silver is 42-43 g/t, and the content of sulphur is low and is 1-1.1% respectively. Of non-ferrous metals, zinc 0.17%, and lead 0.15% are present in insignificant amounts, and the content of harmful impurities antimony and arsenic are insignificant and amounted to 0.01 and 0.05%. The ore sample has a relatively uncomplicated mineral composition: rock-forming minerals represented by quartz, potassium feldspar, calcite, and mica predominate significantly. Ore minerals are represented by pyrite up to 10 %, limonite up to 0.5 %, galena 0.15-0.2 %, sphalerite 0.17-0.2 % and gold. Physical and mechanical properties of the ore were determined. According to the category of crushability, the ore belongs to the category of medium hardness. According to Bond's method, the "index of network Wi" of ball milling was determined for the initial ore, which was 19.3 kW·h/t·$\mu m^{0.5}$**.** Based on the obtained data on the study of material composition, further research will be directed to the study of gravity and flotation enrichment.

Keywords: gold, silver, chemical analysis, mineralogical analysis, granulometric analysis, physical and mechanical properties.

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Introduction

The Aktobe deposit is located in the Moyinkum region of Zhambyl province and is part of the Mynaral ore field. The Mynaral ore field differs from other ore fields of the Chu-Ili ore belt by its peculiar history of geological development, volcanism, magmatism and mineralisation. The discovery of a significant number of occurrences and points of ore mineralisation within its boundaries, as well as a huge number of hypogenic halos, allows us to reasonably distinguish the Mynaral ore cluster as a gold-bearing territory.

Within this field, relatively recently (1984-88) performed prospecting works revealed 20 ore occurrences and about 30 occurrences and points of mineralisation of gold, 1 of silver, 9 of molybdenum, 6 of lead, 3 of beryllium, 3 of manganese and 2 of copper.

The prevalence of gold mineralisation over other metals is overwhelming. This characterises the manifested specialisation of the ore field for gold.

Concerning the study, within the limits of the ore field the conducted works revealed about 50 ore occurrences and manifestations of gold, 5 of which were most fully studied by mining and drilling works, which gave the justification to separate them into one deposit, called Mynaralskoye, with reserves of 30.0 tonnes of gold with an average grade of 12.0 g/t and vein thickness from 1.0 m to 3 m. Currently, this deposit has been mined to a depth of 240.0 metres from the surface by underground mining. The remaining 45 gold occurrences remained poorly explored and underexplored due to the collapse of the USSR and, as a consequence, the cessation of state budgetary allocations. In 2017, TOO "Mynaral Gold" and TOO "Mynaral Resources", having obtained the subsoil use right for the Mynaral ore field, explored the Aktobe deposit of 4.7 tonnes of gold according to the JORC system.

Based on the above, the question arose about the study of the material composition of the sample of gold-bearing ore of the Aktobe to choose a further direction for the development of rational technology of its processing.

Experimental part

This research was carried out in the non-profit joint-stock company " K.I. Satpayev KazNITU" at the Department of "Metallurgy and Mineral Processing" under the grant project №AP19680182 "Development of an effective technology of complex enrichment and processing of refractory gold-bearing raw materials of the Aktobe deposit".

The object of the study was the gold-bearing ore of the Aktobe deposit of the Republic of Kazakhstan.

Used methods of studying the material composition of the ore sample:

- chemical composition [[1], [2], [3]] - determined by spectral, chemical, and assay analysis;

- mineral composition [[3], [4], [5]] - determined by macroscopic study of samples under a binocular loupe MBS-1 and microscopic study of anschlifts on a polarising microscope Leica DM2500 M. For more detailed confirmation of the mineral composition of the ore, X-ray diffractometric analysis was made.

- physical properties [[6], [7]]:

Granulometric composition [[8], [9]] - determined by sieve analysis;

Ore density - measured by pycnometer;

Bulk density of ore - measured by weighing in a vessel of known volume;

Ore strength according to Protodiakonov [[10], [11]] - is determined by the instrument of determination of the strength of POC;

Bond grindability index - determined by Bond's method [[12], [13], [14], [15], [16], [17], [18], [19]].

Sampling for the above analyses was carried out using standard techniques recommended in the study of minerals for enrichment, the meaning of which is the relationship between the size and weight of the sample taken, which with sufficient reliability preserved all the properties of the original process sample and the ore of the deposit.

Discussing the results

Chemical composition:

The results of the chemical composition of the ore are summarised in Table 1.

Table 1 – Chemical composition of initial ore

Element	Mass fraction
Gold, g/t	1.57
Silver, g/t	42.50
Quartz, %	64.50
Aluminium oxide, %	18.11
Calcium oxide, %	0.76
Iron, %	2.14
Sulphur (total), %	1.06
Copper, %	0.01
Lead, %	0.15
Zinc, %	0.17
Arsenic, %	0.05
Antimony, %	0.01

The results of atomic-emission semi-quantitative spectral analysis are shown in Table 2.

According to the results of the assay, chemical and atomic-emission semi-quantitative spectral analyses, the average gold grade in the ore sample received for testing was 1.57 g/t. The silver grade was 42.50 g/t.

The iron and sulphur content of the ore was 2.14% and 1.06% respectively.

Copper content was minimal, lead 0.15 %, zinc 0.17 %.

The content of harmful impurities in the form of arsenic and antimony is minimal.

Mineral composition

The material composition was studied by X-ray diffractometric analysis on an automated diffractometer DRON-3 with ÑuCa-radiation, β-filter.

Table 2 – Results of atomic-emission analysis of initial ore

Element	Concentra-tion, %	Element	Concentra-tion, %
Au	<0.0002	Ni	0.003
Ag	0.004	Mo	0.002
Al	>>1.0	V	0.005
Si	>>1.0	Ga	0.0015
Fe	>>1.0	Ge	<0.0002
K	>1.0	Sr	0.03
Mg	0.5	Bi	<0.0002
Na	0.2	Nb	<0.001
Mn	0.15	Cd	0.001
Ti	0.3	Te	<0.002
Ca	≤1.0	Tl	<0.0005
Cu	0.003	Hg	<0.003
Zn	0.1	Y	0.003
Sn	0.001	Yb	0.002
Cr	0.002	Be	0.00015
W	<0,002	Ba	0.1
Pb	0.15	Ce	0.01
As	0.05	La	0.002
Sb	0.005	Co	0.003
Sc	0.002	Zr	0.01
Li	0.003	In	<0.0005
P	0.15	Ta	<0.01
Pd	<0.0002	Re	<0.0003
Pt	<0.001	Os	<0.001

Results of semi-quantitative X-ray phase analysis (Table 3), diffractogram of the sample (Fig.1).

Table 3 – Results of semi-quantitative X-ray phase analysis

Mineral	Formula	Concentration, %
Quartz	SiO_2	79.1
Potassium feldspar	$KAlSi_3O_8$	7.2
Pyrite	FeS_2	6.0
Calcite	$Ca(CO_3)$	4.6
Mica	$KAl_2(AlSi_3O_{10})(OH)_2$	3.1

The ore sample has a relatively uncomplicated mineral composition: rock-forming minerals represented by quartz, potassium feldspar, calcite and mica predominate significantly. Ore minerals are represented by pyrite up to 10 %, limonite up to 0.5 %, galena 0.15-0.2 %, sphalerite 0.17-0.2 %, gold and silver, which were determined by X-ray diffractometric analysis and confirmed by microscope examination of anschlifts.

Pyrite is observed in two generations, pyrite I - in the form of intergrowths and phenocrysts of individual idiomorphic grains up to 1.0 mm in size, mostly cubic in shape (squares in the anschliff section).

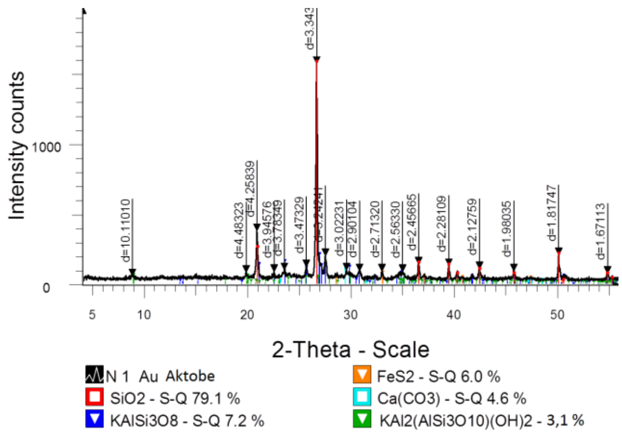


Figure 2 - Diffractogram of a sample of initial ore from the Aktobe deposit

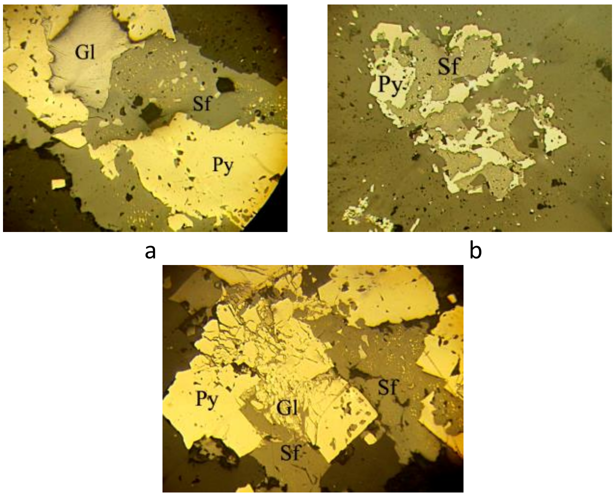
Pyrite II forms fine-grained inclusions in the clastic material of the breccia, up to 0.014 mm in size, the shape of grains is mainly pentagon dodecahedra. Most of the pyrite is observed in association with sphalerite and galena, which intensively replace and corrode it (Figure 3).

Sphalerite forms continuous aggregates and veins, anhedral grains with emulsion phenocrysts of pyrite, from 0.05 to 1.2 mm in size, and often replaces pyrite with the formation of loop structures. Sphalerite is medium-grained, with light-yellow internal reflexes (cleophane) (Figure 3).

Galena is less abundant, as a later mineral by the degree of formation, it performs interstices in non-metallic minerals, and forms veins and mesh-like inclusions. It intensively replaces pyrite and sphalerite. It rarely forms large accumulations (Figure 3).

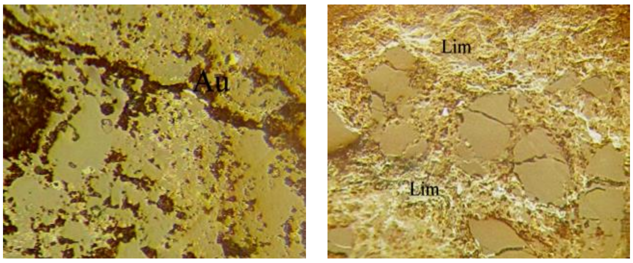
Limonite forms thread-like, net-like inclusions around the grains of nonmetallic minerals, and iron hydroxides form crusts with concentric-zonal structures along the cracks (Figure 4 b).

One inclusion of nugget gold, elongated in shape, 0.035x0.01 mm in size, straw-yellow in colour with high reflection was found in the cavity of limonite leaching (Figure 4 a).



a b c

Figure 3 - a) sphalerite (Sf) intergrowth corroding pyrite (Py) and galena (Gl), b) replacement of pyrite (Py) by sphalerite (Sf) with formation of loop structure, c) sphalerite (Sf) and pyrite (Py) intergrowth, pyrite is corroded by galena (Gl) along cracks



a b

Figure 4 - a) inclusion of nugget gold (Au) in the leach fracture; b) filamentous limonite (Lim) efflorescence enveloping grains of non-metallic minerals

Physical properties

The results of sieve analysis of a sample of gold-bearing ore crushed to 3.3 mm with gold and silver distribution by size class are presented in Table 4.

The sieve analysis results presented in Table 4 showed that the weighted average grade of gold in the analysed ore was 1.56 g/t and silver 42.91 g/t.

The distribution of gold content by size class is uneven. The gold content in the largest class of -3.3+1.6 mm size class was 1.05 g/t and with decreasing coarseness of classes increases up to 3.37 g/t.

The distribution of silver content by size class is uneven. The silver content in the largest class of -3.3+1.6 mm was 37.29 g/t and with decreasing coarseness of classes increased to 78.75 g/t.

Table 5 shows the results of the determination of the physical-mechanical properties of the ore sample of the Aktobe deposit.

Table 4 – Results of sieve analysis of initial ore

Grain size class, mm	Output, %	Content, g/t		Recovery, %	
		Au	Ag	Au	Ag
-3.3+1.6	20.13	1.05	37.29	13.50	17.49
-1.6+1	31.83	1.07	35.17	21.77	26.09
-1+0.63	12.45	1.12	35.71	8.93	10.36
-0.63+0.32	13.45	2.07	40.17	17.86	12.59
-0.32+0.16	7.88	2.06	51.33	10.41	9.43
-0.16+0.074	4.92	2.33	60.17	7.36	6.90
-0.074+0.0	9.34	3.37	78.75	20.17	17.14
Total	100.0	1.56	42.91	100.0	100.0

Table 5 – Physical and mechanical properties of ore sample

Indices	Unit of measurement	Values
ρt - specific weight (density)	g/cm^3	2.69
ρb - bulk density	g/cm^3	1.50
η - porosity	%	44
f - Protodiakonov's coefficient of strength	-	12.12
Bond crushability index	$kWh/h/t{\cdot}mcm^{0.5}$	19.3

Ore hardness according to Protodyakonov was 12.12 - the ore is categorised as medium hardness in terms of crushability. The bond crushability index was 19.3 kW·h/t·µm0.5, the ores of Aktobe deposit are classified as medium crushable.

Comparison of the results of the study of the material composition of gold-bearing ore of the deposit "Aktobe" with the results of earlier studies [[3], [20]], carried out on similar gold-bearing ores, it is established that further research on the development of technology enrichment of ore of the deposit "Aktobe" is advisable to continue with the study of gravity and flotation enrichment.

Conclusions

Based on the results of research on the material composition of ore of the deposit "Aktobe" the following main conclusions can be made:

- according to the results of assay analysis, the average gold content in the studied ore was 1.57 g/t and silver 42.50 g/t;
- the main host mineral is quartz, potassium feldspar, calcite and mica are also present;
- ore minerals are represented by pyrite up to 10 %, limonite up to 0.5 %, galena 0.15-0.2 %, sphalerite -0.17-0.2 %;
- harmful impurities in the form of arsenic and antimony are practically absent, as well as minimal copper content;
- a microscope examination of the samples revealed that the ore is represented by nested disseminated aggregates of galena-sphalerite-pyrite composition. The main ore mineral - pyrite is observed in the form of anhedrals and phenocrysts, individual idiomorphic grains, ranging in size from 0.02 to 1.5 mm in association with sphalerite and galena, developing mainly along fractures. Nugget gold is found in a void in brecciated, intensely leached rock represented by limonite and iron hydroxides. The grain is elongated, 0.035x0.01 mm in size, straw-yellow in colour with high reflection;
- the main components in the ore of the deposit "Aktobe", representing industrial value, are gold and silver.

Based on the obtained data on the study of material composition, further research will be directed to the study of gravity and flotation enrichment with the development of the optimal technological scheme for the enrichment of gold-bearing ore of the deposit Aktobe with the writing of technological regulations.

Conflict of interest. On behalf of all authors, the correspondent author declares that there is no conflict of interest.

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Ақтөбе кен орнының құрамында алтыны бар қиын өңделетін кендерінің заттай құрамын зерттеу

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ТҮЙІНДЕМЕ

Құрамында алтыны бар кендердің заттай құрамын зерттеу, оларды кешенді байытудың тиімді технологиясын әзірлеу бағытын таңдау мақсатында сандық химиялық және минералдық құрамдарды, асыл металдардың қандай түрде болатындығын, гранулометриялық құрамын, физика-механикалық қасиеттерін анықтауды қамтиды. Бұл жұмыс Ақтөбе кен орнының құрамында алтыны бар кендерінің заттық құрамын зерттеуге арналған. Алтынның мөлшері 1,55 – 1,6 г/т, күмістің массалық үлесі 42-43 г/т, күкірт мөлшері төмен және сәйкесінше 1-1, 1% құрайды. Түсті металдардың құрамында аз мөлшерде мырыш 0,17%, қорғасын 0,15%, сурьма мен мышьяктың зиянды қоспаларының мөлшері шамалы 0,01 және 0,05% болады. Кен салыстырмалы түрде қарапайым минералдық құрамға ие: онда кварц, калийлі дала шпаты, кальцит, слюда сияқты тау жыныстарын құрайтын минералдар басым. Кен минералдарының құрамында пирит 10% дейін, лимонит 0,5% дейін галенит 0,15-0,2 %, сфалерит 0,17-0,2% және алтын бар. Кеннің физикалық-механикалық қасиеттері анықталды. Ұсату категориясы бойынша кен орташа қаттылық санатына жатады. Бонд әдісі бойынша бастапқы кен үшін шарлы ұнтақтаудың "Wi таза жұмыс индексі " анықталды. Ол 19,3 кВт·сағ/т·мкм^{0,5} құрады. Заттық құрамды зерттеу бойынша алынған мәліметтер негізінде одан әрі зерттеулер гравитациялық және флотациялық байыту зерттеулеріне бағытталатын болады.

Түйін сөздер: алтын, күміс, химиялық талдау, минералогиялық талдау, гранулометриялық талдау, физика-механикалық қасиеттері.

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Изучение вещественного состава упорной золотосодержащей руды месторождения Актобе

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АННОТАЦИЯ
Изучение вещественного состава золотосодержащих руд включает определение количественного химического и минерального составов, форм нахождения благородных металлов, гранулометрического состава, физико-механических свойств с целью выбора направления для разработки эффективной технологии их комплексного обогащения. Данная работа посвящена изучению вещественного состава упорной золотосодержащей руды месторождения Актобе. Определено, что содержание золота – 1,55-1,6 г/т, массовая доля серебра составляет 42-43 г/т, содержание серы низкое и составляет 1-1,1% соответственно. Из цветных металлов в незначительных количествах присутствует цинк 0,17%, свинец 0,15%, содержание вредных примесей сурьмы и мышьяка незначительные и составили 0,01 и 0,05 %.Проба руды имеет сравнительно несложный минеральный состав: существенно преобладают породообразующие минералы, представленные кварцем, калиевым полевым шпатом, кальцитом, слюдой. Рудные минералы представлены пиритом до 10 %, лимонитом до 0,5 % галенитом 0,15-0,2 %, сфалеритом 0,17-0,2 % и золотом. Определены физико-механические свойства руды. По категории дробимости, руда относится к категории средней твердости. По методу Бонда определен «индекс чистой работы Wi» шарового измельчения для исходной руды, который составил 19,3 кВт·ч/т·мкм^{0,5}. На основании полученных данных по изучению вещественного состава, дальнейшие исследования будут направлены на изучение гравитационной и флотационной обогатимости.
Ключевые слова: золото, серебро, химический анализ, минералогический анализ, гранулометрический анализ, физико-механические свойства.

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