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Study of the mineral composition of promising copper ores of the Republic of Kazakhstan

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ABSTRACT
The article provides a brief overview of the problems of copper production in Kazakhstan. It is shown that the main current problem of copper-smelting production is the involvement of low-grade ores of complex mineral composition. Existing technologies are focused on the processing of ore with higher copper content, accordingly, it is necessary to adjust the existing enrichment and smelting technologies. To determine the mineral composition of some samples of promising copper-bearing ores of the Republic of Kazakhstan, an X-ray phase analysis was carried out. The identification and quantitative calculation of the mineral content were carried out using the DIFFRAC.EVA and DIFFRAC.TOPAS programs. It was shown that the main copper-bearing minerals in the samples are: chalcopyrite, bornite, chalcosiderite - group 1; malachite, lapis lazuli, atacamite, pseudomalachite, brochantite - group 2. The waste rock is represented by the following minerals: quartz, muscovite (mica), chlorite (layered silicate), albite (feldspar), pyrite, calcite, sodalite (feldspathoid), and gypsum. Based on the analysis, the mineral composition of the studied samples was established and a conclusion was made about the dominant nature of the ore. It is shown that in three samples the predominant nature of the ore is sulfide, in one sample it is oxide. The obtained results of the mineral composition and nature of the ore allow us to make practical recommendations on the most effective scheme for ore enrichment and further processing.
Keywords: Material science, composite, material engineering, design, biocomposite.

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Introduction

According to the data International Copper Study Group (ICSG) the deficit of copper in the world market amounted to 415 thousand tons in 2020 y, the deficit was already 439 thousand tons in 2021, and now this figure continues to grow [1]. Kazakhstan has huge reserves of copper ore and ranks seventh in the world in terms of copper production, 92% of which is exported abroad. The main industrial types of ores are cuprous sandstones (71%) and porphyry copper (24%) [2].

The Republic of Kazakhstan has extensive copper reserves of more than 35 million tons (70% of which are in the Zhezkazgan region), which is 4.7% of the world's reserves, and allows Kazakhstan to take 6th place in the world, after Chile, Australia, Peru, Mexico and the USA [2].

Copper in the composition of copper ore can be present in various minerals. Most often, copper is in the form of sulfur compounds: copper pyrite or chalcopyrite $CuFeS_2$, chalcocite Cu_2S, covelitte CuS; can occur in the form of oxides: cuprite Cu_20, tenorite CuO; or be part of hydrocarbonates:

malachite $CuCO_3 \bullet Cu(OH)_2$, azurite $2CuCO_3 \bullet Cu(OH)_2$.

The waste rock of the ores consists of pyrite FeS_2, quartz $Si0_2$, magnesium and calcium carbonates ($MgC0_3$ and $CaCO_3$), as well as various silicates containing Al_20_3, CaO, MgO, and iron oxides along with $Si0_2$.

The degree of opening of the mineral grain, and, consequently, the efficiency of subsequent enrichment will be determined by the mineral composition.

Copper is the most important resource for the development of the economy of Kazakhstan, with about 80% of refined copper being exported. Demand for refined copper is expected to increase in the near future, by about 2.2% annually. Copper is exported in the form of copper concentrate, copper ore, refined copper, and copper alloys [3].

According to the official website of KazMinerals PLC [3], the company produced 144 thousand tons of copper in 2016, 259 thousand tons in 2017, and 295 thousand tons in 2018. The company intends to continue to increase copper production by attracting new resources, optimizing technology, and recycling waste [4].

The increase in production is expected due to the expansion of existing mines, the development of new sections of existing deposits, and the construction of additional processing facilities. So, for example, the quarry at the Konyrat mine has already covered the entire ore body, so it can develop through the development of the sides (now - the eastern one, the ore from which with a copper content of 0.3% should be enough for 13 years, then the question will be raised about the development of the western sides) [5].

It should be noted that these numbers refer only to explored ores that are theoretically suitable for processing, i.e. balance sheet. According to official calculations, copper ores on the balance sheet will be enough for about another 30 years of development. There are more than 100 copper deposits on the state balance sheet, the ores of which can theoretically be processed using the technologies currently used, but the total number of copper deposits is about 8 thousand.

The main problem of copper production is that poorer ores are involved in processing, and this is a global trend. In 2007 the average copper content in the ore was 1.22% according to the Kazakhmys Corporation LLP, in 2017 this number decreased to 0.93% [2]. For example, the promising Bozshakol copper mine has an average copper grade of just 0.35% and the development of this deposit is a priority.

Given these circumstances, the process of enrichment of copper ore is a key factor that determines both the technology and the cost of cathode copper in general.

Another problem is the fact that the raw materials that are currently mined at the deposits are of worse quality or differ significantly in mineral and elemental composition from the raw materials for which processing technologies have been developed. At some factories of Kazakhmys Corporation LLP, they worked with ore, the copper content of which was at least 1.08%, and in the second decade of the 21st century, the copper content in active deposits decreased to 0.7-0.8%.

Thus, despite the fact that Kazakhstan has large reserves of copper, most of it is found in low-grade ores (less than 0.5% copper content), which were previously considered “waste” rock.

Taking into account the above problems, it can be unequivocally stated that in order to select the optimal beneficiation technology, it is necessary to have accurate knowledge of the mineral composition of the ore. In addition, the mineral composition of copper ore determines the composition of slags during smelting into matte and conversion, affects the durability of the lining, and determines the technical and economic parameters of the process. In other words, knowledge of the mineral composition of copper ore is the starting point for the selection and optimization of copper production technology in general.

Recently, the study of the mineral composition of ore by the multimodal microscopy methods has gained popularity, i.e. combination of optical and electron microscopy [[6], [7], [8], [9]]. Using the optical characteristics of minerals (color, reflectance, and refraction coefficients) in combination with the intensity of electronic peaks obtained from various phases, it is possible to obtain a complex picture that allows one to identify the mineral composition of the ore in sufficient detail.

However, this method requires a sufficiently large amount of time for analysis, depending on the professional level of the expert and the quality of the sample surface. Therefore, the method of powder X-ray diffraction remains the most common, objective, and accurate method for identifying the mineral and phase composition of the ore.

Experimental part

The purpose of this study was to study the mineral composition of the presented copper-bearing samples to determine the nature of the ore. As objects of analysis, copper ores of various deposits and copper concentrates were used:

- ore copper sample No. 868
- ore copper sample No. 745
- copper concentrate, sample No. 688
- copper concentrate, sample No. 681

X-ray phase analysis was carried out on a D2 PHASER X-ray diffractometer with the following technical characteristics:

- Anode material: standard sealed X-ray tube: CuKα
- Reflected X-ray Detector: LYNXEYE Solid State Position Sensitive Detector.
- Focus size - 0.4 x 12 mm;
- Nominal operating mode of the X-ray source: 30 kV/10 mA;
- Vertical Theta/Theta goniometer, radius 140 mm;
- Scan method θs/θd related
- Range of scanning angles 2θ: from 3 to 80°;
- scan step 0.010
- scan step time 5 seconds

The following conditions were chosen for taking the diffractogram:

- voltage 30 kW;
- current 10 mA;
- sample rotation - 15 revolutions per minute (allows to obtain more complete data on the composition of the sample);
- shooting range 40.4° - 80.6°;
- shooting step - 0.02°;
- shooting delay time - 1 second.

Taking into account the selected shooting parameters, obtaining one diffraction pattern takes 67 minutes.

Discussion of results.

After the analysis, the following diffraction patterns (Fig. 1-4) [[10], [11]] of the samples were obtained.

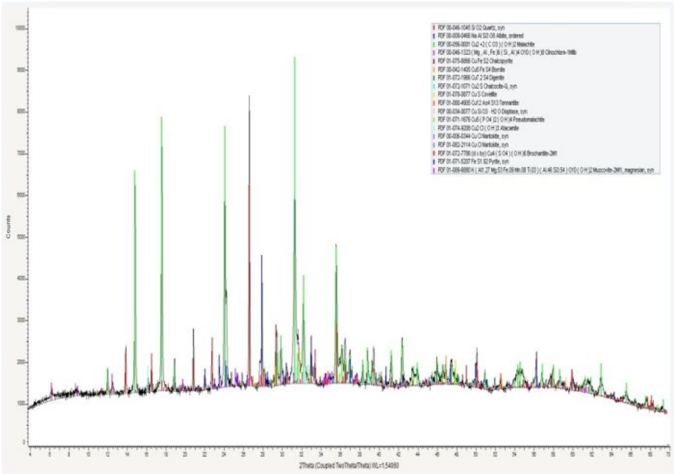

Figure 1 - Diffraction pattern of sample 681

Identification and quantitative calculation of the content of minerals were carried out in DIFFRAC.EVA and DIFFRAC.TOPAS software applications.

The results of the phase composition of the samples obtained by X-ray phase diffractometry are presented in Table 1 [12].

During the X-ray phase analysis, the following minerals were found:

- sulfide copper minerals - chalcopyrite, bornite, chalcosiderite;
- oxidized copper minerals - malachite, azurite, atacamite, pseudomalachite, brochantite;
- other minerals - quartz, muscovite (mica), chlorite (layered silicate), albite (feldspar), pyrite, calcite, sodalite (feldspathoid), gypsum [13].

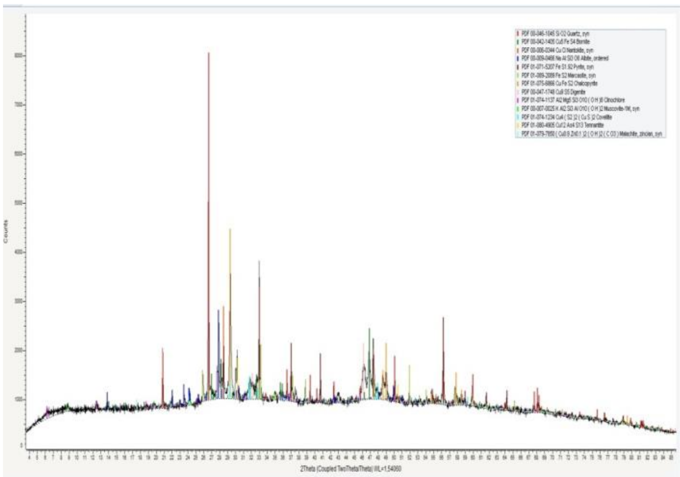

Figure 2 - Diffraction pattern of sample 688

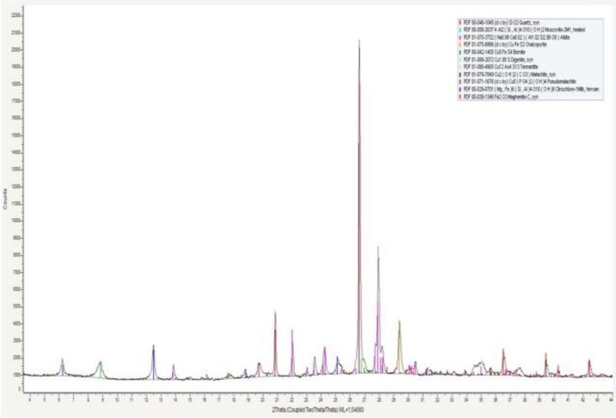

Figure 3 - Diffraction pattern of sample 745

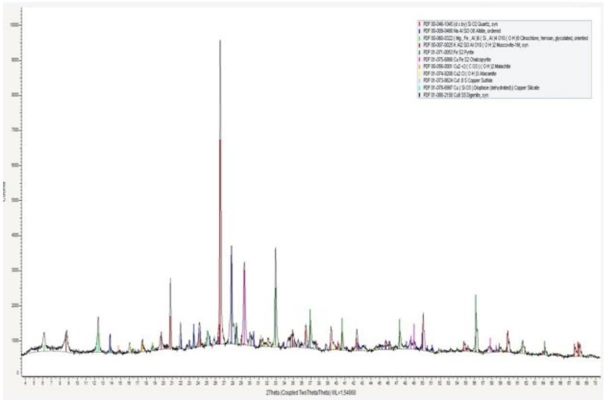

Figure 4 - Diffraction pattern of sample 868

Table 1 - Mineral composition of the studied samples

Mineral phase	Phase content in the sample, %					
	868	745	688	681		
Albite	34.9	21.5	11.6	10.1		
Atakamite	-	1.7	2.2	-		
Bornite	4.6	1.1	1.4	16.8		
Brochantite	-	-	9.1	-		
Digenite	2.2	1.1	2.0	5.2		
Dioptase	-	0.8	0.6	-		
Quartz	28.1	28.4	16.6	24.4		
Clinochlore	13.8	12.5	5.3	3.2		
Covellite	-	-	2.0	1.6		
Maghemite	1.6	-	-	-		
Malachite	1.2	3.0	-	2.7		
Marcasite	-	-	-	5.5		
Muscovite		8.1		15.4	6.3	3.0
Nantokite		-		-	1.1	11.0
Pyrite		-		9.9	3.0	9.6
Pseudomalachite		2.9		-	0.6	-
Tennantite		0.4		-	0.2	1.6
Chalcanthite		-		-	1.1	-
Chalcopyrite		2.2		4.7	1.5	5.4

To determine the nature of the ore, it is necessary to summarize the X-ray phase analysis data in accordance with Table 2 [14].

Table 2 - Constituent minerals of oxidized and sulfide ore

Group copper minerals	Constituent minerals
Oxidized	Cuprite, tenorite, malachite, pseudomalachite, azurite, atacamite, chrysocolla, dioptase, chalcanthite, etc.
Sulfide	Chalcopyrite, cubanite, bornite, chalcocite, covellite, digenite, tennantite, etc.

Comparison of the data of the PDF method and the Table 2 data allow us to conclude on the dominant character (oxidized or sulfide) of each of the presented samples (Table 3) [15].

Table 3 - Data on the nature of the mineral components of the presented samples.

Sample number	Group of copper minerals	X-ray phase analysis, %
868	Oxidized	2.08
	Sulfide	5.63
745	Oxidized	2.99
	Sulfide	5.17
688	Oxidized	28.50
	Sulfide	6.29
681	Oxidized	1.89
	Sulfide	29.9

The obtained results of X-ray phase analysis are new because the copper-containing ores and concentrates presented for analysis have not been studied before. Summarizing the data obtained, we can say that the mineral base is represented by characteristic copper-containing minerals that were previously studied and well described [[9], [11], [14], [16]]. The originality of the data obtained consists of obtaining the quantitative mineral composition of the studied samples, which, taking into account the latest literature data [[17], [18],

[19] [20]], allows us to determine the most optimal method of enrichment.

Conclusion

It can be concluded that the copper mineral components are dominant and, based on this, subsequently recommend a scheme for ore dressing and subsequent redistribution. Based on the analysis, it was found that the studied promising ores have the most effective scheme of research and further processing and require the development of research in order to create an effective environmentally safe technology for deep processing. Thus, it can be assumed that a thorough study of the structure of ore minerals and a number of physico-chemical properties is necessary.

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

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Қазақстан Республикасының перспективалы мыс кендерінің минералдық құрамын зерттеу

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ТҮЙІНДЕМЕ

Мақалада Қазақстандағы мыс өндірісінің мәселелеріне қысқаша шолу жасалды. Мыс балқыту өндірісіндегі негізгі мәселе күрделі минералды құрамдағы кедей кендерді тарту болып табылады. Қолданыстағы технологиялар мыс құрамы анағұрлым жоғары кенді қайта өңдеуге бағытталған, ал қолданыстағы байыту және балқыту технологияларын түзету қажет. Құрамында мыс бар перспективалы кендердің кейбір сынамаларының минералды құрамын анықтау үшін рентген-фазалық талдау жүргізілді. Минералдардың құрамын анықтау және сандық есептеу DIFFRAC.EVA және DIFFRAC.TOPAS бағдарламаларында жүргізілді. Сынамалардағы құрамында мыс бар негізгі минералдар: халькопирит, борнит, халькосидерит – 1 топ; малахит, лапис лазули, атакамит, псевдомалахит, брошантит – 2 топ. Бос жыныстарда келесі минералдар бар – кварц, мусковит (слюда), хлорит (қабатты силикат), альбит (дала шпаты), пирит, кальцит, содалит (фельдшпатоид), гипс. Жүргізілген талдау негізінде зерттелген сынамалардың минералды құрамы анықталды және кеннің доминантты сипаты туралы қорытынды жасалды. Үш сынамада кеннің басым сипаты сульфидті, бір сынамада – оксидті екендігі көрсетілген. Кеннің минералды құрамы мен сипатынан алынған нәтижелер кенді байытудың және одан әрі өңдеудің тиімді схемасы туралы практикалық ұсыныстар жасауға мүмкіндік береді.

Түйін сөздер: Материалтану, композит, материалтану, дизайн, биокомпозит.

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Исследование минерального состава перспективных медных руд Республики Казахстан

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АННОТАЦИЯ
В статье проведен краткий обзор проблем производства меди в Казахстане. Показано, что основной текущей проблемой медеплавильного производства является вовлечение бедных руд сложного минерального состава. Существующие технологии ориентированы на переработку руды с более высоким содержание меди, соответственно, необходима корректировка существующих технологий обогащения и выплавки. Для определения минерального состава некоторых проб перспективных медьсодержащих руд РК был проведен рентгено-фазовый анализ. Идентификация и количественный расчет содержания минералов проводилось в программах DIFFRAC.EVA и DIFFRAC.TOPAS. Было показано, что основными медьсодержащими минералами в пробах являются: халькопирит, борнит, халькосидерит – 1 группа; малахит, лазурит, атакамит, псевдомалахит, брошантит – 2 группа. Пустая порода представлена следующими минералами – кварц, мусковит (слюда), хлорит (слоистый силикат), альбит (полевой шпат), пирит, кальцит, содалит (фельдшпатоид), гипс. На основании проведенного анализа был установлен минеральный состав изученных проб и сделан вывод о доминантном характере руды. Показано, что в трех пробах преобладающий характер руды – сульфидный, в одной пробе - оксидный. Полученные результаты минерального состава и характера руды позволяют сделать практические рекомендации о наиболее эффективной схеме обогащения руды и дальнейшей переработке.

Ключевые слова: Материаловедение, композит, материаловедение, дизайн, биокомпозит

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