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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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RESEARCH OF THE COMPLEX STAGE-BY-STAGE SCHEME OF GRAVITY SEPARATION OF GOLD ORE

Abstract. To extract large free gold, gravity separation is used, which is the most common method for processing mineral raw materials. The object of research is the gold-bearing ore of one of the deposits of Kazakhstan in the Almaty region. According to the results of assay and gravimetric analysis, the average gold content in the ore is 11.84 g/t, silver - 6.10 g/t. According to the content of sulfide sulfur (1.18%), the ore sample is assigned to the low-sulfide type of ore, according to the oxidation state of sulfur (1.67%) - to the primary type of ore. The results of assay, chemical and mineralogical analyzes of the ore have shown that the main industrially valuable component in the ore is gold. Basically, gold is in the form of free grains, and has different shapes and sizes of gold grains. Laboratory studies on gravity separation of ore have been carried out. The influence of the size of the ore and the use of various devices - the concentration table and the Knelson concentrator - have been studied. The highest enrichment rates were obtained at the Knelson concentrator when enriching regrind ore with a size of 80% of -0.071 mm: in one stage, the gold recovery into the gravity concentrate was 73.06%; the gold content in the concentrate is 379.2 g/t; the concentrate yield is 3.23% of the ore mass. Tests were carried out for stage-by-stage gravity separation of ore, including gravity concentration at the first stage, the gold ore crushed to 100% passing -1.0 mm and processed at the concentration table; at the second stage, the tailings of the first stage and tailings of the first re-separation were regrind to 60% passing -0,071 mm and processed at the concentration table; at the third stage, the tailings of the second stage and tailings of the second re-separation were regrind to 90% passing -0,071 mm and processed at the Falcon centrifugal concentrator; and at the fourth stage - gravity control on the concentration table and Knelson centrifugal concentrator. The use of a complex stage-by-stage scheme of gravity separation of ore made it possible to increase the gold recovery in concentrate and enriched products to 83.30-86.11% with a yield of 5.088-5.368% with an average gold content of 251.53-274.27 g/t. Gravity tailings contain 2.86-2.37 g/t gold.

Key words: gravity separation, gold ore, concentration table, centrifugal concentrator, gold.

Introduction. To extract large free gold, gravity separation methodsis used, which is the most common method of processing mineral raw materials [1-3]. Over a long period of time, this method has undergone changes - from simple washing and separation of grains on an inclined plane to the use of centrifugal concentrators. The method of separating mineral grains by density in gravity devices is simple and allows you to enrich alluvial gold in remote areas without an established infrastructure. In addition, this method does not require the use of chemical reagents and is characterized by low energy consumption [2-6].

There are various studies and techniques for gravity methods of gold-bearing ores using concentration tables for large gold and centrifugal concentrators for medium and fine gold [6-18].

In this article, the indicators of tests for gravity separationof gold-bearing ore from one of the deposits in Kazakhstan in order to maximize gold recovery.

Experimental part. The object of research is gold-bearing ore from one of the deposits of Kazakhstan in the Almaty region. According to the results of assay and gravimetric analysis, the average gold content in the ore is 11.84 g/t, silver - 6.10 g/t.

To perform the analysis for other elements, chemical decomposition and determination by the atomic absorption method of the content of associated metals were used. A chemical weight method was used for phase analysis for sulfur. The chemical composition of the ore is shown in Table 1.

Table 1 – Results of the chemical analysis of the ore sample

Components	Content, %	Components	Content, %
Copper	0.028	Aluminiumoxide	13.10
Nickel	0.0028	Calciumoxide	2.80
Cobalt	0.014	Magnesiumoxide	2.90
Zinc	0.009	Sodiumoxide	0.68
Lead	0.004	Potassiumoxide	3.01
Iron	6.59	Totalsulfur	1.20
Arsenic	< 0.01	Sulfidesulfur	1.18
Antimony	0.0045	Sulphatesulfur	0.02
Siliconoxide	54.81	Sulfuroxidationstate,%	1.67

It follows from the results of chemical analysis that the ore sample has a simple material composition. Non-ferrous metals do not represent industrial value due to their low content in the ore. According to the content of sulfide sulfur (1.18%), the ore sample is assigned to the low-sulfide type of ore, according to the oxidation state of sulfur (1.67%) - to the primary type of ore [18].

Complex mineralogical analysis was carried out using X-ray phase, microscopic and optical methods. The samples were studied under a microscope in thin sections, polished sections, artificial briquettes and immersion media. Gold grains were studied on an electronic microanalyzer of the JEOL JXA-8230 Electron Probe Microanalyzer brand.

X-ray diffractometric analysis of average samples was performed on a DRON-4 diffractometer with Cu_{Ka}-radiation, β-filter. Conditions for recording diffraction patterns: U = 35 kV; I = 20 mA; scale: 2000 imp.; time constant was 2 s; shooting theta-2theta; detector 2 deg/min. [18].

Semi-quantitative X-ray phase analysis was carried out on the basis ofdiffractograms of powder samples using the method of equal portions and artificial mixtures. The quantitative ratios of the crystalline phases were determined. Interpretation of diffractograms was carried out using data from the ICDD card index: PDF2 powder diffraction data base (Powder Diffraction File) and diffractograms of minerals free of impurities. For the main phases, the contents were calculated [18].

The mineral composition is shown in Table 2 and Figure 1.

Table 2 –Mineralcomposition

Minerals, massfraction, %													
Oreminerals							Rock-formingminerals						
Pyrite	Ironhydroxides	Pyrrhotite	Chalcopyrite	Ilmenite	Magnetite	Covellin, chalcocite	Quartz	Muscovite, biotite	Tremolite	Albite	Chlorite	Potassiumfeldspar	Calcite and others
3.0-4.0	1.5-2.0	0.5-1.0	0.1-0.2	0.3-0.5	0.2-0.3	Individualsigns	35-36	25-26	20-21	5-6	3-4	2-3	<1

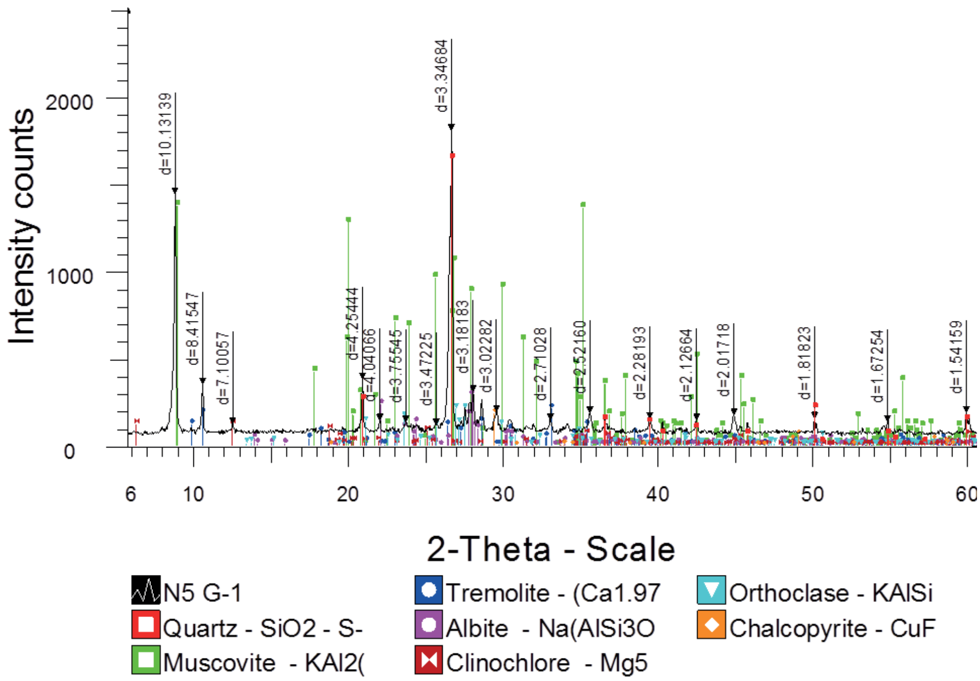

Figure 1–Diffractogram of the sample

Table 2 shows that the main ore minerals of the sample are represented by pyrite, which is 3.5% and iron hydroxides - 2.0%. The main ore minerals are not widely distributed and total about 2%.Of the rock-forming minerals quartz, muscovite and amphibole predominate, accounting for about 80-81%; chlorite, potassium feldspar, albite and carbonate are of subordinate importance [18].

Basically, gold is in the form of free grains, and has different shapes and sizes of gold grains. Approximately 80% of gold grains are observed in the form of thin and small inclusions in pyrite from thousandths to hundredths (Figure 2). There are larger grains of gold (0.25-0.325 mm), which are presented in the form of intergrowths with iron hydroxides (Figure 3).

According to the results of assay, chemical and mineralogical analyzes, only gold is an industrially valuable component.

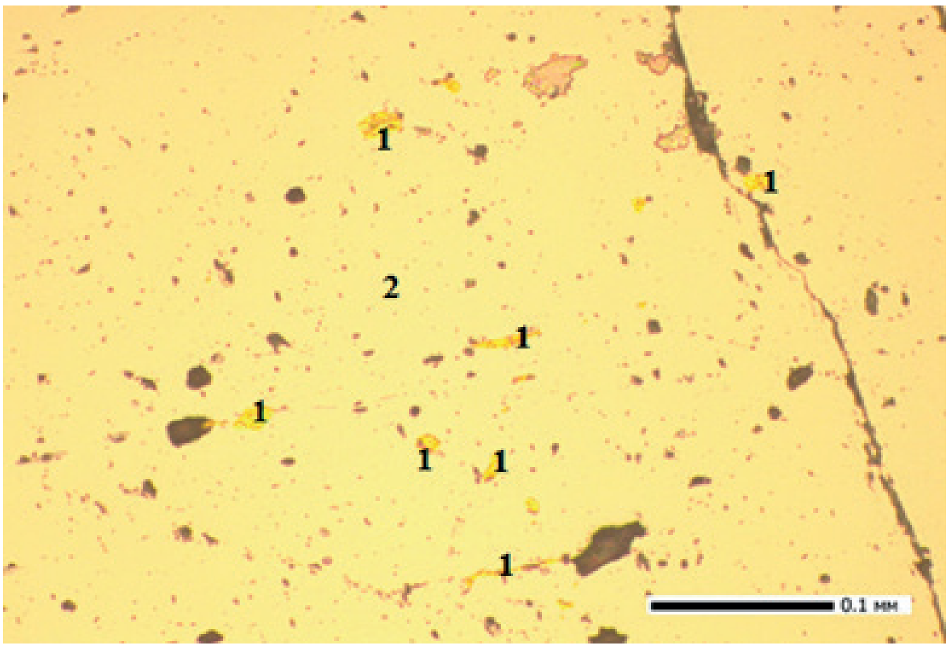

Figure 2– Dispersion of gold (1) in pyrite (2). The size of the gold grains is from 0.005 to 0.06 mm. Polishedsection, magnification 200

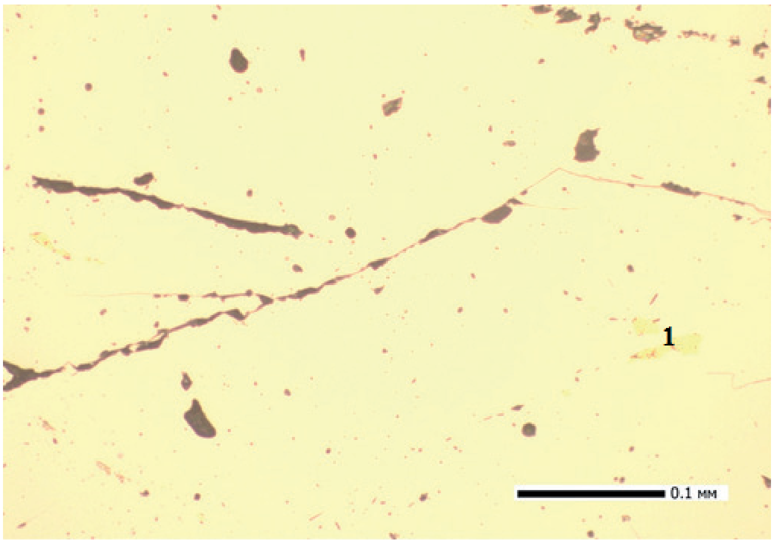

Figure 3– Gold (1) in an intergrowth with iron hydroxides. Polished section, magnification 100

Laboratory research. Gravity separation tests were carried out under various conditions:

- First test of gravity separationon the concentration table.

The first test of gravity separation, the gold ore crushed to 100% passing -1.0 mm and processed at the laboratory concentration table SKL-2 with a deck surface area of 0.1 m^2. The number of deck swings per minute is 250, the length of the deck is 6 mm, the angle of the deck is 5^o, the water consumption is 20 L/kg of ore,the productivity is 12-15 kg/h.

- Second test of gravity separationon the centrifugal concentrator(100% passing -1.0 mm).

The second test of gravity separation, the gold ore crushed to 100% passing -1.0 mm and processed at the Knelson centrifugal concentrator (KC-MD3) under the following modes: centrifugal acceleration - 60G; flow rate of fluidizing water - 3.5 dm^3/min; solid productivity - 0.5–0.6 kg/min; excess pressure of fluidizing water - 10-14 kPa; solids content in the pulp supplied for gravity separation – 25–30%.

- Thirdtest of gravity separationon the centrifugal concentrator(80% passing -0.071 mm).

The third test of gravity separation,the gold ore regrind to 80% passing -0.071 mm and processed at theKnelson centrifugal concentrator (KC-MD3) under similar conditions of the second test.

Results of laboratory research. The concentrates obtained from the tests were analyzed by the assay method for gold content (Table 3).

Table 3 – Results of assay analyzes of gravity concentrates

№	Goldcontent, g/t		
	Test 1: 100% passing -1.0 mm, concentration table	Test 2: 100% passing -1.0 mm, Knelson	Test 3: 80% passing -0.071 mm, Knelson
1	116.79	228.00	292.73
2	115.64	217.79	431.92
3	117.14	186.39	482.04
4	71.47	159.28	310.09
Average	105.26	197.87	379.20

It follows from the data in Table 3 that with the same ore size (-1.0 mm) subjected to gravity separation, the gold content in the gravity concentrate obtained on the Knelson centrifugal concentrator is 1.88 times higher than in the concentrate obtained on the concentration table. The size of the ore entering the gravity separation greatly affects the quality of the gravity concentrate. The gold content in the concentrate obtained at the Knelson concentrator using of 80% of -0,071 mm ore grain size is 1.92 times higher than the gold content in the gravity concentrate obtained at this device with an ore size of -1.0 mm; and 3,6 times higher than the gold content obtained by dressing the ore -1.0 mm on the concentration table.

Table 4 shows the results of assay analyzes of gravity tailings.

Table 4 – Results of assay analyzes of gravity tailings

№	Goldcontent, g/t		
	Test 1: 100% passing -1.0 mm, concentration table	Test 2: 100% passing -1.0 mm, Knelson	Test 3: 80% passing -0.071 mm, Knelson
1	10.56	6.60	4.80
2	11.08	6.84	4.80
3	11.00	6.52	4.40
Average	10.88	6.65	4.67

The highest gold content (10.88 g/t) in the gravity tailings obtained on the concentration table during the separation of crushed ore with a size of -1.0 mm, the lowest (4.67 g/t) in the gravity tailings obtained during the separation of crushed ore at the Knelson device. The Knelson tails with a grain size of -1.0 mm are intermediate in gold grade (6.65 g/t).

Table 5 shows the gravity separation values for the concentration table and the Knelson centrifugal concentrator.

Table 5– Indicators of gravity separation of ore

Product	Yield		Goldcontent, g/t	Goldrecovery, %
	g	%		
Test 1: 100% passing -1.0 mm, concentration table				
concentrate	91.8	3.11	105.26	23.73
tailings	2858.0	96.89	10.88	76.27
ore	2949.8	100.00	13.82	100.00
Test 2: 100% passing -1.0 mm, Knelson				
concentrate	97.3	3.27	197.87	50.12
concentration table	2882.0	96.73	6.65	49.88
ore	2979.3	100.00	12.89	100.00
Test 3: 80% passing -0.071 mm, Knelson				
concentrate	96.4	3.23	379.20	73.06
tailings	2886.0	96.77	4.67	26.94
ore	2982.4	100.00	16.78	100.00

It follows from the data in Table 5 that the highest technological indicators were obtained when using the Knelson concentrator with gravity separation of regrind ore with a size of 80% of -0.071 mm: gold recovery into the gravity concentrate was 73.06% with a gold content of 379.2 g/t, the gravity tailings contain is 4.67 g/t of gold. This indicates that the ore contains both relatively large gold grains and small free ones, which is confirmed by mineralogical analysis (Figures 4-5).

Thus, it can be stated that for the effective extraction of gold from this type of ore containing large and small gold, it will be necessary to use a complex stadium scheme of gravity separation.

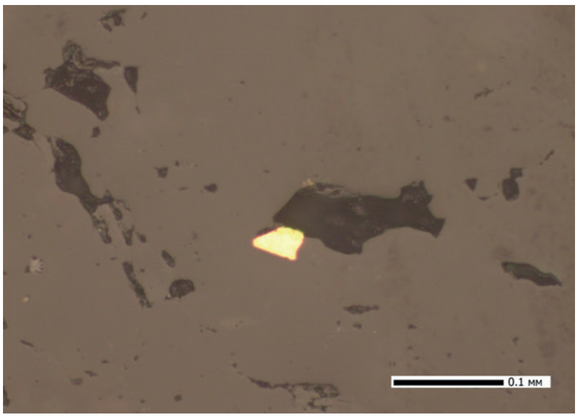

Figure 4– Gold in quartz. Polished section, magnification 200

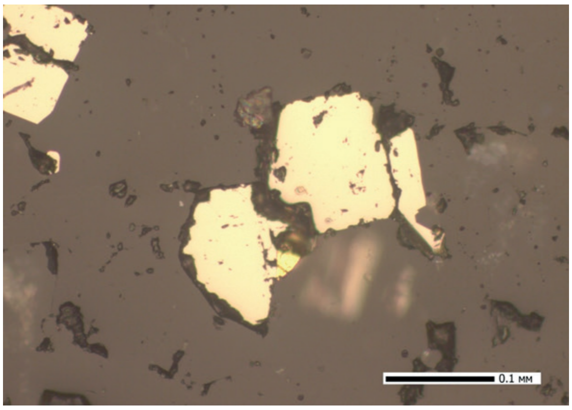

Figure 5– Gold in an intergrowth with pyrite. Polished section, magnification 200.

Research of the complex stage-by-stage scheme of gravity separation. Research of the complex scheme consisted in the stage-by-stage gravity separation of ores of different sizes and the use of various gravity devices [18]. The scheme includes (Figure 6):

- at the first stage, the gold ore crushed to 100% passing -1.0 mm and processed at theconcentration table;

- at the second stage, the tailings of the first stage and tailings of the first re-separation were regrind to 60% passing -0,071 mmand processed at theconcentration table;

at the third stage, the tailings of the second stage and tailings of the second re-separation were regrindto 90% passing -0,071 mmand processed at the Falcon centrifugal concentrator;

- at the fourth stage –gravity control on the concentration table and Knelson centrifugal concentrator.

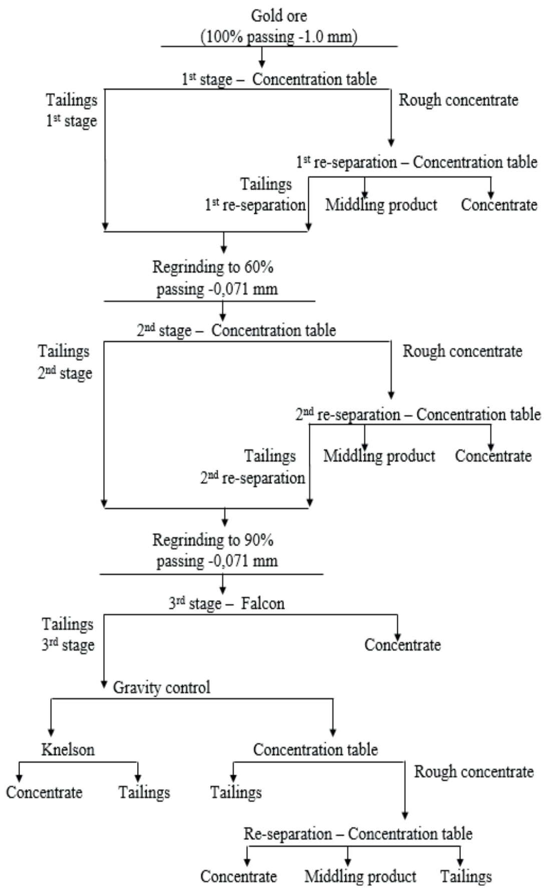

Figure 6– Schematic diagram of the four-stage gravity separation of gold ore

1ststage – Concentration table. At the first stage, the gold ore crushed to 100% passing -1.0 mm and processed at the laboratory concentration table SKL-2.

As a result of gravity separation, gravity rough concentrate and tailings were obtained. Gravity rough concentrate were re-separation on the concentration table, while re-separation concentrate, middling product and re-separation tailings are obtained.

The obtained products of the 1st stage of gravity separation were analyzed for gold content by the assay method. The average gold content in the concentrate was 730.45 g/t, in the middling product 105.90 g/t. The bulk of the concentrate is represented by pyrite and other sulfide-containing minerals, while the middling product are represented by sulfide minerals and gangue minerals with a high specific gravity and larger particles.

The average gold content in the tailings of the re-separation tailings is 17.01 g/t, in the tailings of the 1st stage of gravity separation 5.927 g/t.

Table 6 shows the indicators of the 1st stage of gravity separation of ore with 100% passing -1.0 mm on the concentration table.

Table 6– Indicators of the 1st stage of gravity separation

Product	Yield, %	Goldcontent, g/t	Goldrecovery, %
Concentrate	1.300	730.45	55.20
Middlingproduct	0.605	105.90	3.72
Re-separation tailings (1st stage)	11.307	17.01	11.18
Roughconcentrate	13.212	91.29	70.10
Tailings(1st stage)	86.788	5.927	29.90
Ore	100.00	17.20	100.00

It follows from the data in Table 6 that at the 1st stage, 70.10% of gold is extracted from crushed ore with a grain size of -1.0 mm into the gravity rough concentrate. The yield of the rough concentrate is 13.21%, the estimated gold content in it is 91.29 g/t. The yield of the tailings of the 1st stage of gravity is 86.79%, the gold content in them is 5.927 g/t.

After re-separation of the rough concentrate, the gold content in the re-separation concentrate increased to 730.45 g/t with its yield of 1.30% of the ore mass and gold recovery of 55.20%. The middling product contains 105.9 g/t of gold, its yield is 0.605%, the gold recovery in the middling product was 3.72%. The re-separation tailings contain 17.01 g/t of gold. The gold content in the tailings of the re-separation is comparable to the gold content in the ore, which according to the balance is 17.20 g/t and is significantly higher than the content determined by direct assay analysis of the initial ore, which was 12.675 g/t. This discrepancy is due to the significant amount of relatively large free gold in the ore, which is confirmed by the results of assay analyses of private samples of the refined gravity concentrate.

In general, at the 1st stage of gravity separation of crushed ore with a size of -1.0 mm, sufficiently high technological indicators were obtained: the total gold recovery into the refined concentrate and middling product was 58.92% with their output of 1.9% of the ore mass.

2nd stage – Concentration table. To carry out the 2nd stage of gravity separation, the remains of the tailings of the 1st stage of gravity and the remains of the tailings of the re-separation were used, which are combined and directed to grinding.

Gravity separation of the 2nd stage was carried out similarly to the 1st stage of separation. The tailings of the 1st stage of gravity and the remnants of the tailings of the re-separation were regrind to 60% passing -0,071 mm and processed at the concentration table SKL-2 with the previously specified processing parameters. As a result of gravity separation, tailings of the 2nd stage of gravity and rough concentrate were obtained, which was then re-separation to obtain the concentrate, middling product and re-separation tailings.

The results of assay analyzes of the products of the 2nd stage of gravity separation: the average gold content in the re-separation concentrate of the 2nd stage of gravity is 306.16 g/t, in the middling product is 67.84 g/t, in the re-separation tailings is 10.52 g/t, in the tailings of the 2nd stage of gravity separation 3.99 g/t.

Table 7 shows the indicators of the 2nd stage of gravity separation on the concentration table of tailings of the 1st stage of gravity, regrind to 60% passing -0,071 mm.

Table 7– Indicators of the 2nd stage of gravity separation

Product	Yield,% of the mass of tailings of the 1st stage of gravity	Goldcontent, g/t	Goldrecovery, %
Concentrate	0.591	306.16	27.92
Middlingproduct	0.643	67.84	6.74
Re-separation tailings (2nd stage)	4.472	10.52	7.26
Roughconcentrate	5.705	47.59	41.92
Tailings(2nd stage)	94.294	3.99	58.08
Feed: Tailings (1st stage) + Re-separation tailings (1st stage)	100.000	6.478	100.00

It follows from the data in Table 7 that at the 2nd stage, 34.66% of the gold from the amount contained in the combined tailings of the 1st stage of gravity and the tailings of the 1st re-separation is extracted into the concentrate and middling product. The gold content in the concentrate of the 2nd stage is 306.16 g/t, and the middling product is 67.84 g/t. The re-separation tailings contain 10.52 g/t gold, table tailings 3.99 g/t, which is a large value. Judging by the high indicators of gravity separation at 2 stages from the tailings of the 1st stage of gravity crushed to 60% passing -0,071 mm, we can confidently assume that after regrinding the tailings of the 2nd stage of gravity to a smaller size, it will be possible to extract some more gold.

The total increase in gold recovery into the refined concentrate and refined middling product was 13.82% of the ore mass.

3rd stage - Falcon centrifugal concentrator. The remains of the 2nd stage of gravity tailings and the tailings of the re-separation are combined, averaged and regrind to 90% passing -0,071 mm. The regrind tailings of the 2nd stage of gravity were sent to the 3rd stage of gravity separation using a Falcon L 40 centrifugal concentrator.

The separation parameters are as follows: the flow rate of fluidizing water is 9 L/min; centrifugal force field is 90 G; productivity is 35 kg/h.

As a result of gravity separation at 3 stages, the concentrate and tailings were obtained.

According to the results of assay analysis, the average gold content in the gravity concentrate was 302.33 g/t, which is close to the gold content in the concentrate obtained at the 2nd stage of gravity separation.

Table 8 shows the indicators of the 3rd stage of gravity separation on the Falcon centrifugal concentrator of the 2nd stage of gravity tailings, regrind to 90% passing -0,071 mm.

Table 8– Indicators of the 3rd stage of gravity separation

Product	Yield, % of the mass of tailings of the 2nd stage of gravity	Goldcontent, g/t	Goldrecovery, %
Concentrate	0.30	302.33	22.49
Tailings(3rd stage)	99.70	3.14	77.51
Feed: Tailings (2nd stage) + Re-separation tailings (2nd stage)	100.00	4.04	100.00

It follows from the data in Table 8 that at the 3rd stage (in the operation), the gold recovery into the gravity concentrate was 22.49%. However, the tails of gravity contain 3.14 g/t gold, which is large.

The total increase in gold recovery into refined concentrate and refined middling product was about 5.29% of the ore mass.

In the practice of beneficiation, along with the main operations, additional control operations are used, which make it possible to obtain enriched products and increase the throughput of gold recovery.

In this regard, a control stage of gravity separation was carried out using the concentration table and the Knelson centrifugal concentrator.

4th stage – Gravity control. From the total mass of tailings obtained at the 3rd stage of gravity separation on the Falcon centrifugal concentrator, 2 partial samples were selected, which were directed to control gravity on two different devices - the concentration table and the Knelson centrifugal concentrator.

Gravity control on the concentration table. The test provided for a large output of the rough concentrator for the highest gold recovery and obtaining gold-depleted gravity tailings. The resulting rough concentrate is re-separation to obtain a control gravity concentrate, middling product and re-separation tailings. The test used 3 kg of tailings of the 3rd stage of gravity.

Based on the results of assay analyzes of the control gravity products, the average gold content in the concentrate is 14.32 g/t, in the middling product 2.78 g/t, in the re-separation tailings of 2.57 g/t and in the gravity tailings of 3.06 g/t.

Table 9 shows the results of the gravity control on the concentration table.

Table 9–Results of the gravity control on the concentration table

Product	Yield,%	Goldcontent, g/t	Goldrecovery, %
Concentrate	2.03	14.32	9.41
Middlingproduct	9.34	2.78	8.41
Re-separation tailings	34.97	2.57	29.05
Roughconcentrate	46.34	3.13	46.87
Tailings	53.66	3.06	53.13
Feed: FalconTailings	100.00	3.09	100.00

It follows from the data in Table 9 that, despite the increased yield of rough gravity concentrate, which amounted to 46.34%, it was not possible to obtain gold-depleted gravity tailings. Gold recovery into concentrate was 9.41% in operation.

Table 10 summarizes the results of the gravity separation of ore using the concentration table at the control stage of gravity (gold balance).

Table 10 – Generalized results of gravity separation of ore using the concentration table at the control stage of gravity

Product	Yield, %		Goldcontent, g/t	Goldrecovery, %
	inoperation	fromore		
Concentrate(1st stage)	1.300	1.300	730.45	58.59
Middlingproduct(1st stage)	0.605	0.605	105.90	3.95
Concentrate(2nd stage)	0.591	0.580	306.16	10.96
Middlingproduct(2nd stage)	0.643	0.631	67.84	2.64
Concentrate(3rd stage)	0.300	0.291	302.33	5.43
Concentrate(Control on the concentration table)	2.03	1.961	14.32	1.73
Tailings (Gold-depleted gravity products)	97.97	94.632	2.86	16.70
Ore	–	100.000	16.21	100.00

The total yield of gravity concentrates and enriched products was 5.368%, the calculated gold content in them was 251.53 g/t. The recovery of gold into concentrates and beneficiated products is 83.30%. The estimated gold content in the ore is 16.21 g/t, which is 1.28 times higher than determined by direct assay analyzes of the ore. This discrepancy is due to the presence of relatively large gold grains in the ore and the uneven distribution of gold in the ore.

Gravity control on the Knelson centrifugal concentrator. The test was carried out using a laboratory centrifugal concentrator Knelson KS-MD 3. As a result of the control gravity on the centrifugal concentrator Knelson, a concentrate and tailings of the control gravity were obtained, which were sent for assay analysis. The average gold grade in concentrate is 43.70 g/t and in gravity tailings 2.37 g/t.

The gold content in the concentrate obtained during the control gravity on the Knelson concentrator is 3.1 times higher than in the concentrate obtained in the same operation on the concentration table. The control gravity tailings at the Knelson concentrator contain 2.37 g/t gold, which is 1.3 times lower than the gold content in the control gravity tailings at the concentration table. This indicates that centrifugal concentrators are preferable for the extraction of fine gold rather than concentration tables.

Table 11 shows the results of the control gravity on a Knelson centrifugal concentrator.

Table 11 – Results of the control gravity on the Knelson centrifugal concentrator

Product	Yield, %	Goldcontent, g/t	Goldrecovery, %
Concentrate	1.74	43.70	24.60
Tailings	98.26	2.37	75.40
Feed: FalconTailings	100.00	3.09	100.00

It follows from the data in Table 11 that in the control gravity, 24.60% of the amount of gold in the tailings of the 3rd stage of gravity (Falcon tailings) is additionally extracted into the concentrate, which is 2.6 times higher than that is extracted into the concentrate on the concentration table.

Table 12 summarizes the results of the gravity separation of ore using the Knelson centrifugal concentrator at the control stage of gravity (gold balance).

Table 12 – Generalized results of gravity concentration of ore using the Knelson centrifugal concentrator at the control stage of gravity

Product	Yield, %		Goldcontent, g/t	Goldrecovery, %
	inoperation	fromore		
Concentrate(1st stage)	1.300	1.300	730.45	58.59
Middlingproduct(1st stage)	0.605	0.605	105.90	3.95
Concentrate(2nd stage)	0.591	0.580	306.16	10.96
Middlingproduct(2nd stage)	0.643	0.631	87.84	2.64
Concentrate(3rd stage)	0.300	0.291	302.33	5.43
Concentrate (Control on the Knelson)	1.74	1.681	43.70	4.54
Tailings (Gold-depleted gravity products)	98.26	94.912	2.37	13.89
Ore	–	100.000	16.21	100.00

The total yield of gravity concentrates and enriched products was 5.088%, the calculated gold content in them was 274.27 g/t. The recovery of gold into concentrates and beneficiated products is 86.11%. The estimated gold grade in the ore is 16.21 g/t.

Conclusions. It is established that the main industrially valuable component in the ore is gold. Basically, gold is in the form of free grains, and has different shapes and sizes of gold grains. Approximately 80% of gold grains are observed in the form of thin and small inclusions in pyrite from thousandths to hundredths. There are larger grains of gold (0.25-0.325 mm), which are presented in the form of intergrowths with iron hydroxides. The main ore minerals of the sample are pyrite (3.5%) and iron hydroxides (2.0%). The main of the ore minerals are not widespread and make up about 2% in total. Of the rock-forming minerals, quartz, muscovite and amphibole predominate, accounting for about 80-81%, chlorite, potassium feldspar, albite and carbonate are of subordinate importance.

The recovery of gold in the course of gravity separation of regrind ore with a size of 80% of -0.071 mm in one stage on the Knelson centrifugal concentrator was 73.06%, with a concentrate yield of 3.23% of the ore mass. The gold content in the concentrate is 379.2 g/t.

The calculated gold grade in the ore according to the balance was 16.21 g/t, which is 1.28 times higher than determined by direct assay analyzes of the ore. This discrepancy is due to the presence of relatively large gold grains in the ore and the uneven distribution of gold in the ore and, accordingly, in the products of gravity.

It was found that the use of complex gravity separation of ore, in several stages at different ore sizes and using various devices, increased the gold recovery into gravity concentrates by more than 10% - up to 83.30-86.11%. The average gold content in the combined concentrates was 251.53-274.27 g/t with a yield of 5.088-5.368%. The gold content in gravity tailings decreased from 4.67 g/t to 2.37 g/t.

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АЛТЫНҚҰРАМДЫ КЕНДІ ГРАВИТАЦИЯЛЫҚ БАЙЫТУДЫҢ КЕШЕНДІ СХЕМАСЫН ЗЕРТТЕУ

Аннотация. Ірі бос алтынды алу үшін минералды шикізатты өңдеудің ең көп таралған әдісі болып табылатын гравитациялық байыту қолданылады. Зерттеу объектісі – Алматы облысындағы Қазақстанның кен орындарының бірінің құрамында алтыны бар кені. Сынамалық-гравиметриялық талдау нәтижелері бойынша кендегі алтынның орташа құрамы 11,84 г/т, күміс – 6,10 г/т құрайды, сульфидті күкірттің құрамы бойынша (1,18%) кен сынамасы кеннің аз сульфидті типіне, күкірттің тотығу дәрежесі бойынша (1,67%) – кеннің бастапқы типіне жатқызылған. Кенді сынамалық, химиялық және минералогиялық талдаулардың нәтижелері Кендегі негізгі өнеркәсіптік-құнды компонент алтын болып табылатыны анықталды. Негізінен алтын бос түйіршіктер түрінде болады және алтынның пішіні мен мөлшері әртүрлі. Кенді гравитациялық байыту бойынша зертханалық зерттеулер жүргізілді. Кен ірілігінің әсері және әртүрлі аппараттарды – Knelson концентрациялық үстелі мен концентраторын қолдану зерттелді. Байыту бойынша неғұрлым жоғары көрсеткіштер Knelson концентраторында ұсақталған кенді 80% класты ірілікпен байыту кезінде - 0,071 мм алынды: бір сатыда Алтынды гравитациялық концентратқа алу 73,06% - ды; концентраттағы алтынның құрамы 379,2 г/т; концентраттың шығуы кен массасының 3,23%-ын құрады. Кенді стадиальді гравитациялық байыту бойынша сынақтар өткізілді, оның ішінде 1-сатыдағы гравитациялық байыту ірілігі -1,0 ММ ұсақталған кенді шоғырландыру үстелінде, екінші сатыда гравитациялық байыту ірілігі - 60% -0,071 мм бірінші сатыдағы қалдықтар кластың ірілігіне дейін ұсақталған концентрациялық үстелде, үшінші сатыда гравитациялық байыту Falcon ортадан тепкіш концентраторында екінші сатыдағы қалдықтар, 90% - 0,071 мм ірілігіне дейін ұсақталған және төртінші сатыда гравитациялық байыту – бақылау гравитация арналған концентрациялық үстелде және тепкіш концентраторе Knelson қалдықтардың Falcon. Кенді гравитациялық байытудың кешенді стадиалдық схемасын қолдану Алтынды концентратқа және байытылған өнімдерге алуды 83,30-86,11%-ға дейін арттыруға мүмкіндік берді, оларда алтынның орташа мөлшері 251,53-274,27 г/т.болған кезде 5,088-5,368%-ға дейін жетеді, гравитациялық байыту қалдықтарының құрамында 2,86-2,37 г/т алтын бар.

Түйінді сөздер: гравитациялық байыту, алтынқұрамды кен, концентрациялық үстел, центрифугалық концентратор, алтын.

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ИССЛЕДОВАНИЕ КОМПЛЕКСНОЙ СХЕМЫ ГРАВИТАЦИОННОГО ОБОГАЩЕНИЯ ЗОЛОТОСОДЕРЖАЩЕЙ РУДЫ

Аннотация. Для извлечения крупного свободного золота применяют гравитационное обогащение, являющееся наиболее распространенным методом переработки минерального сырья. Объектом исследований является золотосодержащая руда одного из месторождений Казахстана в Алматинской области. По результатам пробирно-гравиметрического анализа среднее содержание золота в руде составляет 11,84 г/т, серебра – 6,10 г/т. По содержанию сульфидной серы (1,18%) проба руды отнесена к малосульфидному типу руд, по степени окисления серы (1,67%) – к первичному типу руды.

Результатами пробирных, химических и минералогических анализов руды установлено, что основным промышленно-ценным компонентом в руде является золото. В основном золото находится в виде свободных зерен и имеет разную форму и размеры золотин. Проведены лабораторные исследования по гравитационному обогащению руды. Изучено влияние крупности руды и применение различных аппаратов – концентрационный стол и концентратор Knelson. Наиболее высокие показатели по обогащению получены на концентраторе Knelson при обогащении измельченной руды крупностью 80% класса -0,071 мм: за одну стадию извлечение золота в гравитационный концентрат составило 73,06%; содержание золота в концентрате 379,2 г/т; выход концентрата 3,23% от массы руды. Проведены тесты по стадиальному гравитационному обогащению руды, включающему гравитационное обогащение на 1 стадии на концентрационном столе дробленой руды крупностью -1,0 мм, на второй стадии гравитационное обогащение на концентрационном столе измельченных до крупности 60% класса -0,071 мм хвостов первой стадии гравитации, на третьей стадии гравитационное обогащение на центробежном концентраторе Falcon хвостов второй стадии, измельченных до крупности 90% класса -0,071 мм и на четвертой стадии – контрольная гравитация на концентрационном столе и центробежном концентраторе Knelson хвостов Falcon. Применение комплексной стадиальной схемы гравитационного обогащения руды позволило повысить извлечение золота в концентрат и обогащенные продукты до 83,30-86,11% при их выходе 5,088-5,368% со средним содержанием золота в них 251,53-274,27 г/т. Хвосты гравитационного обогащения содержат 2,86-2,37 г/т золота.

Ключевые слова: гравитационное обогащение,золотосодержащая руда, концентрационный стол, центробежный концентратор, золото.

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REFERENCES

1. Meretukov M.A. (2008). Gold: the birth of mining, metallurgy and technology [Zoloto: zarozhdenie gornogo dela, metallurgii i tehnologii]. Moscow: «Ore and Metals» Publishing House. 180.ISBN: 978-5-98191-042-5.(In Russian).
2. Zakharov B.A., Meretukov M.A. (2013). Gold: refractory ores [Zoloto: upornye rudy]. Moscow: «Ore and Metals» Publishing House. 130-135. ISBN: 978-5-98191-068-5. (In Russian).
3. Shokhin V.I., Lopatin A.G. (1993). Gravity enrichment methods [Gravitacionnye metody obogashhenija]. Moscow: Nedra. 5-6.ISBN: 5-247-01452-9. (In Russian).
4. Habashi F. (2016). Gold–An historical introduction // Gold Ore Processing. Elsevier. 1-20. DOI:*10.1016/B978-0-444-63658-4.00001-3*(in Eng.).
5. Wills B.A., Finch J.A. (2016). Chapter 10 - Gravity Concentration // Editor(s): Barry A. Wills, James A. Finch, Wills' Mineral Processing Technology (Eighth Edition), Butterworth-Heinemann. 223-244. DOI: *10.1016/B978-0-08-097053-0.00010-8*(in Eng.).
6. Veiga M.M. & Gunson A.J. (2020). Gravity Concentration in Artisanal Gold Mining. Minerals, 10(11), 1026. DOI: *10.3390/min10111026*(in Eng.).

7. Chen Q., Yang H.Y., Tong L.L., Niu H.Q., Zhang F.S., & Chen G.M. (2020). Research and application of a Knelson concentrator: A review. Minerals Engineering, 152, 106339. *DOI: 10.1016/j.mineng.2020.106339* (in Eng.).
8. Surimbayev B.N., Kanaly Ye.S., Bolotova L.S., Shalgymbayev S.T. (2020). Behaviour of sulfur, arsenic and organic carbon in a gravity concentration of gold from refractory ore // News of the National Academy of Sciences of the Republic of Kazakhstan. Series Chemistry and Technology. 5. 443. 116-125. DOI: *10.32014/2020.2518-1491.88*(in Eng.).
9. Gülcan E., & Gülsoy Ö.Y. (2017). Performance evaluation of optical sorting in mineral processing–A case study with quartz, magnesite, hematite, lignite, copper and gold ores. International journal of mineral processing, 169, 129-141. DOI: *10.1016/j.minpro.2017.11.007*(in Eng.).
10. Surimbayev B.N., Kanaly E.S., Bolotova L.S., Shalgymbayev S.T. (2020). Assessment of Gravity Dressability of Gold Ore - GRG Test // Gornyenauki i tekhnologii = Mining Science and Technology (Russia). 5(2). 92-103. DOI: *10.17073/2500-0632-2020-2-92-103*(in Eng.).
11. Gülsoy Ö.Y. & Gülcan E. (2019). A new method for gravity separation: Vibrating table gravity concentrator. Separation and Purification Technology, 211, 124-134. DOI: *10.1016/j.seppur.2018.09.074* (in Eng.).
12. Sakuhuni G., Altun N.E., Klein B., Tong L. (2016). A novel laboratory procedure for predicting continuous centrifugal gravity concentration applications: The gravity release analysis // International Journal of Mineral Processing. 154. 66-74. DOI: *10.1016/j.minpro.2016.07.004*(in Eng.).
13. Das A., Sarkar B. (2018). Advanced gravity concentration of fine particles: A review // Mineral processing and extractive metallurgy review. 39(6). 359-394. DOI: *10.1080/08827508.2018.1433176* (in Eng.).
14. Surimbaev B.N., Kanaly E.S., Bolotova L.S., Romanenko A.G. (2013). The influence of the material composition of the ore on the indicators of gravity concentration [Vlijanie veshhestvennogo sostava rudyna pokazateli gravitacionnogo obogashhenija]. Industry of Kazakhstan [Promyshlennost Kazahstana]. 2 (77): 24-27. ISSN: 1608-8425. (In Russian).
15. Laplante A., Gray S. (2005). Advances in gravity gold technology // Editor(s): Mike D. Adams, B.A. Wills, Developments in Mineral Processing, Elsevier. 15. 280-307. DOI: *10.1016/S0167-4528 (05) 15013-3* (in Eng.).
16. Surimbaev B., Bolotova L., Esengaraev E., Mazyarkina L. (2017). A study of gravity separation of gold ores of the Raigorodok deposit [Issledovanie gravitacionnogo obogashhenija zoloto soderzhashhih rud mestorozhdenija Raj gorodok]. Industry of Kazakhstan [Promyshlennost Kazahstana]. 2 (101): 40-42. ISSN: 1608-8425. (In Russian).
17. Melnikov V.V., Rogovoy A.N., Yastrebov K.L. (2009). The analysis of the experience of home and foreign researchers in the field of gravitational and centrifugal concentration of dispersed minerals // Bulletin of Irkutsk State Technical University, 2 (38). 178-181. ISSN: 1814-3520. (In Russian).
18. Surimbayev B.N., Kanaly Ye.S., Bolotova L.S., Romanenko A.G. (2015). The complex scheme of gravity separation [Kompleksnaya schema gravitatsionnogo obogashcheniya]. Materials of XII International science conference «Advanced technologies, equipment and analytical systems for materials and nano-materials» and IX international conference «Efficient use of resources and environmental protection - key issues of mining and metallurgical complex development» [Materialy IX Mezhdunarodnoj konferencii «Effektivnoei spolzovanie resursov i ohrana okruzhajushhej sredy – kljuchevye voprosy razvitija gorno-metallurgicheskogo kompleksa» i XII Mezhdunarodnoj nauchnoj konferencii «Perspektivnye tehnologii, oborudovanie i analiticheskie sistemy dlja materialov edenij ainano materialov»]. May 20-23, 2015. Part 3. 238-244. ISBN 978-601-208-393-4. ISBN 978-601-208-396-5. (In Russian).

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