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Studies of enrichment of sulfide and oxidized ores of gold deposits of the Aldan shield

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The paper presents the analysis of studies of the enrichment of sulfide and oxidized ores in Yakutia deposits. The ore of the deposit is a mixture of primary, mixed and oxidized ores. The main useful component of the studied ore samples is gold with a content of 1.5 to 2.8 g/t, the silver content is low – 5-17 g/t. Ore minerals are represented by sulfides, among which pyrite predominates. The total sulfide content does not exceed 3-5 %. The presence in the ore of free and associated gold with a grain size from fractions of a micron to 1.5 mm. Gold is represented by nuggets in intergrowth with sulfides and also forms independent inclusions. Ores are classified as easily cyanidable.

It was found that the content of amalgamable gold is 10-49, the share of cyanidable gold ranges from 66.67-91, the share of refractory gold is 9.0-33.33 %, which in absolute amount equals to 0.24-0.8 g/t. The extraction of gold in gravitation concentrate varies depending on the gold content in the ore and the yield of concentrate and for ores with a gold content of 1.5-2.8 g/t from 40 to 60 %. The direct cyanidation of all studied ore samples established the possibility of extracting gold into solution up to 86.7-92.9 %, the gold content in cyanidation cakes is 0.2-0.3 g/t. Investigations of the gravitation concentrate by the method of intensive cyanidation showed that with an initial gold content of ~ 500 g/t, up to 98.9 % is extracted into the solution. The gold content in intensive cyanide cakes will be 6-15 g/t. A set of studies carried out by the authors of the article at various institutes showed that it is advisable to process ore from the deposit using cyanidation technology with preliminary gravitational extraction of gold.

Key words: gold; ore; gravitation flotation; cyanidation; concentrate; tailings; extraction; material composition; enrichment

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Introduction. The need to solve problems in the development of gold deposits is associated with the deterioration of the country's mineral resource base. According to V.A.Chanturia, over the past 20 years, the gold content in ores has decreased by 1.2-1.5 times, the share of refractory ores in the total volume of raw materials supplied for enrichment has increased from 15 to 40 %. The depletion of reserves forces to develop the potential of deposits with refractory ore, which increases logistics costs and determines the profitability of mining [3, 5, 6], such are deposits of the Republic of Sakha (Yakutia). Based on data from open sources in 2017, 58 enterprises in Yakutia were engaged in gold mining, 11 of them – at ore deposits and 47 – at gravel gold deposits. The main gold mining enterprises are the following: OJSC “Aldanzoloto GRK” (part of the Polyus Gold holding), LLC “Neryungri-metallic” (part of the Nordgold company); they are developing the Temny-Taborny and Gross deposits in the Olekminsky district, OJSC “Sarylakh-Surma”, OJSC “Zoloto Seligdara”, CJSC “Zapadnaya GRK” in the Oymyakon district are developing the Badran deposit, LLC “Duet” mine is developing the Duet deposit. According to statistics for 2017, 24.8 tons of gold were mined in the Republic of Sakha: 14.6 tons – ore, 10.2 – gravel gold.

Based on the data presented, it can be concluded that Yakutia is one of the largest gold mining regions, and the further development of gold deposits is a strategic and promising direction for the development of the Republic and the Far East.

Formulation of the problem. Currently, the reserves of gravel gold deposits have been substantially depleted, the mineral and raw material base of gravel gold have deteriorated, namely, the share of hard-to-recover gold fractions in the feedstock has increased [1-2].

The analysis of previous researches of different authors [10, 13, 14, 16, 19] showed that the increasing volume of oxidized and mixed ores delivered for processing complicates the technology and worsens the technical and economic indicators of the enrichment of raw materials.



Gold deposits, for example, Kochkarskoye, Bogolyubovskoye, Svetlinskoye, Bere-zovskoye, Vorontsovskoye, mainly have several types of technological ores. This creates cer-tain difficulties in the development of ore processing technology [17, 20]. In this regard, obtain-ing new data on the enrichment of gold-bearing ores for further development or improvement of technology is a prominent area of research. The scientific novelty of the work is the theoretical justification of the proposed technology for the integrated processing of sulfide, mixed and oxi-dized gold-bearing ores.

This research aimed to conduct and analyze the research of the enrichment of gold-bearing ores of various types, considering the issues of the integrated use of mineral raw materials for the subse-quent development of rational processing technology.

Research objectives:

- to study of the chemical, granulometric and mineralogical compositions of ore, characteristics of gold, as well as the phase composition;
- to conduct the laboratory tests for enrichment efficiency by gravitation and flotation methods;
- to study the metallurgical processing of ore and the obtained concentrates.

Methodology. The research methods were based on the theoretical principles of mineral processing. The study of the material composition of ore and concentration products was carried out using chemical, assay, thermal, and spectrometric methods, as well as atomic emission spec-trometry [2, 7, 8].

The study of the mineral composition was carried out by optical methods in polished and thinned sections. At the Research and Design TOMS Institute “Mineral Processing Technology” (Irkutsk) and Research and Production Enterprise “GEOTEP” (Moscow), the ore samples were tested for enrichment by gravitation and flotation methods. Metallurgical processing was carried out using hydrometallurgical methods.

Discussion and results. As a result of studying the mineral composition of various samples, the main natural varieties of the ore of the deposit are identified, which can be divided into three types: primary sulfide; semi-oxidized mixed; oxidized (a product of the processing of primary ores under conditions of hypergenesis).

In terms of material composition, the types of ores do not differ from each other and vary only in the quantitative content of sulfide and oxidized minerals.

Silver minerals were not found in the samples, they are present as impurities in nuggets (10-15 %), and no harmful impurities complicating the extraction of gold were also detected (Table 1).

Table 1

Mineral composition of the studied samples

Minerals	Sample content, %				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Quartz	2.91	9.70	9.70	12.5	7.48
Kalifeldspath	63.50	70	71	64	66
Plagioclase	2.30	1.60	1.20	1.60	1.86
Carbonates	0.10	–	–	0.50	0.17
Protobase	0.40	0.10	0.10	0.20	0.25
Pyroxene	signs	–	–	signs	signs
Muscovite, sercite	25	11.00	7	12	10.87
Epidote	Signs	signs	signs	signs	signs
Sphene	0.10	signs	signs	signs	0.04
Pyrite	0.59	0.50	2.90	4	1.65
Chalcopyrite	0.10	0.10	0.20	0.10	0.11
Sphalerite	signs	signs	signs	signs	signs
Halenit	signs	0.10	0.10	0.10	0.06
Hematite	4	6.90	8.50	5	5.64

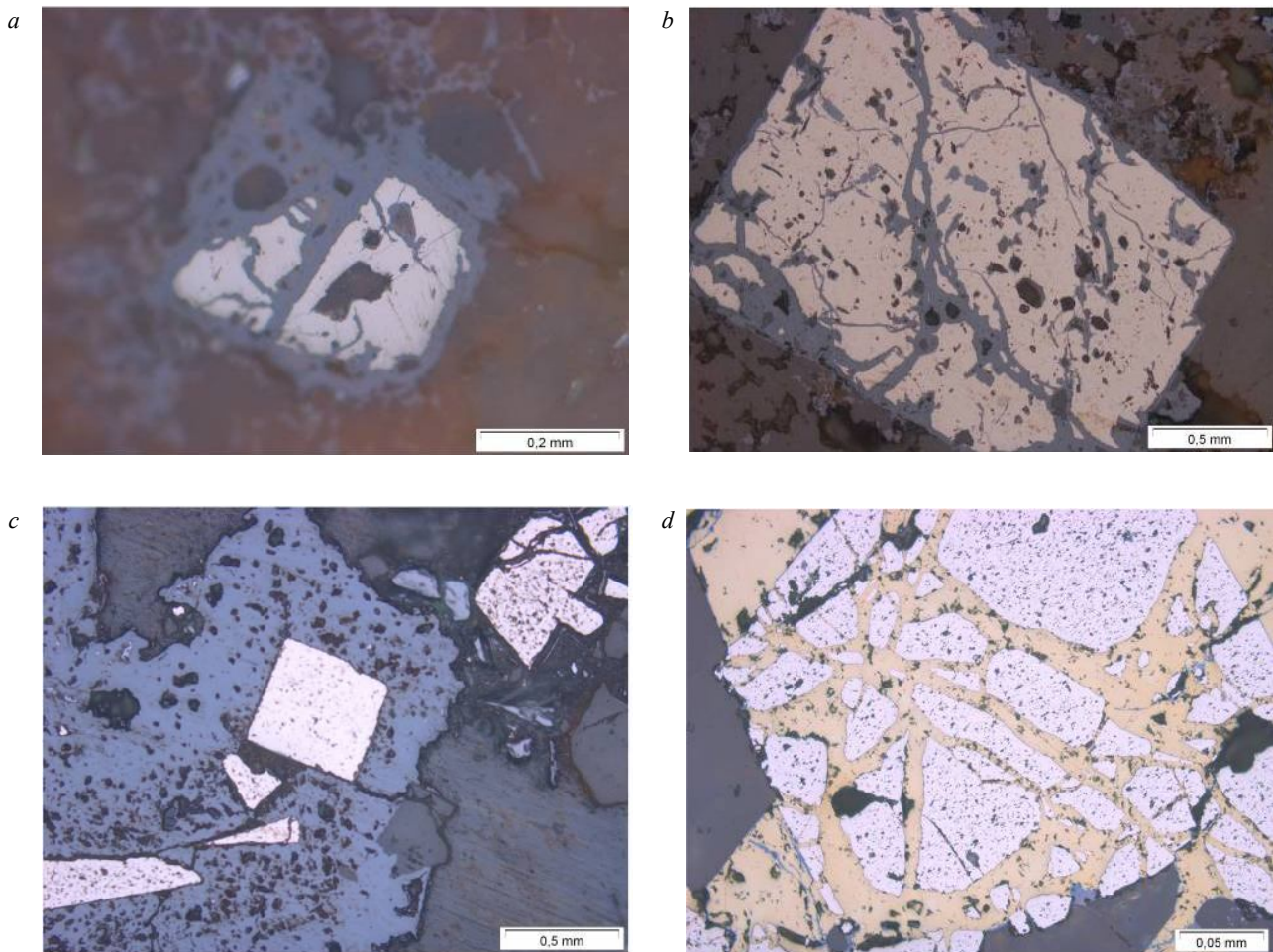


Fig.1. Polished thin section: relicts of pyrite in hematite (*a, b*); pyrite crystals coated in hematite (*c*); veins of chalcopyrite in a pyrite crystal (*d*)

According to mineralogical analysis, the samples have slight differences. The majority of samples are represented by kalifeldspath and mica (76.0-88.5 %), ore minerals in all studied samples are represented by sulfides, among which pyrite predominates.

In samples, pyrite constitutes uniform impregnations and less often aggregates in ore-bearing rocks. The size of pyrite crystals varies from fractions up to 2-3 mm, the aggregates of pyrite crystals reach 5 mm. Quite often, pyrite is replaced by hematite, which forms edges on crystals of iron sulfide and micro-veins (Fig.1). Similar data are presented in [4, 9].

Other ore minerals, chalcopyrite, sphalerite, covellite, marcasite, and hematite were registered in the samples. Hematite is observed in the form of patches up to 5 mm in size, micro-veins, and edges on pyrite. Except for hematite, other minerals are rare, they are found in the form of individual grains.

Characteristics of gold. The gold content ranges from 1.5-2.8 g/t. Gold is represented by nuggets in intergrowth with sulfides, less often it forms independent inclusions. The presence of gold is recorded only in heavy fractions. The gold size is 0.01-1.5 mm. The morphology of native gold is not diverse. The shape of the gold grains is usually round, the edges are even, outgrowths are less often observed, sometimes elongated grains with a ratio of length to width 4:1 are found (Fig.2).

Chemical composition. The study of the chemical composition of the studied ore samples was carried out using chemical, assay, X-ray fluorescence, atomic emission, and optical spectral analyzes, the results are shown in Table 2.

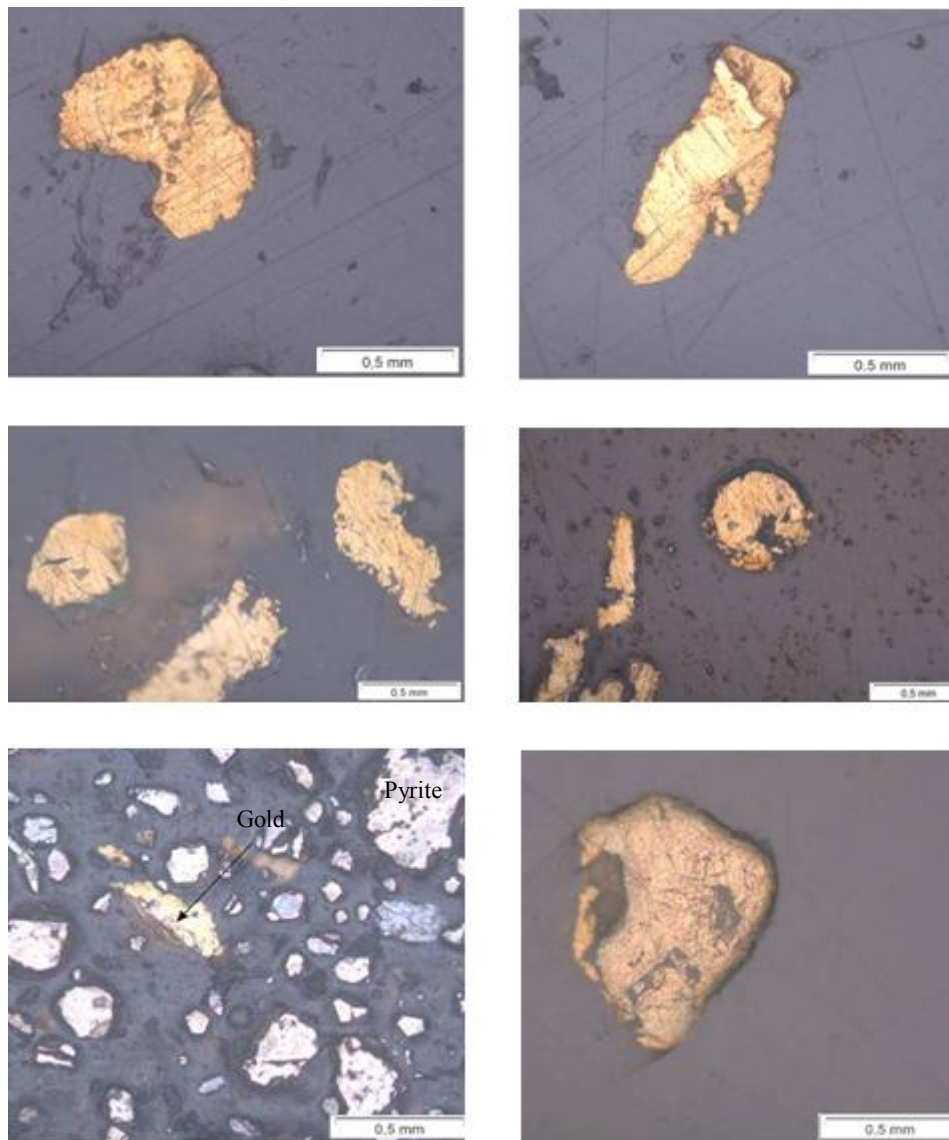


Fig.2. Polished sample of heavy fraction

Table 2

Results of the chemical composition of technological ore samples (RPE "GEOTEP")

Components	Content, %				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Na ₂ O	0.58	0.42	0.37	0.50	0.51
MgO	0.26	0.19	< 0.1	< 0.1	0.15
Al ₂ O ₃	18.3	16.3	15.0	14.4	16.59
SiO ₂	59.4	61.8	60.5	60.9	60.4
K ₂ O	14.3	13.5	13.4	12.8	13.61
CaO	0.18	0.28	< 0.1	0.53	0.27
TiO ₂	0.32	0.50	0.45	0.42	0.41
Fe _{tot.}	4.13	4.85	5.94	5.32	4.78
FeO	0.73	< 0.05	< 0.05	0.46	0.43
MnO _{tot.}	0.070	0.19	0.52	0.049	0.13
S _{tot.}	0.32	0.36	1.58	2.47	1.00
SO ₃	< 0.1	< 0.1	< 0.1	0.46	0.12
S _{sulfide}	0.32	0.36	1.58	2.29	0.95
CO ₂	0.29	< 0.1	< 0.1	0.29	0.19
C _{tot.}	0.49	0.74	0.48	0.56	0.56
C _{org.}	0.18	0.43	0.13	0.13	0.21
Au, g/t	2.8	1.5	1.7	1.6	2.10
Ag, g/t	5.3	10.7	17.5	17.3	11.88



It is established that the main valuable component in the ore is gold. The sulfide sulfur content in the samples was 0.3-2.3 %, which indicates a small number of sulfide minerals in the ore.

Phase analysis. To establish the forms of gold and the nature of its relationship with the ore components, a phase (rational) analysis of ore samples was performed, the results of which are shown in Table 3.

Table 3

Summary results of determining the phase composition of gold in technological ore samples

Forms of gold in samples	RPE "GEOTEP"										TOMS Institute	
	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 1*	
	g/t	%	g/t	%	g/t	%	g/t	%	g/t	%	g/t	%
Free Gold (amalgamated)	1.2	50	0.8	33.34	0.2	11.1	0.2	10	0.73	32.4	1.29	49.3
Gold in compacts (recovered with cyanide)	0.9	37.5	0.8	33.33	1.2	66.7	1.5	75	1.1	48.9	1.1	41.7
Total cyanide gold	2.1	87.5	1.6	66.67	1.4	77.8	1.7	85	1.82	81.3	2.39	91
Gold insoluble in cyanide: coated with oxides and iron hydroxides, in carbonates	0.3	12.5	0.8	33.33	0.4	22.2	0.3	15	0.42	18.7	0.24	9
associated with sulfides	0.1	4.2	0.3	12.5	0.1	5.55	0.1	5	0.15	6.4	0.08	3
finely disseminated in quartz	< 0.1	–	0.2	8.33	0.1	5.55	< 0.1	–	0.5	2.4	0.09	3.5
	0.2	8.3	0.3	12.5	0.2	11.1	0.2	10	0.22	9.9	0.07	2.5
Total:	2.4	100	2.4	100	1.8	100	2	100	2.24	100	2.64	100

A significant mass fraction of gold in the studied samples is in an amalgamated form (gold extracted by gravitation enrichment methods) – 10-49%, and cyanide gold in the samples contains 66.67-91 %. Resistant (not recoverable by direct cyanide) gold accounts for 9-33.33 %, which in absolute amount is 0.24-0.8 g/t. Based on the results of the phase analysis, it was concluded that the ore of the deposit is favorable for processing by combined methods using gravitation processing and metallurgical methods.

To determine the nature of the distribution of gold by size classes of crushed ore, particle size analysis was performed (Table 4).

Table 4

Granulometric and assay analysis results with gold distribution by size class

Size class, mm	RPE "GEOTEP"								TOMS Institute	
	Sample 1		Sample 2		Sample 3		Sample 4		Sample 1*	
	g/t	%	g/t	%	g/t	%	g/t	%	g/t	%
-2+1	1.8	27.5	2	33.2	1.1	26	1.2	29.6	1.42	10.62
-1+0.5	1.1	11.1	1.6	18.4	1.1	16.1	0.9	14	1.64	20.41
-0.5+0.2	2.9	21.2	1.6	13.3	1.2	12	1.6	18.2	2.28	25.81
-0.2+0.1	5.2	15.8	0.8	2.8	2	9.3	2.2	10.7	2.7	12.46
-0.1+0.074	4.5	7.6	0.7	1.4	2	5.2	2.2	5.7	3.5	4.16
-0.074+0.044	4.8	5.7	3.6	6	2.8	5.9	2.8	5.5	4.6	5.79
-0.044+0.020	7	8.9	7.8	15.5	5.3	12.1	5.3	12.1		
-0.020	1.8	2.2	5.2	9.4	4.8	13.4	2.6	4.2	5.3	20.75
TOTAL:	2.43	100	2.1	100	1.57	100	1.54	100	2.37	100

It is recorded that the distribution of gold by size classes is uneven. This distribution pattern is indicative of the presence of free particles of gold in the crushed ore. High gold grade in fine class was noted. It was found that when the gold content in the initial ore is 1.5-2.4 g/t in the fine classes (Table 4), the gold content varies from 0.9 to 7.8 g/t.



The comparison of the results of particle size analysis performed by RPE “GEOTEP” and the TOMS Institute allows us to conclude that the samples on the content and distribution of gold are slightly different from each other. The gravel gold is in the class with a fineness of $-2-+0.2$ mm with significantly higher relative gold contents in finer classes.

From the results of the particle size analysis performed at the TOMS Institute, we can conclude that the test sample 1*, as well as the samples studied at RPE “GEOTEP”, is quite resistant to grinding and sludging (the yield class of 0.045 mm is 9.27 %).

Studies on the enrichment by gravitational methods. The nature of the association of gold in the studied ore samples in the presence of free gold recoverable by amalgamation (up to 49 %) makes it reasonable to research gravitation enrichment methods [11, 12]. The studies were performed using a concentration table, a centrifugal separator, as well as using a heavy liquid to determine gravitational contrast [1].

Gravitation analysis showed that the samples are quite contrasted in the gravitation terms. The extraction of gold into the heavy fraction with an initial fineness of 2 mm was 45.3-55.3 %, and the gold content in the light fractions was 0.8-1.1 g/t.

According to the same gravitational analysis of various samples in a heavy liquid, it was found that, theoretically, with a grinding size of less than 0.074 mm at a concentrate yield of 5-12 % the 81-96 % of gold can be extracted. The gold content in the tailings will be 0.2-0.4 g/t. When performing research work using various gravitation equipment, the data of gravitation analysis in a heavy liquid were not confirmed. Extraction into gravitation concentrates for most samples with a significant yield (5-10 %) does not exceed 40-60 %. A decrease in the yield of concentrate leads to a decrease in the extraction of gold in the concentrate.

The analysis of the results of ore dressing at the concentration table indicates the possibility of extraction into gravitation concentrate with a yield of 3-4 % from 37.8 to 76.5 % of gold. Summary data on the enrichment of samples on the concentration table (RPE “GEOTEP”):

Indicator	Sample 1	Sample 2	Sample 3	Sample 4
Gold content in ore, g/t	2.22	2.31	1.6	1.69
Extraction of gold in gravitation concentrate, %	76.5	37.8	42.2	51
Gold content in tailings, g/t	0.54	1.5	0.98	0.88

When ore samples were enriched according to a two-stage scheme on a centrifugal separator, lower gold recovery rates were obtained as compared with table concentration. The enrichment was carried out in two stages with a reduction in particle size from 0.5 to 0.1 mm. Summary of enrichment of samples on a centrifugal separator (RPE “GEOTEP”):

Indicator	Sample 1	Sample 2	Sample 3	Sample 4
Gold content in ore, g/t	2.83	1.97	1.62	1.92
Extraction of gold in gravitation concentrate, %	62.9	25.2	15	13.8
Gold content in tailings, g/t	1.07	1.5	1.4	1.69

At the TOMS Institute, gravitational studies were carried out using centrifugal separation. Two types of separators were used – with periodic and continuous discharge of concentrate. The enrichment was carried out with a particle size reduction of 90 % less than 0.071 mm.

The operation of a centrifugal separator with a periodic discharge of concentrate on a circulating mill was simulated. As a result of enrichment according to this scheme, concentrate with a gold content of 438 g/t was obtained. The extraction of gold in concentrate amounted to 38.66 %.

To establish the possibility of maximum gold recovery by gravitational methods, large-scale studies were carried out according to a two-stage scheme using two types of centrifugal separators –

with periodic and continuous discharge of concentrate [14]. The result was a combined gravitation concentrate with a yield of 11.06 % and a gold content of 14.56 g/t. The extraction of gold in concentrate amounted to 60.74 %. The extraction of gold from ore with a gold content of 2.65 g/t with single-stage enrichment with a low yield was 38.66 %, the gold content in the tailings of 1.63 g/t with two-stage enrichment with a low and high yield, the extraction of gold into gravitation concentrate was 19.88 and 40.86 %, respectively, the gold content in the tailings was 1.17 g/t.

As a result of gravitational enrichment of all studied ore samples of the deposit, tailings were not obtained, that is, the gravitational methods can be included in the scheme only for capturing free gold in the initial stage of the process.

Due to the presence of free gold in the ore (up to 1.5 mm), gravitation concentration in the grinding cycle is recommended for the constant removal of free gold particles from the circulating stream. The use of gravitational enrichment minimizes the risk of loss of large metal during subsequent processing (flotation, cyanidation).

Studies on the enrichment by flotation methods. Preliminary studies of ore samples of the deposit to determine the concentration by flotation methods carried out in RPE "GEOTEP" showed that the initial ore by the combined gravitation-flotation scheme is enriched very efficiently, however, the data of large-scale studies on the ore charge indicate that no more than 76.8-82.3 % can be extracted into the combined concentrates.

Metallurgical ore processing (RPE "GEOTEP"). The results of direct leaching of the initial ore at a cyanide concentration of 0.1 % and leaching time of 24 hours are presented in Table 5.

Table 5

Results of direct cyanide agitation leaching of the initial ores with a grinding of 100 % class of 0.074 mm

Sample number	Content in ore, g/t		Content in leach cake, g/t		Extraction of Au in solution, %		Reagent consumption, kg/t of ore		
	Au	Ag	Au	Ag	Au	Ag	NaCN	CaO	
Direct leaching mode									
Sample 1	2.8	5.3	0.3	< 3.0	89.3	43.4	1.7	2.4	
Sample 2	1.5	17.4	0.3	4.0	80.0	77.0	1.7	2.4	
Sample 3	1.6	17.5	0.3	4.6	81.3	73.7	1.1	2.7	
Sample 4	1.5	10.7	0.3	6.6	80.0	38.3	1.1	2.6	
Sorptions leaching (resin AM-2B)									
Sample 1	2.8	5.3	0.2	< 3.0	92.9	43.4	1.6	2.3	
Sample 2	1.5	17.4	0.2	< 3.0	86.7	82.8	1.4	2.7	
Sample 3	1.6	17.5	0.2	4.4	87.5	74.9	0.9	2.8	
Sample 4	1.5	10.7	0.2	6.0	86.7	43.9	1.3	2.6	

It was found that the maximum recovery of gold and silver during sorptions leaching of the samples of the initial ores of various sections of the deposit was: 92.9 and 43.4 % for sample 1; 86.7 and 82.8 % for sample 2; 87.5 and 74.9 % for sample 3; 86.7 and 43.9 % for sample 4.

Extraction of gold from ore in the sorptions mode ensured an increase in recovery of 3.6-6.7%, which indicates the presence of sorptions activity of the ore and the need to leach both ore and enrichment products in a mode that reduces the influence of this factor (sorptions or intensive).

During the study, the leaching of the ore enrichment products of the deposit was studied. The results of leaching of flotation tailings, as well as flotation and gravitation concentrates obtained from the feed of initial ores, are given in Table 6.



Table 6

Results of the leaching of enrichment products

Product (sample)	Content in the initial product, g/t		Residual content in cyanidation cake, g/t		Extraction into solution by cake, %		Reagent consumption, kg/t	
	Au	Ag	Au	Ag	Au	Ag	NaCN	CaO
Gravitation concentrate	44	115	6	73	86.4	36.5	7.6	6.5
Flotation concentrate	23.2	122	5.8	82.4	75	32.5	7.9	6.5
Combined concentrate	29.1	120	8.5	82	70.8	31.7	8.1	6
Flotation tailings								
Sample 1	0.3	< 3	< 0.2	1.0	33.3	66.7	1.6	–
Sample 2	0.5	< 3	< 0.2	2.0	60	33.3	1.4	–
Sample 3	0.6	8.6	< 0.2	< 3.0	66.7	65.2	1	–
Sample 4	0.4	14.2	0.3	5.8	25	59.2	1.5	–

Gold recovery from flotation tailings was 25-60 %, direct cyanide leaching of concentrates of the charge mixture of the initial ores in the agitation mode of pulp agitation (T:L = 1: 2, CNaCN = 1 g/l, pH = 10.5-11.0, time – 24 hours) ensured gold recovery of 86.4 % for gravitation concentrate and 75.0 % for flotation concentrate. The extraction of silver was 36.5 and 32.5 %, respectively. The consumption of sodium cyanide was 7.6-8.1 kg/t of concentrate, lime – 6.0-6.5 kg/t of concentrate.

RPE “GEOTEP” also performed heap leaching tests. As a result of the study of ore samples at various sites, gold recovery was 20-52.6 %. It should be noted that the results were preliminary because the tests used non-representative small samples (1 kg).

Based on the research carried out by RPE “GEOTEP”, three ore processing schemes were proposed:

- sorption leaching of all ore with a grinding size of 95 % – 0.074 mm;
- using flotation and gravitation enrichment of ore and leaching of beneficiation products;
- using gravitation enrichment and leaching of enrichment products (recommended in the final report of RPE “GEOTEP” for industrial implementation).

Research at the TOMS Institute. The cyanidation of the gravitation concentrate was carried out in the intensive cyanidation mode (cyanide concentration 2 %, caustic soda 0.2 %, leaching temperature 60 °C). Gravitation tailings and feed ore were leached in a sorption mode (activated carbon of the Norit brand in an amount of 30 % of the total volume).

The results of cyanidation of ore and beneficiation products:

Product	Gold content in the initial product, g/t	Gold content in cake, g/m	Extraction of gold in solution, %
Head ore	2.65	0.30	88.68
Gravitation tailings	1.57	0.24	84.71
Gravitation concentrate	547.0	6.1	98.88

As a result of the leaching of the initial ore, the cake with a gold content of 0.3 g t was obtained, which corresponds to the extraction of Au into the solution of 88.68 %.

The gold content in the cake after leaching of the gravitation concentrate was 6.1 g/t, the extraction of gold into the solution was 98.88 % of the cyanidation operation or 40.4 % of the initial ore. The obtained result showed good cyanidation of the gravitation concentrate and the promising use of the intensive cyanidation for its processing.

After hydrometallurgical treatment of the gravitation tailings, the gold content in the cake was 0.24 g/t, the extraction of gold into the solution reached 84.71 % of the cyanidation operation or 50.1 % of the initial ore.

The research at the RPE “GEOTEP” and the TOMS Institute showed that the studied ore and concentration products are easily cyanidable. It is advisable to process ore from the deposit using



cyanidation technology with preliminary gravitational extraction of gold. In this case, cyanidation of the gravitation concentrate should be carried out in a separate intensive cyanidation cycle, and the gravitation tails should be leached in the CIL mode (sorption leaching without preliminary cyanidation of the product). This scheme provides a minimum of gold content in the tailings. When the gold content in the ore is 2-2.5 g/t, the level of its extraction into a concentrate with the gravitation scheme of ore processing is 60-76.5, gravitation-flotation – 76.8-82.3, gravitation-cyanidation – up to 92.9 %.

Based on the performed set of studies of ore and mineral processing products by metallurgical methods, a gravitation-cyanidation scheme with separate hydrometallurgical processing of tailings and concentrate is recommended.

Given the significant loss of gold during sorption cyanidation of ore (gold in the liquid phase, coal fines), it is recommended to extract metal into the gravitation concentrate in the grinding cycle, followed by intensive cyanidation [15]. Excesses of gold-containing solutions of intensive cyanide and cake after regrinding can be sent to processing by sorption cyanidation together with tailings of gravitation enrichment. This combination of intensive and sorption cyanidation minimizes the loss of gold [18].

It was established that with a change in the gold content in the ore supplied to the factory within the range of 1.8-2.5 g/t, the predicted recovery in commercial products will be 83.3-87.2 % (taking into account losses during cyanidation with coal fines and the liquid phase of the tailings). A decrease in the gold content in the ore will lead to a decrease in the total extraction of gold in commercial products.

Conclusion. The following natural types of ores were identified at the deposit: primary, mixed and oxidized, which can be classified as aluminosilicate. The predominant elements are silicon, aluminum, and potassium.

The main useful component of the ore of the deposit is gold, with the content of 1.5-2.8 g/t in the studied technological samples, the silver content is low – 5-17 g/t. Silver will be extracted along with gold and does not represent inherent value in the ore.

According to the data obtained during the phase analysis of various ore samples, the content of amalgamated gold is 10-49 %. The proportion of cyanidable gold ranges from 66.67 to 91 %. Resistant (not recoverable by direct cyanidation) gold accounts for 9-33.33 %, which in absolute amount is 0.24-0.8 g/t.

When grinding ore to a particle size of 90-95 %, class 74 μm , most of the gold (up to 91 %) is in a form available for direct cyanidation (in a free or partially free state in intergrowths with rock and sulfide minerals).

The extraction of gold in gravitation concentrate varies depending on the gold content in the ore and the yield of concentrate and for ores, with a gold content of 1.5-2.8 g/t it varies from 40 to 60 %.

As a result of gravitational enrichment of all investigated ore samples of the deposit, tailings were not obtained, i.e. gravitation methods can be included in the scheme only for trapping free gold at the initial stages of the process. The maximum extraction of gold from ore is possible only using combined processing schemes.

The direct cyanidation of all studied ore samples provides the possibility of gold extraction into solution up to 86.7-92.9 %; the gold content in cyanidation cakes is 0.2-0.3 g/t.

Investigations of the gravitation concentrate by the method of intensive cyanidation showed that with an initial gold content of ~ 500 g/t, up to 98.9 % is extracted into the solution (from the operation), the gold content in cakes is 6-15 g/t.

The set of studies carried out by RPE “GEOTEP” and the TOMS Institute showed that it is advisable to process ore from the deposit using cyanidation technology with preliminary gravitational extraction of gold.



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