Study of gold-bearing ores material and mineralogical composition in Lower Angara region

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Abstract. In connection with the involvement in new deposits exploitation, represented by refractory oxidized ores with a fine-dispersed phase and valuable component low content, there have been trends in the processing of this type of raw material. The alluvial gold-bearing sands of Lower Angara region are of practical interest. The results of the material and mineralogical composition of gold-bearing ores made it possible to establish that most rock fragments are quartz-mica schists, which are dilapidated by weathering up to 15% of the sample mass and clay inclusions. Ore by 61.5% is presented with grain size of more than 20 mm. Gold is distributed almost evenly by size class. Basically, gold is found in intergrowths with quartz, mica, pyrite, and clay components. The size of the gold grains ranges from 0.03 to 0.05 mm to several microns. The content of the valuable component was about 3-5%. The result of gravity concentration of the original ores showed the possibility of obtaining gravity concentrates with a metal content of 220-250 g/t, with extraction up to 93-95% and obtaining tailings from 0.3-0.5 g/t, followed by leaching of cyanide and sulfur-alkaline solutions. The extraction of the valuable component into the solution was 80% and 98%, respectively. The results obtained indicate the possibility of processing these types of ores in Lower Angara region.

1. Introduction
Placer gold deposits are formed as a result of erosion processes, destruction and redeposition of materials of ore bodies. Placers are secondary deposits formed due to the destruction of bedrock. The nature of the placer formation can be greatly influenced by the location of the gold deposit relative to the river valleys in which placers are formed.

The problem of fine gold, which is not recoverable by existing concentration plants, is new and poorly studied in placer technology. Placer sampling carried out in recent years in a number of gold-bearing regions using highly effective methods has made it possible to establish in some of them an increased high (up to 70-90%) yield of fine gold. A large yield of fine gold has been established in those placers where there are primary sources, which are characterized mainly by fine gold. Optimal conditions for the release of such gold from the vein material and its accumulation in loose sediments take place in the weathering crust. The most favorable for the accumulation of gold are eluvial-slope deposits. The content of fine gold in these deposits is in direct proportion to the clay components. Sandy-pebble alluvium is not very favorable for the concentration of fine gold [1].

The researchers came to the conclusion that the reserves of the metal in the known placers, due to fine gold, can be increased up to 20%. There are real prerequisites for revaluation of placers with substantially fine gold in order to classify them as independent industrial facilities. It is known that until recently the gold content in placers was estimated by the presence of coarse gold in them, which can be
mined by gravity methods. It is known that in many placers the content of fine gold is about 50%, sometimes much more. With such ratios of coarse and fine gold, the currently used methods of exploration and development of placer deposits cannot be considered economically justified. According to the degree of prospects and possible practical significance, a number of natural objects have been outlined, where significant accumulations of hydrogenic origin gold may arise [2].

Recently, in the practice of operational and geological exploration, as well as at ore processing facilities, more modern and efficient installations are being introduced, which make it possible to extract fine gold from refractory raw materials.

Currently, the main sources of gold production are primary gold-bearing ores, which are subdivided into sulfide and oxidized. For these types of ores, independent processing schemes have been formed, in particular, oxidized ores are processed by leaching a valuable component in cyanide aqueous media with subsequent concentration by sorbents. Oxidized quartz and unoxidized ores are beneficiated by gravity and flotation methods to obtain the corresponding concentrates suitable for further processing in the metallurgical process [3].

In connection with the involvement in the exploitation of new deposits, represented by refractory ores of the weathering crust of rocks with a finely dispersed phase and a low content of the valuable component, there have been trends in the development of technological schemes for the processing of mineral raw materials.

At present, alluvial gold-bearing sands of one of the deposits of Lower Angara region are of practical interest.

The purpose of these studies is to study the material and mineralogical composition of refractory gold-bearing ores of new deposits with the aim of bringing them into operation [1, 2].

2. Research methodology

For the study, the material of gold-bearing ore sample is presented by quartz-like silty-schists with veins and streaks of quartz. The average gold grade ranged from 4.4 g/t to 5.3 g/t. The size of the maximum piece was up to 110 + 0 mm.

The entire mass of the sample was subjected to granulometric analysis with the determination of the yield of each class and the distribution of gold by class. The results of the analysis showed that 61.5% of the sample consisted of pieces with a particle size of more than 20 mm. The distribution of gold in the ore is almost uniform. Allows to draw a conclusion about the finely dispersed nature of the gold of this ore. Due to the fact that gold in the ore is in finely dispersed state, in order to study the material and mineralogical composition, the ore was crushed to a size of -0.074 + 0 mm and sent for X-ray structural analysis, and the class -1 + 0 mm was used for further dressing at the concentrating table, the parameters of which correspond to the traditional scheme of dressing of these types of ores on the tables. The flow rate of water was 11.5 liters per minute, the operating time of the table was from 4 to 5 minutes. Then the obtained gravity concentrate with a gold content of up to 20 g/t was dressed in heavy medium of the Clerici liquid. The density of the liquid was maintained within the limits of 3.7 g / l. To determine the size of the gold grains, polished sections were made. Dimensions were measured under a microscope at high magnification.

In the study of gold-bearing sands, the possibility of their dressing at the centrifugal concentrator "Knelson" was studied.

Ore in the amount of 5 kg was ground in a ball mill with a weight of 1 kg, for 25 minutes, to a particle size of -0.2 + 0 mm. Then the ore was ground to a class of -0.074 mm, it was about 65%.

The water consumption was up to 12 liters per minute for the device, the operating time was 10 minutes. The productivity of the apparatus was 30 kg / h. 90 g of heavy fraction was obtained from 5 kg of sand.

- For leaching gold, a lime-sulfur reagent was used, obtained by dissolving elemental sulfur in an aqueous suspension of calcium hydroxide. The broth was prepared at a temperature of 100 °C for 5-8 hours. The content of sulfur and calcium hydroxide varied in a wide range, the
concentration from 12.5% to 100 g / L S and from 50 g / L to 200 g / L Ca (OH)₂. The process of leaching gold with this solution was carried out at room temperature and the ratio S: L = 1: 3 in bottle-type agitators. The ore was preliminarily crushed to a grade of 0.074 + 0 mm and combined with fine grades of the original ore. The cyanidation of the original ore and its beneficiation products was carried out under the selected optimal conditions, which are used in the traditional scheme for these types of raw materials. The concentration of CN⁻ was 0.02%. The duration of the leaching process is from 8 to 24 hours. Barium peroxide was used as an oxidizing agent, the ratio S: L = 1: 2.

- The resulting products were analyzed by the following methods: spectral, chemical, assay, atomic absorption on «Soloarm» spectrophotometer, X-ray structural, scintillation.

3. Research results

Pit forward for research gold-bearing sands consist of fragments of sulfur with greasy lustre of quartz and weathered dilapidated partially silicified quartz-mica schists. Gray massive weakly fractured quartz of the sample has an uneven color due to yellowish-brown spots and veinlets of iron hydroxides, veinlets of kaolinized feldspars, dark gray spots of contamination of quartz by host rocks. Quartz is practically devoid of visible ore mineralization. The shales are of yellow and brown color with a golden sheen of hydromica, different density due to the different degree of their silicification - from dense micaceous quartzites to ordinary quartz-mica schists. Quartz-mica varieties of shales are semi-destroyed by weathering, up to 15% of the sample mass is easily crumbled, represented by loose small clouds and clay inclusions.

Ore minerals are present in the sample in insignificant amounts, represented by pyrite, pyrrhotite, chalcopyrite, bismuthite, magnetite, rutile, hemaitae, hydrohematite, goethite, hydrogoethite. Pyrite has a small distribution among the sulfides of the sample. In the quartzite-schist part, the pyrite sample is somewhat larger than in the quartz part. The rare scattered dissemination of cubic metacrystals of pyrite in the quartz and shale parts of the sample is mostly shadow, since the metacrystals are almost completely, to pseudomorphs, replaced by iron hydroxides (goethite, hydrogoethite, and hydrohematite), and the pyrites themselves are present only in the form of replacement relics. Larger pyrite grains are found in quartz veins and form granular aggregates together with coarse quartz grains.

Chalcopyrite is less exposed to weathering than pyrite, occurs in the form of rare and small rounded inclusions in quartz and quartzite, without forming intergrowths with other ore minerals.

In rare cases, pyrrhotite forms small rounded inclusions in quartzite.

Bismuthite was found only in the quartz part of the sample in the form of needle-shaped and spear-shaped precipitates, the size of the precipitates is up to 0.06 mm. Slightly distributed.

Iron oxides and hydroxides — hematite, hydrohematite, goethite, and hydrogoethite — are fairly well represented in the material of the sample (brown membrane) both in the quartz and quartzite parts of it. A fine mixture of these minerals fills cracks in the form of micro-veins, drip-like forms in microvoids, intensively develops along the precipitates of pyrite and magnetite, replacing them up to complete pseudomorphosis, and stains the sample material of brown colors. The size of such limonite precipitates reaches significant sizes.

Quartz makes up more than half of the sample material, forming round, less often acute-angular forms of grains. In general, quartz grains are weakly fractured and the grain continuity is not disturbed. Along the microcracks, emphasizing them, there are membranes of iron hydroxides. Quartz grains are overgrown and replaced by albite and microcline, forming relic islands within the larger feldspar grains. The cement of such quartz grains is usually a tourmaline-chlorite-mica aggregate.

Feldspars - microcline and albite are quite common materials and form larger segregations in vein quartz - disseminated aggregates and individual grains. The fracturing of feldspars is moderate without breaking the continuity of the grains. Small inclusions of ore minerals are sometimes observed along the grain boundaries. Individual veins of feldspars bear traces of weathering, emphasized by the development of a kaolin aggregate along them.
Tourmaline in quartzites makes up 10-50% of their mass. Such a mass fraction of tourmaline determines the nematogranoblastic structure of quartzites, with an increase in the size of quartz grains, the size of tourmaline grains, which is unevenly distributed in the sample material, and its grains are fractured and are replaced along fractures by quartz and chlorite.

Muscovite predominates among micas in the sample, reaching in some areas up to 20% of the mass of quartz-mica schist. Usually it forms bundle-like aggregates of scaly grains. Bundles of muscovite aggregates alternate with interlayers of granular quartz and together with them are often sharply curved to form micro-layering.

Biotite occurs in the form of irregularly shaped individual scales, unevenly located in the main tissue of quartz-mica schists.

Chlorite in some areas reaches 5% of the mass of the quartz-mica part of the sample. Its size is generally comparable to the size of granoblastic quartz grains. The shape of the grains is elongated, rounded and, less often, radially radiating [4].

Kaolinite and nontronite are clay minerals in the sample material with a particle size of up to 0.2 mm. These minerals are extremely unevenly distributed. Kaolinite forms clusters in the form of scattered disseminated nests or stripes of feldspars tracing veins. Individual grains of kaolinite have prismatic shapes, and the aggregates are fan-shaped, the grain size is up to 0.2 mm. Nontronite forms greenish-brown spherocrystals of a radially-radiating internal structure. Nontronite crystals form separate inclusions.

As a result of selective weathering of sands with an abundance of cells, recesses filled with clay matter, all ore is impregnated with iron hydroxides.

The clay component with a particle size of 0.01-0.001 mm was determined by the thermal method. The analysis of the thermogram showed that the bulk of the clay is kaolinite-hydromica in composition with the presence of 0.5-1.5% quartz impurities, as well as iron hydroxides.

According to the scintillation analysis of clays, the maximum amount of gold grains falls on the first discrimination level, i.e. the size of gold grains does not exceed 0.03 mm to 0.05 mm, usually several microns. The forms of gold grains are varied: from lumpy to hook-shaped and lamellar. More often, gold is found in intergrowths with quartz, mica, and pyrite.

The chemical composition of the ore showed the silicate nature of SiO₂ ores from 72.8% to 82.0% with insignificant contents of carbon dioxide (CO₂ - 0.057%) and sulfur (S - 0.013%) and predominance of potassium - 2.7% over sodium - 0.52%.

Analysis of impurity elements indicates their insignificant content, %: lead - 0.02; zinc - 0.1; copper - 0.02; bismuth - 0.01; manganese - 0.1 and complete absence of arsenic and antimony.

According to the granulometric analysis, the ore is 61.5% larger than 20 mm. The granular part is 29%, the clay component is up to 10%. Gold by size classes is distributed almost evenly, the content is on average up to 3 g/t up to 5 g/t.

Based on the obtained results of material granulometric and chemical analyzes of gold-bearing sands, it was established that gold is associated with all minerals represented by a fine-grained phase. Clay components are unevenly distributed, forming clusters in the form of nests and rare individual inclusions [5].

The analysis of the beneficiation of such types of gold-bearing raw materials has shown that the most promising is the use of new promising apparatuses with subsequent leaching of gravity tailings [6].

The investigated gold-bearing initial sands of -0.074 mm class with a concentration of the valuable component from 5-5.3 g/t were subjected to gravity concentration at the central concentrator "Knelson". The results are shown in table 1.

The results of gravity concentration showed the possibility of obtaining gravity concentrates at a yield of 1.6% with a metal content (according to assay analyses) of 221-250 g/t, with metal recovery up to 93-95% and obtaining tailings at an output of 93-98.4% and the metal content in the cakes is up to 0.3-0.5 g/t. Then, the possibility of leaching gold from the original ore (class - 0.074 mm) with a metal content of 5.3 g/t and gravity tailings with a metal concentration of 0.3-0.5 g/t with a cyanide solution with a CN-0.02 concentration was investigated %, barium peroxide was used as an oxidizing agent,
which is used according to the traditional technology at the plant. The duration of the leaching process was 24 hours.

Table 1. Initial ore dressing results.

| Products    | Yield, % | Metal assay, g/t | Metal recovery, % |
|-------------|----------|------------------|------------------|
| Concentrate | 1.6      | 250.0            | 95               |
| Tailings    | 98.4     | 0.5              | 5.0              |
| Initial ore | 100.0    | 5.3              | 100.0            |

We also studied the possibility of offering a lime-wax-sulfur reagent as a solvent that is environmentally friendly and promising. The original sands and gravity tailings with a grain size of -0.074 + 0 mm were subjected to leaching with a sulfur-alkaline solution obtained by dissolving elemental sulfur in calcium hydroxide. The optimal leaching conditions for this reagent were selected on the basis of previous studies on similar types of raw materials. The leaching process took about 8 hours. The research results are presented in table 2.

Table 2. Results of metal leaching from gold-bearing raw materials.

| Name of products | Gold assay in initial products, g/t | Solution concentration g/l | Gold assay in the cakes, g/t | Gold recovery in the filtrate, % |
|------------------|-----------------------------------|-----------------------------|----------------------------|---------------------------------|
| Initial ore class -0.074 mm | 5.3                                         | Sulfur-alkaline solution 50 g/l S+100 g/l Ca(OH)₂ | 0.01                           | 98                             |
|                   |                                            | Cyanide solution 0.02 %     | 0.04                           | 92.5                           |
|                   |                                            | Sulfur-alkaline solution 50 g/l S+100 g/l Ca(OH)₂ | 0.001                          | 98.5                           |
|                   |                                            | Cyanide solution 0.02 %     | 0.09                           | 80                             |
| Dressing tailings | 0.5                                         |                             |                                |                                 |

The obtained results of metal leaching show that the gold recovery is quite high. The residual content in the cakes is 0.01 g/l from the original sands when leached with a sulfur-alkaline solution when recovered into the filtrate up to 98%. The residual gold content of the concentration tailings in the cakes was 0.001 g/t with 98.5% recovery in the filtrate. When using cyanide solvents from the original sands, the residual concentration of gold was 0.04 g/t with 92.5% recovery in the filtrate. The residual gold content in the cakes from the beneficiation tailings was 0.09 g/t with up to 80% recovery in the filtrate [7].

Reagents alternative to cyanide compounds, which have proven themselves in gold recovery, are used only on an experimental scale. The main advantages of cyanide compounds over other solvents of gold are high selectivity with respect to noble metals, low consumption of reagents, high recovery of gold into solution and its subsequent separation from cyanide solutions, low corrosive activity of the medium.

With undoubted advantages, the cyanidation process is characterized by significant disadvantages. The main technological disadvantage of the cyanide process is its long leaching time. From the point of view of ecology, the extremely high toxicity of alkali metal cyanides, which belong to the substances of the first hazard class, and the products of their interaction with ores, are also disadvantages. For a number of gold mining regions, the high costs of environmental protection measures make the development of promising deposits unpromising. The problem of neutralizing waste water from concentration plants has not been fully resolved.

At present, a fairly wide range of solvents has been identified, which are considered as an alternative to cyanide salts in the processes of extracting gold from ore raw materials.

The search and evaluation of new solvents of noble metals is carried out not only for environmental reasons, but also pursues other goals, for example, the possibility of processing gold-bearing ores that are difficult to cyanide leaching. In relation to this type of ore, a lime-sulfur reagent is of interest. The
reagent is non-toxic and environmentally friendly. Sulfur-alkaline solutions are formed by the interaction of elemental sulfur with solutions of various hydroxides. These are multicomponent systems containing mono- and poly-sulfide, metal thiosulfates and free alkali in various ratios. When elemental sulfur interacts with an aqueous suspension of potassium hydroxide, a lime-sulfuric broth is formed. It is a cherry-red liquid containing hydrosulfide ion (HS\(^-\)), thiosulfate ion S\(_2\)O\(_3\), polysulfide Sn\(_2\)-.

The data of chemical analysis on the material composition of the cakes indicate the selective nature of the action of the reagent on the original ore. The reagent dissolves the metal without entering into chemical interaction with other elements in the original ore (sulfur, arsenic, titanium, etc.), which pass into the waste cakes.

The analysis results show that when the content of elemental sulfur in the original ore is up to 0.8%, its content in the waste cakes varies from 0.14 to 1.14%, averaging 0.64%, i.e. actually corresponds to the content in the feedstock.

It follows from this that in the process of leaching there is no transfer of sulfur from the process reagent in the form of sulfate ions to the waste cakes. Moreover, cakes are not environmentally harmful and can be stored as substandard ores at specially prepared sites. Based on the results of the research, a technical regulation was drawn up for the extraction of gold from refractory ores [8].

4. Conclusion

Gold-bearing ores presented for study are quartz-mica schists, mica microquartzites, sometimes tormolinized with quartz veins, veinlets of quartz feldspar, chlorite, carbonate and mixed composition. The content of sulfides is poor, up to 2.0%. Perrotine, pyrite, chalcopyrite in insignificant amounts prevail in the composition of sulfides, false galena and galena are embedded in single amounts of arsenopyrite. Among the oxides are ilmenite, rutile, and iron hydroxides. Oxidation traces of the ore are negligible.

The chemical composition of the ores showed a delicate character (SiO\(_2\) from 72.8 to 81.9%) with insignificant contents of carbon dioxide and sulfur. Impurity elements indicate their insignificant content.

The results of the granulometric analysis allow us to conclude about the fine-dispersed nature of gold. The distribution of gold by size class is almost uniform. The sizes of individual gold grains do not exceed 0.03-0.05 mm. Usually a few microns. More often, gold is found in intergrowths with quartz, mica, and pyrite.

According to the analysis of enrichment, it can be concluded that the most promising at present is the enrichment of the original sands in the centrifugal concentrate "Knelson". The research results showed the possibility of obtaining concentrates with a gold content of up to 221-250 g/t while recovering up to 93-95% and obtaining tailings with a valuable component content from 0.3-0.5 g/t, which were sent to cyanidation according to the traditional technology used at the plant. The extraction of gold into the filtrate ranged from 71-80% with a residual metal content in the cakes up to 0.09 g/t. When leaching gold from gravity tailings with a sulfur-alkaline solution, a filtrate was obtained with gold recovery from 95 - 98% and residual content in cakes from 0.02-0.001 g/t.

The results obtained indicate the possibility of using the proposed technology for processing refractory gold-bearing ores from Lower Angara region.

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