

# Geological and technological evaluation of gold-bearing mineral material after photo-electrochemical activation leaching

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**Abstract.** The paper reports the lab test results on simulation of heap leaching of unoxidized rebellious ore extracted from deep levels of Pogromnoe open pit mine, with different flowsheets and photo-electrochemically activated solutions. It has been found that pre-treatment of rebellious ore particles –10 mm in size by photo-electrochemically activated solutions at the stage preceding agglomeration with the use of rich cyanide solutions enhances gold recovery by 6%.

## 1. Introduction

A life cycle of a gold mine using heap leaching in Transbaikalia area consists of two bold stages. The first stage is extraction of gold from oxidized ores of the upper horizons. The second stage operations embrace low-grade proto-ore of the lower horizons, which results in reduction in recovery rate by tens percent. For this reason, purposely to sustain economically sound extraction of gold from rebellious ore, the innovative approaches to ore pre-treatment and leaching are required, with the parameters and regimes adequately supported by geological and technological evaluations.

The aim of this research was to assess influence of photo-and-electrically activated solutions used in ore pre-treatment and agglomeration on the ratio of extraction of useful component from proto-ore of Pogromnoe deposit.

## 2. Research

Pogromnoe deposit occurs in the Shilka district of the Transbaikalia, 15 km eastward of Shilka town. The deposit adjoins a scute of the complex-structure overthrust of the Mongolia–Okhotsk suture. The overthrust scute is composed of Triassic–Low Jurassic igneous–sedimentary rocks, with sandstone and siltstone at the bottom and rhyolite clastic flow at the top of the formation. Horizontally, the scute is 1–1.5 km thick. The scute is rhomb-lens-shaped with the northeastward extension for 5–6 km. During active overthrusting, the ore-hosting rocks were heavily altered and transformed into clastic rocks. Metasomatic processes are widely developed in rocks, up to formation of secondary quartzite [1].

Gold-bearing ore of the deposit belongs to the gold–moderately sulfide–quartz formation represented by two morphological types: ore-fold quartz–carbonate–arsenopyrite–pyrite species in metasomatically altered effusive blanket (ore body 1) and strong-and-vein quartz species (with pockets of sulfides) in altered carbon-bearing shale (ore body 10). Material constitution of the ore is to 85–90% quartz, sericite, albite and carbonate, and 10–15% of the composition is ore with the main



components of pyrite and arsenopyrite. The accessory minerals (tenth of a percent) are mainly sphalerite, chalcopyrite and pyrrhotine. The most typical textures are dissemination, veins, less often spots and strings. Cataclastic textures, breccias, jointing and schistosity are abundant. In ore body 1, most of gold particles (75–80%) have size less than 16  $\mu\text{m}$ . Gold is free and mainly high-grade. Ore body 10 contains different size gold grains, from fine and dispersed to coarse (larger than 0.25 mm). Also, gold is free and high or very high grade [2].

The Transbaikal Integrated Research Institute has revealed two commercial types of ore: type I is gold–albite–sugary grained quartz with or without arsenopyrite (pyrite), jatosite and scorodite; this is the oxidized ore of the residuum, making up 85–90% of the in-place reserves; type II is gold–sugary grained quartz–poor sulfide proto-ore amounting to 10–15% in the in-place reserves. Type I ore of the upper horizons at least down to a depth of 50 m is assumed as easy-to-concentrate. Based on that, the Transbaikal Integrated Research Institute has proposed to use the method of heap leaching after two-stage crushing to a size of -20 mm. From the laboratory testing data, gold recovery in this case will make up 71.4–91% depending on ore porosity [3].

In 2005 Aprelkovo Mine commenced mining and heap leaching of Pogromnoe ore. In 2007, the Mine reached the design capacity at annual gold-bearing ore production of 850–1000 kg. The average content of the useful component was 1.2 g/t at the standard deviation of 0.19 g/t. However, gold recovery was 60% up to 2012 and reduced to 47–48% in 2012–2015.

The reduction in the gold recovery was connected with the commencement of mining and processing of type II unoxidized ore. From the evidence of the TOMS Institute, the mineral composition of this ore contains 96.5% of rock-forming minerals, including quartz, feldspar, micaceous minerals and carbonates. Ore minerals revealed in a sample in a quantity of 2.3% are all sulfides. More than 65% of sulfides is pyrrhotine, the rest are equal amounts of arsenopyrite and pyrite. Sphalerite is met as units. Accessory minerals total 1.2% in the gross mass of the ore [4].

For percolation filtration tests, samples of gold–quartz–poor sulfide proto-ore with the size of particles of -10 mm had 17.4% content of size grade +10 mm. Bulk weight of the test material was 1544.7 kg/m<sup>3</sup>, moisture content—17.79%.

For cyanidation in the laboratory percolation filters, the initial samples were washed off slime that was cyanated in bottle conditioners. The content of size grade of -0.01 mm ranges between 10.8 and 12.4%.

Prior to cyanidation in percolation filters, the ore samples were treated in photo-electro-chemically activated solutions. Efficiency of these solutions has been proved in the earlier studies accomplished by the researchers of the Chita Division of the Institute of Mining, Siberian Branch of RAS [5].

The solution activation procedure included: introduction of reagents to process water up to a certain concentration; stirring and saturation of the solution with atmospheric oxygen using a compressor; electrochemical and photochemical treatment of the solution. Fresh photo-electrochemically activated solution was added to the test ore samples once a day. Spent solution was discharged.

The percolation test included three stages of treatment with cyanide solutions and two stages of washing of samples with water in accordance with Zelenov's procedure [6]. The test results are given in Table 1.

The percolation tests of the proto-ore samples show that gold recovery from the initial samples with the particles -10 mm in size is 34.0%, while after cyanidation of the samples preliminarily treated with photo-electro-chemically activated solutions, the average gold recovery grows by 2% and makes 36% (refer to Table 1).

For the comparison, it is noteworthy, that gold recovery in pregnant solution of samples with particles -10 mm in size in percolation tests of the solid oxidized ore of the top horizons of the deposit by Zelenov's procedure made 82% [3]. So, recovery of the useful component from the proto-ore after cyanidation in percolation filters has more than halved as against cyanidation of the oxidized ore.

**Table 1.** Results of percolation tests of proto-ore samples after pre-treatment in photo-electro-chemically activated solutions.

Test No.	Sample No.	Gold recovery in solution, mg	Recovery rate of gold, %
1	1048	0.442	36.8
2	1081	0.478	38.5
3	1045	0.592	49.3
4	1049	0.430	35.6
5	1025	0.277	23.5
6	1063	0.426	34.9
7	1042	0.379	31.7
8	1020	0.446	38.1
Average		0.434	36.05
Standard deviation		0.088	7.21

Average gold recovery from slime after cyanidation in bottle conditioners was 32 unit fractions (on the assumption of slime gold content of 1.15 g/t). As it is, gold recovery after agitation (for 6 hours) should be higher than after percolation filtering. Based on that, it is assumed that slime gold content is under 1.0 g/t actually. However, gold content of slime was not determined.

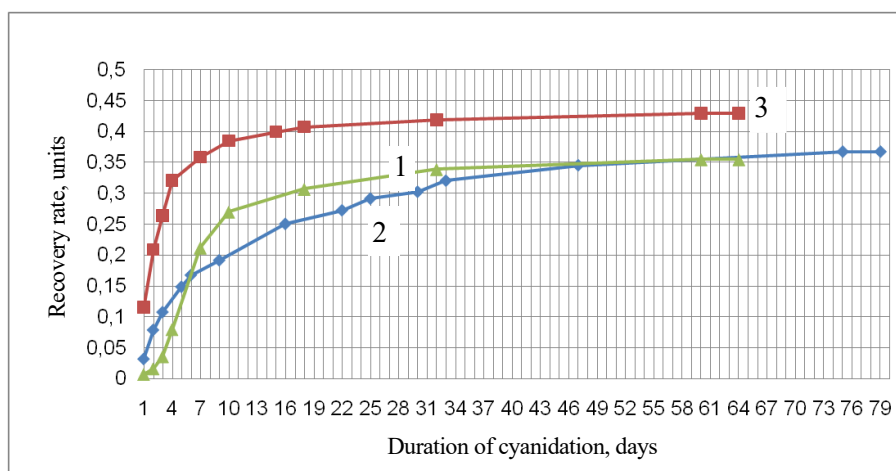
Heap leaching tests of agglomerated proto-ore with the particles –10 mm in size in percolation filters included three different schemes.

Scheme 1. Agglomeration of ore with strong cyanide solution. The process solution was made by feeding water in percolation filter.

Scheme 2. Prior to agglomeration, the ore sample was treated in the photo-electrochemically activated solution. Agglomeration stage also used the photo-electro-chemically activated solution. The process solution was weak cyanide solution.

Scheme 3. Pre-agglomeration treatment of the ore sample in the photo-electro-chemically activated solution. Agglomeration uses a strong cyanide solution. The process solution is made by feeding water in percolation filter.

The figure depicts the cyanidation outcome. Gold recovery rate (at the ore gold content of 1.15 g/t) is 0.37 unit fractions in scheme 1 (curve 1), 0.36 unit fractions in scheme 2 (curve 2) and 0.43 unit fractions in scheme 3 (curve 3). Each curve is plotted base on average values of two concurrent tests.



Cyanidation of agglomerated proto-ore of Pogromnoe deposit: leaching scheme 1—curve 1; leaching scheme 2—curve 2; leaching scheme 3—curve 3.

The tests have demonstrated that ore pre-treatment with the photo-electrochemically activated solutions enhanced recovery rate of gold from proto-ore and shortens duration of cyanidation.

It is seen in the figure that in reference leaching scheme 1, recovery rate of gold is 0.37 unit fractions and active passing of gold into solution (increment in recovery rate more than 1% per day) ends on the 47th day of leaching. This scheme uses no photo-electrochemically activated solutions.

In scheme 2, the photo-electro-chemically activated solution is included both in ore pre-treatment and agglomeration stages. The process solution is a weak cyanide solution. The gold recovery rate in this scheme is 0.36 unit fractions, and active passing of gold into solution comes to an end by the 32nd day of leaching.

In scheme 3, agglomeration and generation of process solutions is in accordance with scheme 1, but the ore is treated with the photo-electrochemically activated solution before agglomeration. As a result, the gold recovery rate is 0.43 unit fractions, and active passing of gold into solution makes 32 days of leaching.

Thus, pre-treatment of proto-ore by the photoelectric activated scheme (scheme 3) prior to agglomeration in strong cyanide solutions has increased gold recovery rate by 6% as compared with the reference scheme (scheme 1). Moreover, duration of the active leaching period is shortened by 15 days (see the figure).

When ore pre-treatment and agglomeration uses the photo-electrochemically activated solutions and a weak cyanide solution (scheme 2), the gold recovery rate remains nearly the same as in the reference scheme (scheme 1). However, kinetics of leaching in scheme 3 is more complicated. The duration of active leaching period is reduced (refer to the figure).

Let us compare the presented results with the tests on column heap leaching of agglomerated ore at the TOMS Institute. Agglomeration used cement, lime and a weak cyanide solution. The process solution was a weak cyanide solution, too. With the samples with particles -7 and -5 mm in size, gold recovery in solution made 41.42 and 49.3%, respectively. The active leaching period ended by the 40th day [4].

Table 2 offers the generalization of the described test data on heap leaching agglomerated ore of different size grades.

**Table 2.** Gold recovery in heap leaching of agglomerated proto-ore of different size grades.

Test No.	Ore size, mm	Gold recovery, %	
		Without pre-treatment	After pre-treatment by the photoelectric activation scheme
1	-10	37.0	43.0
2	-7	41.4	—
3	-5	49.4	—

Comment: agglomeration uses cyanide solutions

It follows from the analysis of Table 2 data that there is a clear relationship between the gold extraction after heap leaching and the size grade of proto-ore. Furthermore, as per the test data, ore pre-treatment by the photoelectric activation scheme enables gold extraction of 43.0% from ore with the particles -10 mm in size, which is by 1.4% higher than the extraction of the useful component in cyanidation of ore with the particles -7 mm in size without the pre-treatment (Table 2). On this basis, it has been concluded that for the material -10 mm in size, influence of the photo-electrochemical activation pre-treatment on the gold recovery rate after heap leaching of agglomerated ore is comparable with the ore crushing to the size of -7 mm.

### 3. Conclusion

Two experimental series to simulate concentration of rebellious proto-ore from Pogromnoe deposit by the method of heap leaching with the photo-electrochemically activated solutions have been carried out.

The first tests series used laboratory percolation filters and ore material with the size of -10 mm. The process solutions were filtered through the test ore layer in the mode of one day irrigation and one day pause. The test aimed to study the influence of the ore pre-treatment with the photo-electrochemically activated solutions on the gold recovery rate of leaching. It was found that the extraction of the useful component after the regular percolation filtration was 34%, while after the ore pre-treatment with the photoelectrically activated solution, the gold extraction grew by 2%.

The second leaching test series used laboratory percolation filters and agglomerated material with the size of -10 mm. The tests followed three schemes. The first, reference scheme used a strong cyanide solution in agglomeration. In the second scheme, the test proto-ore material was pre-treated with the photoelectrically activated solution prior to agglomeration. The agglomeration stage also used the photoelectrically activated solution and a weak cyanide process solution. In the third scheme, the ore agglomerated was preceded by the pre-treatment with the photo-electro-chemically activated solution and the agglomeration used a strong cyanide process solution.

As a result, it was found that the pre-treatment of the proto-ore sample with the particles -10 mm in size using the photo-electro-chemically activated solutions before the agglomeration in the strong cyanide solutions enhanced gold extraction by 6%.

Finally, it has experimentally been proved that the use of the photo-electro-chemically activated solutions at the stage of ore pre-treatment enables enhanced gold extraction from proto-ore of Pogromnoe deposit by 2–6% depending on the process scheme of heap leaching. It is noteworthy that the presented results are obtained on ore samples with the particles -10 mm in size. It is arguable that with smaller size grade material, the use of the photo-electrochemically activated solutions will be even more efficient as in the stages of ore pre-treatment and agglomeration, and in the stage of leaching.

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