Consequences of Industrial Mineral Processing in the Arctic Zone of Yakutia

S Moskvitin

1Institute of physical and technical problems of the North (IPTPN) the FRC Siberian Branch (FRC SB), Yakutsk, Russia

E-mail: s.moskvit@yandex.ru

Abstract. The Arctic zone of Yakutia is the industrially developed territory of the Republic. Processing of tin, rare earth metals and gold deposits for decades has led to formation of a huge mass of waste in the form of dumps and tailings. In the area tailing dumps of Batagai, Deputatskiy and Kularsky processing plants can be found nowadays, where ore tailings were dumped. In this work mineralogical compositions of mining wastes are presented, and the structure and condition of the tailings dumps at present time are studied. The impact of actually applied technologies on the environmental situation in extracting tin, gold and rare earth minerals as well as mechanisms are examined. The impact of weathering processes on the environmental safety of the region was established. As a result of the study, it was concluded that the tailings dumps pose a real ecological threat to the environment. In case of any accident, there will be consequences causing irreparable damage not only to the ecology of The Yana and Indigirka river basins, but also to the water area of the entire continental shelf of the North-East of Yakutia. Elimination of environmentally hazardous substances through industrial processing will reduce the risk of environmental threats to the territory and the entire Arctic basin.

1. Introduction

Northern regions of the Arctic Yakutia of the Republic of Sakha (Yakutia) are the most industrially developed region of the Republic. From the 1940s to the early 1990s in the territory there was intense mining of large indigenous deposits of tin, rare earth metals, as well as ore gold processing in the 80's. The ores from these deposits were processed in Batagai processing plant No. 418, Deputatskiy CF and the Kular gold extraction plants. Currently these plants are abandoned without remediation work.

The existing three tailing dumps located in the Arctic zone of the Republic of Sakha(Yakutia) have accumulated hundreds of tons of ore processing waste in the form of dumping tails. Tailing dumps are complex hydraulic constructions.

2. Results and discussions

In this work, the tailing dump facilities of the processing plants are examined. The tailings of the Deputatskiy and Kularsky plants are constructed on the flood plains of creeks, which are tributaries of major watercourses. In the Batagai processing plant, the tailings dump is of the sloping type. On the East side it is bounded by the over-floodplain terrace of the Yana river valley, on the West by the protective dam separating it from the Yana river channel. All the tailing dumps are of the liquid type.
The study of the material composition of the tailings accumulated in the dumps showed that a solid phase of the tail pulp consists of a mixture of mineral particles of different sizes from 3 mm to a part of micron. During the long-term accumulation in the bed of tailing dumps, technical water is filtered under them, which seeps into the ground water and adjacent reservoirs, clogging them with harmful impurities. When individual sections of tailing dumps dry out, natural disintegration of particles occurs under the influence of natural factors, and in wind erosion fine particles spread over the earth's surface, causing their contamination with harmful components that are dangerous for the flora and fauna of the areas adjacent to the tailing dumps [1].

The analysis of the Batagayskiy plant showed that there are cassiterite-sulphide ore tailings of Ege-Khayskiy deposit in the tailing dump and two cassiterite-sulfide ore deposits in a smaller volume. From 1966 until the closure of the plants in 1973 the ore dressing of cassiterite-rare-metal-quartz was noted. Ore deposits of tin, rare earths, and gold were processed by means of the existing technology and equipment at that time. The general view of the tailings dump is shown in figure 1.

Figure 1. Overall view of the Batagai tailing dump.

Cassiterite-sulfide ores mined in Batagai processing plants contain a variety of ore minerals: oxides, sulfides, silicates, phosphates, sulfosalt minerals, native metals such as gold and silver. Almost all minerals contain admixtures of various elements: cassiterite and tungstite contain admixtures of Ta and Nb, in sulfides there is admixture of In, Co, Bi, Hg, Tl, TR, and others [2]. Some sulfides, oxides and silicates in ores are characterized by high indivisibility. In concentrations range from 0.0002 to 0.135% . In the main mineral pyrrhotite, impurity elements ( % ) were determined: In-0.0001-0.009; Ag -0.024; Co-0.01; Te-0.0013; Se-0.0023; Tl-0.002; Bi -0.005; Hg -0.00001 [3].

The analysis of technological schemes of the processing plants showed that the processing in the plants was carried out according to the gravity scheme. According to the existing technology and equipment at that time cassiterite and wolframite were extracted, and unclaimed rare minerals and minerals containing impurities of various metals were dumped. Due to the ore intensive crushing, the fine components of the useful component went with a light fraction into the sludge. Thus, higher concentrations of Co-0.031% - 0.06% were revealed in cassiterite - sulfide ores and Ag-115.3-129.6 g / t. Silver and cobalt stocks with associated components were found in the deposits, but they were not extracted by the applied technology in ore mining.
The processed cassiterite-rare-metal-quartz ores of Kester Deposit are represented by cassiterite, phosphates, sulfides, and sulfosalts. Cassiterite contains an isomorphic admixture of Ta - 3240g/t and Nb-3530g/t. Rare and even very rare minerals are common in the ore deposits: torbenite (Cu,UO2)(PO4)n•H2O, metatorbenite Cu(UO2)2(PO4)2•8H2O, manganotantalite (Mn,Ta2O6), microlite (CA ,Na)2 Ta2(O,OH,F)7;, semirezite (Na, CaNb2O6F) with Pb and U admixture,sagenite a variety of rutile with an admixture of Fe, TA,NB,CR,V,SN,tuhualite is a uranium-containing high-carbon substance containing 48.5% ThO2 U3O8 and up to 50% TR mineral [4]. cinnabar (HgS) and native silver.

According to the mineral and geochemical studies, the content of cassiterite in the tailings silt sand is from 0.04 to 0.34%. Cassiterite in the sand is tiny and concentrated mainly in ‘slurry’ hardly-concentrated classes. The analysis of ore dressing results shows that the content of the class -0.074 mm in the final tailings of the plants is about 50%, and the loss of tin with thin size grade is 70% of the total loss. The content of sand comprises Rb2O from 0.057 to 0.258 %, Li2O-from 0.125 to 0.445 %, the maximum value of Cs2O being 0.031 %, the minimum value 0.01 %. Lithium, rubidium, and caesium are associated with mica in a light fraction larger than -0.05 mm. The basic part of tantalum and niobium, in the sands of the Batagai tailing dump is associated with columbite, tantalite, and cassiterite. The technogenic deposit is characterized by higher composition of Pb, Zn, Cd, Cu and S, typical for primary ores. Of the microelements no full compositions of TA, Be and U are marked, they belonging to hazard classes I-II. In the water of the tailing dump the content of substances of hazard class I was revealed: uranium-0.032 mg/l, thallium-0.0002 mg/l (two times exceeding the standards for drinking water supply), substances of hazard class II: beryllium-0.032 mg/l (30 Maximum permissible concentration for household drinking water), cadmium-0.1 mg/l (100 MPC). A complex of hazardous elements such us Tl, Be, Nb, Rb, Cs, U, As, Hg, Ga, Gl, Cd, Li. is revealed in watercourses located near the tailings dump. The concentration of these elements often ranges from 1 thousand to 10 thousands MPC (reaching 80 thousands MPC in some areas) [5].

In the tailing dump of the Deputatsky OME ore tailings of the Deputatskiy cassiterite-silicate-sulfide deposit were accumulated. This deposit is considered the geological and industrial type of tin-bearing greisens and veins (Figure 2).

**Figure 2. Tailings of the Deputatsky OME**

The ore composition contains mostly cassiterite, wolframite, pyrrhotite, sulfides of the following elements: Fe, Zn, Ch, Pb, Bi, Mo, Ag, Sn and non-metallic minerals. Also there are native metals Bi, Ag and sulfosalts Ag and Sb. Getite, lemoynite, jarosite, fibroferrite, melanterite, scorodite, pizanie, melnikovite, kaolinite, gypsum are widely spread minerals.[6].
The study of the material composition of the Deputatsky OME tailings showed that the tailings basin is presented as a large geochemical anomaly of ore-bearing and associated elements and its concentration is rated a hundred times higher than MPC parameters. Besides cassiterite the stale sands of the Deputatsky tailing dump contain a variety of sulfides, including sphalerite with admixture of In and Bi. The average content of cassiterite is at least 0.5%. In cassiterite, there is admixture of In-25.0-89.0 g/t; Sc-10.0-65.0 g/t and Nb-63.0-93.0 g/t.

It is known that in domestic processing plants 30-40% of cassiterite pass into sludges during ore concentration, of which 20-35% are lost with tails. Losses of easily concentrated ores in the North-East of the country amount to 7-20%, the same losses probably noted in the Deputatsky CCP [7].

In the Kularsky tailing dump gold-bearing ore tailings of the gold-rare-metal deposit is accumulated. The gravity-flotation dressing scheme was used [8]. According to our data, small native gold and in the form of accretions with quartz and widespread sulfides. Fine native gold and accretions with quartz and widespread sulfides are the main and only useful component in the tailings sands. According to our data, the tailings water is characterized by higher content of Fe-up to 5 MPC, Zn - up to 10 MPC, Cu - up to 90 MPC. In samples of bottom sediments higher content of Hg-up to 5 MPC was revealed, whereas a significant amount of heavy metals is noted in the water and bottom sediments of the tailing dump.

Gold placers are accompanied by rare earth mineral-monazite, called kularite by I.Nekrasov, which makes up the main part of the associated processing minerals. Their content in gold-bearing Sands varies widely. In some areas, kularite is found containing radioactive thorium (ThO2 up to 1.14% and U3O8 up to 0.41% of the mineral composition [9].

Stockpiled kularites in the dumps of the Kularsky gold-bearing territory comprise 56 to 85 thousand tons with the average grade of kularite in the dumps 1.5 – 3 kg/m3. In addition, the dumps contain fine gold with kularite as well, the total reserves of them are estimated at 15-20 tons. Figure 3 shows rock dumps after gold mining.

Figure 3. The landfill for mining alluvial gold- rare earth deposit, in the background the dumps containing kularite, fine industrial gold tailings.

In case of any accident in the Deputatsky and Kularsky tailings the area of flooding will be negligible, as the bulk of water will flow to the tributaries, but will damage biological resources of the rivers Indigirka and Omoloy, where the above-mentioned tributaries run into. If there is an accident in
the Batagai tailings dump, consequences will be more severe as the entire Yana river will be polluted. These three major rivers run into the Laptev sea of the Arctic ocean. At present there are three ways to solve the problem: continuous monitoring, conservation, or recultivation.

Continuous monitoring is the long-lasting monitoring of the tailings, conducted since closing the OME. Wherein the tailings will create a permanent threat for many decades and serve as a source of persistent pollution of the area with possible irreversible consequences.

 Conservation involves water drain and dumping the tailings basin with empty landfill rocks, destroying limiting dams, conserving drainage tunnels, and returning to the old streambed where the tailings are laid. This is an option with unpredictable consequences.

Recultivation, i.e. liquidation, involves the processing of stale sands of tailings dumps, which should be considered, as the industrial mineral deposit.

Industrial processing of tailings contents is currently possible due to the development of new efficient technologies for ore dressing methods and new types of mineral processing equipment for the recent decades [10].

Involving the contents of tailings dumps in industrial processing will give opportunity to create modern enterprises of deep waste processing, new jobs and receive a positive vector of the economic development of the region.

3. Conclusions
1. The long-term waste accumulation in the bed of tailing dumps is an environmental threat as there is filtration of industrial water under them, which seeps into groundwater and adjacent reservoirs, clogging them with harmful impurities.
2. Under the influence of weathering processes in tailing dumps, the natural disintegration of ore substance is noted and finely dispersed particles are spread over the earth's surface, causing their contamination with harmful components that are dangerous to the flora and fauna in the surrounding areas.
3. According to our data, the liquidation option is the most economically feasible. However, the industrial processing of tailings accumulation requires preliminary technological study of stale sands, including mineral-geochemical and technological research. These are factors that determine the elimination of tailings: 1 - presence of large industrial and transport hubs, settlements near the tailings; 2 - lack of need for stripping works, 3- preparation of raw materials for processing; 4 - economic background - high content of various scarce and expensive elements that are currently demanded by new technologies and the metallurgical industry.
4. The elimination of tailings dumps will reduce the risk of environmental threats to the territory and the entire Arctic basin.

4. References
[1] Khanchuk F M, Kemkina R A, Kemkin I V, Zvereva V P 2012 Mineralogical and geochemical substantiation of processing stale sands of tailing dumps of Solnechny MPP (Komsomolsky district, Khabarovsky territory) Vestnik KRASC Sciences of Earth 1 vol. 19 pp 22-40
[2] Flerov B L 1976 Tin deposits of the Yana-Kolyma folded region (Novosibirsk) The Science. SOAS p 286
[3] Ivanov V V 1963 Mineralogical-geochemical features and tin-ore deposits in Yakutia (Moscow) The Science p 252
[4] Kokurin M V 2009 Rare minerals of the forgotten field Geology and minerals of Eastern Siberia (Irkutsk: Publishing house of the Irkutsk state University) pp 136-147
[5] Veremeeva L I, Baeva I G, Vdovina L G, Kopyeva T V 2015 Features of distribution of useful and harmful components in stale sands of Batagai tailings Republic of Sakha (Yakutia) Proceedings of the XV International meeting on geology of placers and deposits and weathering crusts (RQV2015) - study, development, ecology The Perm State National Research University pp 30-32
[6] Moskvitin S G, Salomatov A K 2015 Environmental issues of industrial development of the Arctic zone of Yakutia (Kular, Deputatsky) Geomechanical and geotechnological problems of effective development of solid mineral deposits in the Northern and North-Eastern regions of Russia Materials of the 3rd Scientific Conf. dedicated to the memory of RAS corr. member Novopashin M. D. Yakutsk: The publishing house SMIK-Master Polygraphy pp 211-214

[7] Matveev A I, Eremeeva N G 2011 Technological assessment of tin deposits in Yakutia (Nov-sk: Acad-e publishing house ”geo”) p 119

[8] Matveev A I 1993 Development of a flotation technology for processing tin-containing slurries of the Deputy Mining and processing center with the use of acoustic fields Abstract thesis on competition of a scientific degree of Cand. technical. sciences' (Yakutsk) p 16

[9] Nekrasov I Ya 1972 New data on a monazite-cheralite-huttonite group mineral DAN USSR Vol. 204 4 pp 941-943

[10] The North and the Arctic in the spatial development of Russia: scientific and analytical report 2010 RAS Scientific Council on regional development SOPS under the Ministry of economic development of the Russian Federation and RAS Presidium IEP Kolsky scientific centre, RAS Komi SC Ural RAS Moscow – Apatity-Syktyvkar: The Publishing house of Komi science center, Russian Academy of Sciences p 213

Acknowledgments
Work was executed with the financial support of the project RFPF №18-43-140018/18.