Technogenic Placer Deposits of the Artic Zone of Yakutia

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Abstract. The northern parts of the Arctic Zone of the Sakha Republic (Yakutia) are the most industrialized regions of the Republic. Since the 1930s, there has been intensive mining of alluvial and primary tin and gold placers. The 60-70-year mining operation has accumulated huge mining residues in the region, leaving behind useful components owing to deficiencies in mining technology at the time and deviations from mining technology. These wastes are considered technogenic placer deposits. The study of these wastes has identified the following types of technological: 1 – technogenic placers of tin and gold; 2 - technogenic combined placers of gold and kularit; 3 - technogenic placers of tailings ponds consisting of mining wastes of gold and tin ore placers.

1. Introduction

Industrial development of the Arctic zone of Yakutia began in the 1930s. The large-scale geological and exploratory work in a short period of time revealed rich alluvial and primary placers of tin and gold. To date, they have been completed to a great extent and the remaining resources are available off-balance sheet.

With the closure of processing plants, the tailings ponds are now abandoned and represent a permanent environmental threat to the region. In a case of any accident, these objects will cause irreparable damage not only to the ecology of the Yana and Indigirka river basins, but also to the entire continental shelf of the Arctic zone of the north-east of Yakutia.

The purpose of the work is to qualify the remaining waste as technogenic placer deposits with economic profitability in mining by means of analysis. The involvement of technogenic tin and gold placer deposits in industrial processing will solve the problem of eliminating an ecologically dangerous facility and reduce the risk of ecological threat to the territory and the entire Arctic basin. The region will receive a positive economic development vector, as well as ensure proper monitoring of waste condition and allow to establish modern enterprises of deep processing of waste. New jobs will be created in these enterprises.

2. Research materials and methods

In this work, the structures of three tailings ponds, the Batagai, Deputatsk and Kular enrichment factories were studied. The tailings ponds of the Deputatsk and Kular factories are built in floodplains, which are tributaries of large watercourses. At the Batagai Enrichment Factory, the tailings pond belongs to a cross-garden type. On the east side it is limited by the floodplain terrace of the Yana
Valley, from the west by the protective dam separating it from the channel of the Yana. All the tailings ponds that were built are of a liquid type.

The analysis of enrichment schemes of ore and alluvial tin placer deposits of the North-Yansk, Central-Yansk and South-Yansk ore and alluvial regions was carried out. Enrichment schemes and waste storage conditions in the Kular gold-bearing district were analysed as well. Figure 1 shows the location of gold and tin mining areas in the Arctic zone of Yakutia.

![Figure 1](image)

**Figure 1.** Ore and placer deposits of gold, tin, tin-tungsten of the Arctic zone of Yakutia.

3. **Results and discussion**

3.1. **Technogenic gold placers of the Kular gold-bearing district**

Numerous gold placers in the Kular district were discovered in the early 1960s and almost immediately a start was made with its processing. Gold placers were formed for a long period of time, characterized by different stages of the relief development and conditions of accumulation of loose gold-bearing alluvial sediments and conditions of distribution of gold. In terms of the formation and age of gold-bearing loose sediments, all placer deposits are classified into structurally genetic types: the older Paleogen burial placers; Pleistocene-Lower and Valley buried placers of major waterways [1].
Table 1. Average situs analysis of structural-genetic types of gold placers (according to A.I. Sergeyenko, 1975).

| Structural-genetic types | Fraction yield, % |
|--------------------------|-------------------|
|                          | 0,0-0,25 | 0,25-0,5 | 0,5-1,0 | 1,0-2,0 | 2,0-3,0 | +3,0-5,0 |
| aleogen burial placers   | 5,1      | 12,1     | 36,1    | 29,8    | 14,8    | 2,1      |
| Pleistocene-Lower Valley | 2,8      | 31,0     | 33,0    | 16,2    | 8,4     | 6,4      |

The main reason for the loss of gold is mainly the violation of technological regulations for washing gold sands. At the end of May, when a washing season began, the underground sands did not thaw well, but they were already being washed. In open-pit mining, the frozen sands were subjected to intensive mechanical tilling by heavy bulldozers, but the gold-bearing sands did not always melt before washing. The sands were washed down to the onset of 24-hour frosts until the beginning of October. And in the Arctic, night frost begins in mid-August, and in September night negative temperatures are noted. It was officially proved that 10% was lost during washing, but actual losses exceeded this number three times [2].

Technological losses are caused by imperfect gold extraction mechanisms. Technical parameters of the washing apparatus were provided with standards for technological losses depending on a type. Standard extraction factors have been developed to calculate these losses. For hydro-silo sluice (HSS) or hydro-silo barrel (HSB) washing machines the standard extraction coefficients are 0.350 to 0.996 according to a size of a metal [3]. This instruction specifies that the extraction rate declined due to sizes of the utility component. As it can be seen from Table 1, the Kular gold-bearing district is dominated by small-scale gold, which is wasted by the technology.

Gold losses are also related to geological features of the placer deposits: 1 - presence of the smaller fine gold of fraction 0.25 mm (2.8 to 20.2%) of the so-called «scaly gold», which is not captured by conventional lock systems, as lightweight scales float on water; 2 - the bulk of gold-bearing sands of the placers containing clays - kaolinite - montmorillonite, which made it very difficult to extract gold. According to the technologists at favourable temperatures the gold extraction did not exceed 50%.

3.2. Waste from processing of gold in the Kular gold-bearing district
In the Kular gold-bearing district, the Kyllah gold mine has been enriched since 1986 in the Kular gold-bearing plant (GBP). In the Kular tailings pond there are tailings of the enrichment of gold-bearing ore of the gold-rare placer deposit. The gravitational-flotation enrichment scheme was applied. Tiny gold and gold in quartz and widespread sulphides were the main utility component in the tailings pond sand. According to the screen analysis, the predominance (over 65%) of gold in ore of small fractions (0.1-0.5) is established. With depth, the share of tiny gold of large fractions decreases (0.5-1.0) (Table 2).

Table 2. Dimension of free gold of the Kyllah ore placer deposit processed in the Kular GBP.

| Structural – morphological type | Fractions, mm | Fraction yield, % |
|--------------------------------|---------------|-------------------|
| Layer subconforming veins       | 0,1 | 1-0,3 | 0,3-0,5 | 0,5-1,0 | +1,0 | 3,2 | 3,7 | 35,1 | 24,4 | 3,6 |
3.3. Kularit concentrates in gold-bearing residues

In the 1960s, placers of rare-earth mineralization were discovered in the northern area of Yakutia. In the Kular region, a rare-earth monazite was found and identified among placer minerals during the search and exploration for gold-bearing alluvial placer deposits. The mineral has been found to accompany gold placers everywhere and form the bulk of the placer minerals. Their content in gold-bearing sands varies widely. The highest monazite content is found in the gold-bearing placers of the south-western part of the district.

Monazite mineralogy from the alluvial ore of the Kular district was studied in detail by I.Y. Nekrasyt and R.A. Nekrasytaya, who established that the mineral composition is intermediate between monazite [CeP04] and huttonite [CaTh (PA4)]. In terms of the chemical composition, physical properties and associated mineral composition, they gave the name Kularit to the mineral [4].

A. I. Sergyenko found that the rich content of kularit is associated with the area crust of weathering of Upper Permian and Lower Triassic Argillite-Aleurite clay placer deposits. In the weathering cores the content of kularit ranges from 4.0 to 7.0 kg/m3. The contours of gold-bearing jets do not coincide with those of the rare-earth monazite, usually monazite-enriched jets are wider than gold-bearing jets and located at the top of the gold-bearing stratum. The study of monazite distribution in Cenozoic placer deposits showed direct relationship of its accumulation with paleogene-neogene acidic (sub-polar) weathering crusts [5].

The studies have found that there are 16-17 rare-earth elements in kularit, with the amount of between 62.46 and 68.95 per cent. These are mainly elements of the cerium group from 89.94 to 97.72 per cent, and elements of the yttrium group from 2.44 to 10.06 per cent. The significant rare-earth elements in kularit comprise of cerium 28.81-51.87 per cent, lanthanum 5.42-31.33 per cent and neodymium 14.00-38.57 per cent. Thus, in composition, kularit is a cerium-lanthanum-neodymium mineral on the phosphate silicon matrix.

In the alluvial areas of the Kular gold-bearing districts, the average kularit content ranges from 0.1 to 2 kg/m3 and average about 1 kg/m3. In the tailings of gold placers stored in effluent dumps at the site of mining operations, the content of kularit increases by a factor of 1.5-3. In the southern part of the Kular district, the prevalence of kularit placer deposit of gold placers is noted, in which the kularit content, according to N.G. Patyk-Kara, averages 1,067 kg/m3. The gold-rare-earth placer deposits of the Kular district are now exhausted, and the excavated reserves of kularit are stored in the effluent dumps at waste landfills. Approximately several tens of thousands of tons of kularit [6] are concentrated in the waste dumps of the Kular district.

Involvement of the rare earth placer deposits of the Kular region in the industrial development is very promising. But to succeed, it is necessary to set targeted research. Nowadays, there is need to assess the extent of distribution and a level of kularit concentration in the tailings of gold-bearing sands throughout the Kular district. The second most important issue is the development of kularit concentrate enrichment technology from these wastes. The enrichment technology scheme should be comprehensive and oriented on the extraction of not only kularit but small, hard-to-recover gold as well.

Based on the total amount of alluvial gold recovered, it can be assumed that there are at least 30-40 tons of small unstressed gold in pebble-like heaps. In addition, technogenic dumps contain significant stocks of rare-earth kularit, estimated at 40,000 tons.

3.4. Tin and tungsten technogenic placer deposits

Three tin and tungsten mining areas have been identified in the Arctic region: North Yansk, Central Yansk and South Yansk (Figure 1).

3.4.1. Technogenic alluvial placer deposits of the North-Yansk tin area

In the North Yansk region both tin and gold placer deposits were mined. In the territory of the Deputatsky Ore and Alluvial District, since 1951 the unique alluvial placer of the basin Shaman’s Grave river was exploited more than 25 km long, including a spacer of the riverbank Burevestnik. In
the same area the country’s largest Tyrechtikh and rich Mamont Tasappa spacers were mined. In the North Yansk region, the Tenkeli Cherpunya and Chokurdakh coastal and marine placer deposits in the Vankina Guba Bay were explored. In the period of the most intensive development of spacers in the 1960s and 1980s more than 5,000 tons of tin and 350 tons of tungsten were extracted annually in the Arctic Zone of RS(Y). In total, more than 30,000 tons of tin were extracted from the spacers of the Deputatsk District during this period.

Ore enrichment wastes of these metals were accumulated in the tailings ponds located in close proximity to the processing plants. The tailings ponds contain components that have not been extracted due to lack of extraction technology or have not been used by industry. They are also technogenic placer deposits containing a range of useful components of tin and gold-containing primary ores.

Tin spacers are generally represented by the complex of loose paleogen-quaternary sediments that are relatively mature in width and capacity, with an uneven distribution of the tin-containing cassiterite mineral. Tin sands contain tungsten mineral (tungsten oxide) and tourmaline as an impurity. The balance of the distribution of cassiterite by grain size: +25 mm -13.83%; (-25+2 mm) - 50.86%; (-2+0.1 mm) 22.31%; - 01 mm -13.0%. On average, cassiterite is 84-88% in free state, and about 12-16% of them contain in sections with tungsten, tourmaline and quartz. Furthermore, in the fine fraction the cassiterite quantity in the joints increases, for example, at the Tirekhtyah placer in the large class +25 mm the cassiterite parameters in the joints is 3.36 per cent, in the class -25 per cent12.23% [7].

The tin placers of the region have been exploited by traditional seasonal hydro-silo sluce (HSS) or hydro-silo barrel (HSB) washing machines with varying productivity. The washing and sorting complex WSC-1200 was used for mining of the tin placer of the Tirekhtyah District. The washing machines were installed at mining sites directly in the contours of the placer deposit, usually in the watercourse valleys where tin sands were located.

When rinsing tin placer deposits, cassiterite losses occur for the same reasons as for alluvial gold placer deposits. It was found out that in the mining process of several Chukotka tin placer deposits the ratio of extracted cassiterite to dumped cassiterite was 3:4. In total, according to the assessment of technologists for tin washing in the North Yansk region, up to 50% cassiterite was lost, dumped in dumps (message of V.P.Polevanov and Lunyashin).

Tailings of processed sands with residual undisturbed cassiterite can be considered as a distinct type of technogenic placer deposits. Due to the lack of methodological development for exploration and estimation of reserves, technogenic tin placers in pebble-effluent dumps have not been investigated and are not in demand.

3.4.2. Technogenic mining residues

The tin ores of the Deputatsk ore assembly were reprocessed from 1977 in the Deputatsk Central Ore Processing Factory (COPF), and the processing wastes in the form of tailings of ore enrichment were accumulated in the tailings ponds and were represented by small particles of crushed ore and waste rock.

In the tailings pond of the Deputatsk COPF ore processing wastes of the Deputatsk cassiterite-silicate-sulphide placer deposit were stored. The processed polyformation placer deposit relates to the geological-industrial type of tin grapes and veins. Cassiterite, wolframite, pyrrhotin, and the following sulphides: Fe, Zn, Cb, Pb, Bi, Mo, Ag, Sn and non-metallic minerals predominate in ores. There are also native metals Bi, Ag and sulfosalts Ag and Sb, natural silver [8].

Hypergenic minerals are common such as hetite, limonite, jarosite, fibrouferrite, melanterite, skuradit, pisanite, melnicovite, caolinite, gypsum. 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 30-40% of cassiterite is lost with tailings in the process of ore refining. Losses of lightly enriched ores of the North-East of the country amount to 7-20%, the same losses probably occurred in the Deputatsk COPP. The light fraction contains a large number of lithium minerals of spodumen and lepidololith, characteristic of grazens. These minerals are the lithium extraction raw material used to produce lithium batteries.
3.4.3. Technogenic tin placer deposits of Central Yansk and South Yansk tin-bearing regions

In the 1930s, primary tin placer deposits were discovered in the territory of the Verkhoyansk region. From 1941 to 1973 the cassiterite sulphide ore of the Ege-Haya placer deposit and the small ore of the two cassiterite-sulphide placer deposits Alys-Haya and Ilin-Taas were processed in the Batagai enrichment plant in the Verkhoyansk district. Cassiterite-sulphide ore was enriched in two cassiterite-sulphide placer deposits Alys-Haya and Ilin-Taas, and from 1966 until the closure the cassiterite-rare-quartz ore of the placer deposit Kester was mined. The composition of the useful particle content depends largely on the mineral composition of the processed ore and the applied enrichment technology. Tailings from ore processing are considered one of the hazardous groups of technogenic wastes. Long-term waste storage in tailings ponds filters the technogenic water beneath them, which seeps into groundwater and adjacent waters, clogging them with harmful impurities. When parts of the tailings ponds are dried, particles are naturally disintegrated under the influence of natural factors and fine particles are spread over the surface of the earth during wind erosion, causing contamination of them with harmful hazards to the plant and animal world.

The Batagai factory applied a gravitational enrichment scheme. According to technology and equipment available at the time cassiterite and wolframite were extracted, while other minerals containing a variety of metals were discarded as waste because they were not used. The composition of the sand in the tailings pond is determined by the composition of the processed ores. In the factory since 1941 the ore of the Ege-Haya cassiterite-sulphide placer deposit was enriched mainly, in subsequent years there was enrichment of the ore of two cassiterite-sulphide placer deposits (Alys-Haya and Ilin-Thas), and then the cassiterite-rare-quartz ore of the placer deposit Kester from 1966 until 1973 when the factory was closed. According to mineral geochemical studies, processed cassiterite-sulphide ores contain increased concentration of Co - 0.031% - 0.06% and Ag - 115.3-129.6 g/t, but they were not extracted during ore processing. These cassiterite-sulfide ores, in addition to cassiterite, contain sulphides, silicates, phosphates, sulfosols, gold and silver. They contain impurities of various elements: cassiterite and tungsten containing Ta and Nb; pyrotron contains impurities (%): 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; other sulphides In, Co, Bi, Hg, Tl, TR [9]. Some ore minerals and silicates contain In at concentrations ranging from 0.0002 to 0.135%.

According to the mineral geochemical studies, the concentration of cassiterite in the lying sand of the tailings pond ranges from 0.04 to 0.34 per cent. Cassiterite in the sand is small and concentrated mainly in «sludge» hard-to-enrich classes. The analysis of the enrichment results shows that the class content -0.074 mm the tailings of the factory is about 50%, and the losses of tin with thin size classes reach 70% of the total losses. The sand contains Rb2O from 0.057 to 0.258%, Li2O from 0.125 to 0.445%, Cs2O maximum value is 0.031%, minimum value is 0.01%. Lithium, rubidium and cesium are associated with mica containing in a light fraction, in the size class more than -0.05mm. The bulk of tantalum and niobium contained in the sand is related to minerals such as columbite, tantalite and cassiterite [10] The placer deposit is characterized by higher content of Pb, Zn, Cd, Cu and S, which are characteristic of the primary ores. Thus, the primary composition of the ores being processed and the applied ore processing technology result in the accumulation of various elements in the tailings of the ores.

The cassiterite-rare-metal-quartz ores of the Kester placer deposit have rare minerals in addition to cassiterite and sulphides. Phosphates, sulfosols, carbonates and oxides are particularly common. A variety of uranium-thorium-tantalum niobium containing rare minerals have been found in the ores [11].

The light fraction of the Batagai gold-bearing plant also contains lithium minerals.

The tailings ponds contents can be recycled now due to the development of new efficient ore enrichment technologies and related enrichment equipment. [12].

The studies carried out in these mining areas have shown that the technogenic placer deposits in the Arctic zone of Yakutia represent a real environmental threat. In abandoned mining areas of the northeastern Arctic zone during the more than 50-year period of processing the tin-bearing and gold-bearing
placer deposits, dumps of empty waste rock have been accumulated. They occupy the river valleys and terraces up to the watersheds. The tailings ponds are the most potent and long-term source of chemical pollution of the natural environment, especially surface watercourses and industrial underwater horizons of the primary placer deposits. The environmental risks related to the hotbed of pollution from MPC are rated as high and regional in scale of potential impact. [13].

4. Conclusions
1. In the Kular gold-bearing region the pebble-eaffel dumps of gold-bearing placers, complex kularit gold-bearing piles in the south of the Kular region and the tailings pond of the Kular COPF are rated as the technogenic gold placer deposits.
2. The tin technogenic placer deposits in the north-Yansk tin area are the pebble-eaffel dumps of processed tin placers of Chokurdach, Cherpunya, Oyuun-Unokkhthah (Deputy Creek), and the stream Petrel, Mamont-Tassapa, Tierektyah. The tailings pond of the Deputatsky MPC is the complex technogenic placer deposit.
3. In the Central Yansk and South Yansk tin bearing zone the tailings pond of the Batagay COPF is the technogenic gold placer deposit.

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