Assessment of conditions and experience of technogenic placer dredging

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Abstract. The article describes the dredging method used for developing technogenic placers. Quantitative indicators and qualitative characteristics of rocks were described. Positive and negative experience of placer dredging was analyzed; research results were interpreted. The dredging of technogenic placers using multi-unit dredges was described in terms of specific conditions and parameters. Observation results reflecting changes in dredging parameters, equipment utilization coefficients and uneven operation of dredges were analyzed. Recommendations on dredging efficiency improvement, including the use of controlled dredging, were given. Controlled dredging will help change parameters of chip removed by dippers. Directions of placer dredging involving improvement of existing technical solutions, justification of rational parameters of technological schemes and development of mass conversion technologies were substantiated.

1. Introduction
The living standards of the population and the volume of resource consumption are interrelated. The volume of mining works is growing rapidly. Mining enterprises pollute the environment by discharging contaminated water, emitting harmful substances into the atmosphere, disturbing land, and storing associated rocks on the surface. Waste is generated during mining and processing of raw materials. Dumps accumulated over many decades are a potential raw material for mining and construction industries.

Gold, platinum and diamond mining was cost-effective and accounted for a significant part in the total production volume which formed technogenic resources of a different quality. For example, Ural technogenic deposits contain tens of tons of platinum metals (platinum, osmium and iridium), tens of thousands of tons of high-chromium platinum chromium spinels and tons of associated gold.

Currently, platinum-bearing placers are being actively developed. When developing technogenic placers of the world famous platinum mines, more than 300 tons of platinum were mined. The Conder placer (Khavarovsk krai) is going to be re-developed. When developing technogenic deposits, it is planned to produce 10 tons of platinum. In Koryakia (Kamchatka), a project for the secondary development of a platinum placer is being implemented. It is planned to extract about 6 tons of platinum.

Huge gold reserves are accumulated in placers of Trans-Baikalia, Krasnoyarsk, Khabarovsk, and Primorsky krais, Amur, Irkutsk, and Magadan oblasts [1]. The total amount of gold in technogenic placers is about 3.3-5.0 thousand tons, which is at least 18% of the total amount of gold reserves in natural placers. The amount of gold reserves is enough for 15-70 years of development [2-4].
2. Formation of technogenic placers
Due to the long-term exploitation of placers intended for dredging, gold reserves are being actively mined [7]. There is no increase in reserves due to exploration works in all the Russian regions. Therefore, the main mineral resource base for gold dredging is technogenic resources of primary deposits.

In the second half of the 20th century, in Russia, 60-75% of sands were processed by dredges. After years of dredging, a huge number of technogenic deposits were formed. Their role is constantly growing due to the fact that mining enterprises lack raw materials, mining conditions are worsening, and environmental safety requirements are toughening. The dredging method causes significant mineral losses (30-45%). Analysis of technogenic deposits of the gold mining regions of the Russian Federation showed that they have been formed due to gold losses (35 tons per year) [5]. Therefore, the main technogenic placers are products of dredging; they account for 60-80% of technogenic products [3,6].

The total amount of useful components in technogenic deposits is comparable and sometimes even exceeds their annual production volume.

Metal content is not lower than in pillar placers. Technogenic deposits have a certain distribution structure for mineral components, secondary enrichment zones; however, in contrast to the former ones, they have a low content of valuable minerals.

The technogenic placers are formed due to
– incomplete exploration of reserves (30-40% of actual reserves);
– inaccurate determination of reservoir parameters (thickness and area);
– high operational sand losses, especially when using the dredging method (15-30%);
– significant technological losses of useful components (15-25%).
– extraction of some reserves using the open mining method which changes the mining conditions (the average gold content is about 6 times higher), some reserves are left in situ or removed with overburden rocks.

Analysis of the development of pillar and technogenic placers suggests that the actual initial amount of useful components is 1.5-2 times more than that extracted during the primary development.

3. Dredging of technogenic placers
Currently, almost half of the drags are used at technogenic placers, including dumps which were formed 20-40 years ago.

In Russia, the first platinum and gold deposits were technogenic [8]. Technogenic mining has been under way for more than a century. Examples show that economic efficiency of technogenic reserves is comparable to the pillar deposits containing raw materials of the best quality. At the same time, results of development of technogenic deposits are quite stable.

Experience of mining enterprises shows that the cost of metal mining is much lower (sometimes by 5 times) compared with the development of pillar placers. The latter is due to a sharp decrease in the volume of mining and hydro-technical works and improved washability of minerals.

In the Urals and Yakutia, the development of technogenic clay placers turned out to be the most effective due to low washability of productive sediments as a result of which a significant share (up to 50%) of undisturbed clay sands fell into the pebble dumps. After many years of aging, under the influence of weathering, non-blurred clay pieces (pellets) were destroyed and valuable components were released and extracted during the dredging using the same processing equipment.

During the dredging of technogenic diamond placers, 40-50% of the useful components were extracted. When developing technogenic gold placers in Transbaikalia, 34-60% of primarily mined gold was extracted. In the Lena gold-bearing region, this share was 45%. On average, about 30% of valuable components are extracted during the dredging of technogenic placers [7, 9–11].

At the same time, there are examples of poor operation of technogenic placers caused by poor knowledge of remaining reserves and the lack of analysis of primary mining experience.
Dredging on washings is not efficient since with the same processing equipment, 5-10% of the primary gold volume is extracted from the tailings (the clay extraction share is 30%). Therefore, in the absence of significant operational losses of sand, the dredging is ineffective.

4. Features of dump dredging
To date, a lot of technical solutions have been developed to improve the dredging method. The authors have participated in the development of these technical solutions as well [A.C. 1097797, 1263849, 1694901, patent No. 2215875]. At the same time, some issues of dredging are understudied. Most experts observed an increase in dredge performance by 30% but they did not analyze the reasons and justify the dredging parameters.

In fact, when dredging old dumps, the dredging method and parameters change significantly. According to our long-term observations of technogenic diamond-bearing placers [12], performance of dredges increases by 20-30%. Dredging of technogenic placers requires higher filling of dippers (0.8-1.2), the equipment utilization rate increases from 17-18 hours to 19-21 hours. Due to the increased washing capacity, the equipment copes with the increased load.

The comparison of the total number of arrhythmias (average deviation of the actual productivity from the planned one) for pillar and technogenic placers showed that in the latter case dredges work more rhythmically. The exception is periods when production targets have been exceeded.

Uneven drag operation coefficients varied within 0.177-0.245 for pillar reserves, and within 0.025-0.071 - for technogenic ones. Comparison and analysis of the uneven operation of dredges allows us to conclude that at technogenic placers dredges work much more uniformly, and uneven operation coefficients are lower than when working at pillar placers. This characterizes a more uniform loading and operation of the technological equipment of both dredges throughout the entire period.

To study the development dynamics, the period under study was divided into months and decades. The analysis found that during the development of the pillar placer, the share of the upward mode (an increase in production from the beginning to the end of the month) was 87.5%, and the share of the downward mode was 12.5%. When developing technogenic placers, the share of the upward mode was 33.3%, the share of the uniform mode was 23.8%, and the share of the downward mode was 42.9%. Consequently, at technogenic placers, the equipment operates more evenly and less intensively during the season.

However, during the dredging with a sufficiently large capacity of loose deposits, dredging conditions are complicated due to the collapse of the upper part of the face. The length of the crumbling part reached 2/3 of the width with a thickness of up to 3 m (see Figure 1), i.e. almost it increased by one step of a 250-liter dredge.

![Figure 1](image-url). The contour of the face of a 250-liter dredge at the time of bottom cleaning during the development of reserves with a capacity of 10 m and a freeboard of 0.5 -1.0 m: 1 - the upper part of the face; 2,3 - contours of scoop chain movement in dredged and subsequent faces; a - thickness of the collapsed part of the face.
The intensive collapse of the upper part is due to the lower natural slope angle of pebble dumps (40-45°) compared to the angle of slopes formed by the dredge (50-70°), as well as to the loosened state of the upper part of the rocks due to preliminary surface planning. With an increase in the dump height by 15-30 m, the angle of the upper part of the face increases to 85-90°, and the collapse volumes can reach half of the dredged rock mass. Due to the uneven collapse of the upper part of the face, embankments of different widths and heights were formed in its lower part (Figure 2).

Figure 2. The longitudinal profile of the face during excavation of unstable (dump) sediments: 1 – sand; 2 – bottom; 3 – scoop chain; 4 – natural slope of productive deposits; 5 – slope formed by the dredge; 6 – collapsible visor; 7 – sand at the bottom of the face.

In some cases, after stepping, the scoop chain does not reach the surface of productive sediments, and dredging under water is carried out by gradually lowering the scoop frame until it contacts the productive sediments. As the depth of digging increases, the length of chip increases; closer to the bottom, it is extremely large.

In order to ensure a uniform loading of the dredging equipment, it is necessary to reduce the thickness or width of chip with some delay determined by the time the scoop rises from under the water and the dredger’s reaction.

When dredging, the granulometric composition of the rocks will regularly change. In this case, the dredger should ensure maximum filling of the scoops with coarse fractions ($K_n = 1.0-1.2$) and allowable filling of the scoops with fine-grained sand according to the enrichment conditions ($K_n = 0.4-0.8$).

In case of layer dredging of sand, these factors cause a greater uneven load and a different degree of filling of the scoops. Loading regulation by raising and lowering the scoop frame led to additional time losses and reduced dredge performance. Thus, efficiency of dredging works is determined by the skills of the dragger.

Collapsing (sloughing) of the upper part of the face represented by pebble deposits leads to the mixing of productive deposits while dredging fine-grained sand in the lower part of the face, which is a favorable factor for the equipment. Therefore, it is advisable to dredge with a pod which increases the scoop filling, ensures uniform loading of the equipment. The rocks are better mixed with different
compositions. When developing high dumps, excavation with a pod can be carried out in the middle part of the face, which will prevent possible emergency situations due to simultaneous collapses of loose deposits.

The location of the first dredged layer in a vertical plane can be established by lowering the scoop frame in the area with the greatest collapse \( (a_{\text{max}} \text{ cm}, \text{Figure 2}) \) to a depth that ensures normal filling of the scoops. After that, productive rocks are excavated with a pod, and the upper part of the face collapses along the entire width of the face. The vertical profile of the face can be aligned over the entire width. A uniform profile created along the width of the face will allow for more uniform filling of the scoops during subsequent layer-by-layer dredging. Taking into account the new vertical profile and the gradual expansion of the excavation site due to collapsed (crumbled) sands, power of the dredged layers should be reduced, i.e. chip parameters should be changed.

5. Problems of technogenic placer development
Despite the high efficiency of the dredging method, the number of dredges has decreased by more than three times. Factors contributing to this circumstance are as follows:

- Economic and tax reforms, elimination of the state gold monopoly, transition to the world gold prices, large-scale investment in the development of ore resources, which allowed us to develop old placers.
- Lack of a unified systematic approach to the formation of technogenic reserves (methods of exploration or revaluation of reserves, including forecasting methods, entering of the reserves on the balance sheet of enterprises).
- Incomplete identification of small (0.25-0.1 mm) and thin (<0.1 mm) gold during the inventory assessment.
- Imperfect sand enrichment technologies.
- Environmental restrictions, especially in areas where reclamation works were performed or in areas with partial self-organized vegetation where mining operations can cause degradation of the landscapes.
- Outdated dredging equipment.
- Lack of effective dredging technologies.

6. Associated conditions for the development of technogenic placers
Technogenic deposits of precious metals have attracted much attention due to two trends. One of them is new technologies and equipment which can increase the extraction or improve the economic performance of extraction. The second trend is a steady decrease in the average content of metals and diamonds in the balance reserves of pillar placers, at deep horizons and flanks of deposits, and an increase in costs of mining and preparatory works. As a result, at natural and technogenic deposits, unit costs of extraction of valuable components are converging, and technogenic deposits become more cost-effective.

The feasibility of technogenic deposit development is determined by a number of economic, social and environmental factors. Due to the involvement of technogenic raw materials

- costs of re-development of old deposits decrease;
- existing enterprises operate in difficult climatic conditions, far from the center in developed mining areas whose residents work in the mining industry, there are housing, transport, energy and information infrastructures.
- social conditions can be improved by providing people with jobs, increasing employment and budget revenues.
- fixed assets, mining equipment, repair facilities can be used.
- final land reclamation can be carried out and sources of environmental pollution can be eliminated.

The environmental situation will improve in gold mining areas where most of the developed deposits have not been fully reclaimed, and significant areas occupied by overburden dumps, tailings, slags
etc. remain withdrawn from the economic land use and adversely affect the environment.

In addition, in these areas, there are mining machines, design documents for the production of new and modernization of obsolete dredges, specialists in scientific and design organizations and mining enterprises

7. Directions for improving the dredging method used at technogenic placers

Development of technogenic resources is an important scientific and practical problem which requires special attention. It is advisable to resolve a number of subsoil use issues related to the inventory assessment and mining licensing, creation of preferential tax and other priority conditions for enterprises developing technogenic placers and using territories occupied by mining waste.

When substantiating the direction of development and creation of dredging technologies, it should be noted that the dredging method is the most efficient one for technogenic placers. The average content of sand processed by dredges was several times lower in comparison with open and underground methods of placer mining. The scale and efficiency of development of poor sands is due to high performance of dredges, continuity, mechanization and automation of almost all the production processes. Currently, all the advantages of the dredging method have been preserved. Individual equipment and dredges can be modernized. There are some technical solutions for the development of technogenic placers, including those protected by patents. Therefore, it is advisable to use the dredging method to increase productivity of technogenic placers. It is necessary

1. to continue research on improvement and development of the technology
   – including the conversion of natural and technogenic placers using mining machinery and equipment (mechanical loosening, removal of oversized materials and redistribution of rocks) for subsequent development in order to exclude poor, difficult to dredge rocks from the technological process;
   – involving formation of a rock mixture of a target composition and quality, which can stabilize sand excavation and enrichment;
   – allowing for washing the most enriched parts of dredged dumps which will make it possible to reduce the volume of processed low-grade rocks, remove or reduce losses and repeated operations in the future.

2. to improve existing technical solutions and justify rational parameters of technological schemes:
   – to use a development system changing a direction of dredge’s moves relative to the initial one to reduce operational losses;
   – to change dredging parameters;
   – to increase the depth of digging and ensure the excavation of abandoned intersectional and interspersed pillars, spillage of sand from the scoops etc.;
   – to apply the dredging method with the exception of selective extraction of fine-grained sand;
   – to use the dredging method for loose sediments and mixing rocks of different granulometric compositions (see the above example of dump mining);
   – to improve technological schemes of sand enrichment which should allow for extraction of both large and small classes of previously lost metal;
   – to update the equipment used for the extraction and processing in accordance with operation conditions.

These areas do not require large capital investment; they are feasible and will be in demand in the near future.

Development of new open mining technologies for technogenic alluvial deposits can be based on works of leading research organizations (RAS IPKON, YaF of the RAS SB, FEO of the RAS, IR-GIREDMET). These studies suggest using continuously operating equipment. It is necessary to develop high-performance processing machines taking into account the extraction of various classes of metals lost during the enrichment.

Physicochemical technologies for extracting useful components from low-grade ores and sands and various methods of geo-technological preparation of placers are promising if they can ensure environmental safety.
8. Conclusion
The development of technogenic placers with confirmed quality characteristics of sand proved economic and technical feasibility of the mining equipment (cyclic excavators, bulldozers, multi-unit dredges). Dredging yields positive results: equipment performance and productivity of extraction of valuable components increase, while unevenness of equipment operation, costs of washing stocks and production decrease. At the same time, mining conditions require justification of dredging parameters which differ significantly from those at primary placers.

It is necessary to improve the technogenic placer dredging technology, reduce its cost and improve its efficiency.

New open-pit mining solutions for technogenic placers should be based on continuous and cyclical continuous methods.

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