Application and improvement of technologies for underground mining of placer deposits in Yakutia

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Abstract. The historical background is presented, and the experience gained in application of equipment and technologies of underground placer mining in Yakutia is considered. The variant of chamber mining with application of bolter miners and backfilling self-propelling machinery is proposed. The variant allows increase in productivity of development heading and actual extraction by 4–5 and 2.5 times, respectively, and reduces mineral loss and dilution.

1. Introduction

One of the key branches of the mining industry in Yakutia is gold mining. It is connected with discovery of the Aldan gold placer in 1923. In 1925 Aldanzoloto Union Trust was founded. If we take overall level of underground placer mining as the basis, the period from on the start of the industrial development and up to now can be conditionally be divided into stages.

Stage I is 1928–1945. Together with dredging and hydraulic mining of placers, the underground method was widely used since 1928. In 1932 in the Aldan mines, belt conveyors were for the first time tested and introduced for sand haulage, including elevation to ground surface. Some mines employed scrapers and self-dumping skips. Stopping was carried out manually. Efficiency of labor was from 1.12 to 2.3 m³/manshift. Aldan placer mines in 1932–1938 were the most advanced and best equipped gold mines in the country [1]. In 1931 Aldanzoloto was converted into Yakutzoloto Trust, which enabled geological exploration all over the territory of Yakutia Autonomous Republic. In 1936, on the basis of discovered and explored gold placers, within Yakutzoloto, Allakh-Yun Gold-Mine Management was established and in 1939 transformed into independent Dzhugdzhurzoloto Trust. The Trust carried out some underground operations with the help of placer miners.

Stage II began after 1945 with discovery of deep-buried placers near Allakh-Yun settlement. At the same time, the decision was made on the formation of Indigirka Mine Management. Underground operations were mostly concentrated the placer mines Marshal and Nelkan. Mining was either seasonal or year-round using various methods. Machinery and equipment were selected for every process of underground mining, energy supply systems of the mines were expanded, electric power plants were constructed, a series of all-metal gold washing machines of various designs, drilling rigs, high capacity scraper winches, etc. were engineered. In view of high consumption of timber, difficulties of face-entry drivage and mine ventilation, the Institutes of Permafrostology and...
Irgiredmet in 1965–1970 proposed breast-and-pillar systems of mining with roof supported by pillars and timber props, applied until now, mostly, in the regions of Indigirka.

**Stage III** should be related with gold discovery in the area of the Kular Ridge westward of the Yana River mouth.

Commercial development of the Kular gold field started in 1962. Since 1963 Kular Mine developed gold placers by the opencast and underground method. It was transformed to Kularzoloto Mining and Processing Plant in 1976. Complex geological conditions of placer mining in the Polar Region (repeated-wedge ice in mine roof, expensive imported timber) conditioned application of shortwall system proposed by VNII-1 Institute in 1965. The underground placer mining enjoyed the widest polarity in 1960–1985 when the specific weight of the underground gold mining in the Republic reached 25–35% of the overall gold production. Kularzoloto MPP ensured almost 70–90% of the total gold production. At that time, Yakutzoloto Production Association developed 8 gold fields via annual operation of 30–40 mines with underground gold production of 1.2–2.0 Mm$^3$/year. The largest fully mechanized projects were the mines in the Arctic zone of Yakutia (Kularzoloto MPP). The company was the first to carry out heading and stoping operations in underground permafrost placer mines tunneling machines GPK in inclined shaft sinking as well as self-propelling machines (drill jumbos and diesel-drive load–haul–dumpers) and powered roof support T-13K in actual excavation. Annual mine productivity totaled 100–150 thousand m$^3$, and the mines were the largest placer mines in the world. Such success was thanks to introduction of R&D projects of the Institute of Mining of the North, SB RAS, and VNII-1. Economic performance data of the applied mining systems are compiled in Table 1 [1].

In the considered system, given the place width of 100 m, the length the mine fields was 400–500 m for the year-round mines and 250–300 m for the seasonal mines; in case of placers 50–200 m wide, the mine field length was 250–350 m. The maximum length of the mine field reached 1000–1400 m at the placer 40–60 m wide.

**Table 1.** Economic performance data of mining systems.

| Description                              | Mining system |
|------------------------------------------|---------------|
|                                          | Longwall      | Room- and-pillar | Shortwall |
| Specific weight of development and temporary drives, % | 5.0–7.5       | 11.8             | 15–25      |
| Sand loss in pillars, %                  | 3.0–4.5       | 5.5–7.0          | 10–15      |
| Timber consumption per 1000 m$^3$, m$^3$ | 50            | 18               | —          |
| Underground miner productivity, m$^3$/shift | 4.2          | 7–9              | 10–12      |
| Mine productivity, m$^3$/day             | 100–170       | 300              | 350–500    |

In the regions of Indigirka, underground mining of of permafrost placers was mostly seasonal (winter). Mining period was 8–10 months, including 30–40% of time spent to get access to mineral and to prepare mine fields of extraction. Subject to current underground mine planning and design, access roadways were driven in October–November, development entries and temporary roadways—in November–December, and actual production was carried out in January–May. The Arctic mine operated year-round, as a rule, and access roadways were driven in summer as well.

Underground mining of Tirekhtyakh tin deposit was initiated in 1997–1998 at the mining depth of 40 m; the available reserves at the given mining rate ensured the mine life for 25 years. The mining technology used drilling-and-blasting with portable and import self-propelling equipment (drill jumbos and diesel-drive load–haul–dumpers). The system of mining was shortwalling with pillars 3 m wide between the shortwalls; the annual mine productivity was 80 thousand m$^3$.

The recommended self-propelling machines for underground mining of permafrost placers are listed in Table 2 [2].
Table 2. Self-propelling machines for underground permafrost placer mining.

| Operation                        | Face height 2.0–3.5 m | Face height 3.5–5.0 m | Face height above 5.0 m |
|----------------------------------|------------------------|------------------------|-------------------------|
| Hole drilling                    | UBSH-406, Minimatic    | UBSH-406, Minimatic    | UBSH-406, Maximatic     |
| Hole charging                    | PMZSH-2                | PMZSH-2                | —                       |
| Loading and haulage to haulage drift | ST-5A, Tor-200, LK-1, Wagner, GKHKH-4.1 | PD-8B, Wagner, Tor-300, Tor-350 | PD-8B, Tor-400, Tor-500 |
| Haulage to ground surface       | MoAZ 7405, MoAZ 7429   | MoAZ 7405, MoAZ 7429   | MoAZ 7405, MoAZ 7429    |
| Auxiliary operations             | Buses PA-40, 1V1G, AP-1, crane PK-5M | Haulage machines 1-BOM-1, Fuel filling—GSM, PSA-5 |
| Inspection and safety of roof   | SP-8A MOK-10           | SP-8A MOK-10           | SP-8A MOK-10            |
| Cleaning of mined-out area      | PD-5A, PD-8B           | PD-8B, Wagner, Tor-300, Tor-350 | PD-8B, Tor-400, Tor-500 |

2. Room-and-pillar system for underground mining of permafrost placers

As an illustration of underground mining of permafrost placers, it is proposed to use the room-and-pillar system with employment of heading machines, self-propelling equipment, and with backfilling (Figure 1).

![Figure 1. Initial mining stage in extraction panel: 1—main shaft; 2—auxiliary shafts; 3—haulage drift; 4—mined-out room to be backfilled; 5—chamber prepared for bedrock cleaning; 6—stop; 7—rib pillars (secondary chambers); 8—cutter-loader; 9—backfilling machine; 10—load-haul-dumpers; 11—bulkhead; 12—cuts.](image-url)
At this stage of mining, the equipment pack includes: cutter–loader AM-75, loaders PNB-3K and other, dump trucks MoAZ (or self-propelling cars), load–haul–dumpers LHD for backfilling and backfilling machine UMZK [3].

Access to the extraction panel is got via two inclined shafts (Figure 1). The entry shaft 1 and exit shaft 2 are connected by the haulage drift 3 and perimeter drifts used later on for ventilation or second exits from stopes. The inclined shafts (motot ramps) are driven at an angle of 8–10° by middle-class machines (AM-75, P-220, KSP-42 and others) using LHD at the cross-section of 12–18 m².

Development drives are headed by cutter–loaders. Directions and inclinations of the drives are pre-set and periodically controlled by a surveyor. Haulage drift is cut in the productive seam and has a cross-section of 20 m²; perimeter drive (ventilation drives) have cross-section of 16 m². During haulage drift drivage, cuts 12 are made to a depth to 1.5 to serve later on as niches to shelter miners during movement of LHD. Chambers are arranged at an angle to the haulage drift axis 3 for convenient maneuvering of self-propelling machines. Before preparation of secondary chambers, intersections of the primary chambers and haulage drift are reinforced with rock bolts and steel meshing. Extraction both in primary and secondary chambers is carried out after cross connection of the access and perimeter drives. Actual sand production uses cutter–loaders. The project cross-section of the chambers is 20 m², the width is governed by the stability of unsupported roof spans.

When the productive seam width is sufficient for operation of self-propelling machines, the seam is extracted full width by cutter–loaders. In thinner seams 0.2–1.0 m thick, extraction is separated: above the same an opening is drive with a width equal to the chamber width and the height sufficient for the self-propelling equipment operation, then the productive seam is extracted. The engineering solutions set the cross-sections of 5×4 = 20 m² both for primary and secondary chambers.

Sand haulage and piling on the ground surface involves underground dump trucks, loading to dump trucks is carried out using loading machines PNB-3K (shoveling). After cross-connection of the chamber and the perimeter drive, cleaning of the mined-out area (bedrocks) by LHD buckets; then, the chamber is assume prepared for backfilling.

After extraction and backfilling of the primary chambers, the pillars between them are developed in the same sequence. The secondary mining (extraction of secondary chambers) is depicted in Figure 2.

Figure 2. Extraction of secondary chamber: 1—interchamber pillars; 2—rock pillars; 3—bulkhead.

Ground control in this mining system combines rigid interchamber pillars (when primary chambers are extracted) and smooth subsidence of roof on yielding pillars made of backfill (when secondary pillars are extracted). It is recommended to prepare backfill gangue after drivage of
chambers and shafts, as well as overburden of operating opencast mine. Retreat backfilling is executed from the mine field boundary to the haulage drift. Haulage of backfill material from shafting and other drivage is performed by LHD, and overburden from the surface is transported via specially drilled large-diameter holes and by dump trucks.

Technical-and-economic comparison of the shortwall mining and room-and-pillar mining shows advantages of the latter. Efficiency of road heading and actual extraction exceeds by 4–5 times and 2.5–3 times, respectively. The volume of road heading makes 30% in shortwall mining and 10.8% in rock-and-pillar. The mineral loss and dilution reduces in the latter case from 19.1 to 2% and from 45 to 10%, respectively.

3. Conclusions
Improvement of technology and equipment for underground permafrost placer mining in Yakutia should include such basic trends as:

— upgrading of the current technology and machinery for road heading and actual mineral extraction at the increase in mineable thickness to 3 m and more;

— creation of a new cyclic-and-continuous technology providing mechanical (cutting and percussion-drag) destruction of coarsely clastic permafrost rocks as well as modern heading machines.

References
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