

# Conditions and development case studies for mountainous deposits in Siberia

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**Abstract.** The article contains the materials on deposits development intensification under challenging climatic and mining conditions, including mountainous areas of Siberia. The exploitation case studies for mountainous deposits all over the world and in Russia have been described. The authors have been set out the factors impeding the development of such deposits, and the extent of mining and transportation equipment performance degradation is also indicated. There have been stated the characteristics and the description of one of the newly mountainous gold ore deposits in Siberia which is being developed at an altitude of 2684m. A number of specific factors concerning its development have also been introduced as well as the description of mining technologies engineered by Irkutsk National Research Technical University (IRNRTU) specialists. The depth and principal dimensions of the open pit together with the mining and transportation equipment and facilities have been justified. The prime cost analysis of mineral extraction has been made, which results showed the substantial growth in expenditures for the transportation of the overburden rocks and ores. In view of the above mentioned research, there appeared the necessity for the search of new and the enhancement of current transport vehicles and communications.

## 1. Introduction

Owing to the growing demand for mineral resources and intensive development of deposits with the favourable mode of occurrence, more and more reserves sited in remote hard-to-reach areas with complicated mining characteristics started to be developed. There has been an annual increase in proportion of the deposits being developed in the permafrost regions. Such deposits experience high watering; they also have complicated structure and uneven distribution of mineral resources and valuable components. The elevation marks of newly developing deposits are being increased too. High in the mountains, there are the deposits of gold, copper, silver, iron, molybdenum, tungsten and etc.

All around the world, there are a number of mountainous deposits located at altitudes higher than 1500-2000m above sea level. First of all, these are copper deposits in Chile: Chu-quicamata (surface marks at about 3000m), Rio Blanco, Los-Bronces, Sur-Sur (3500-3800m); gold ore deposits in Kyrgyzstan: Kumtor (higher than 4000m), Makmal (about 2800m), Jerooy (3600m), as well as Kara-Keche coal deposit (3200m). The most mountainous deposit in the world (gold) is being developed in the Peruvian Andes at an altitude of 5100m in the vicinity of La Rinconada [1-3].

## 2. Results and Discussion

In Russia there have been developed quite a large number of mountainous deposits with somewhat



lesser elevation marks, including those in Altay: Ozeroye (silver) – 2500-3000m, Karegulskeye (gold-bismuth-cobalt) – up to 2700m, Alakhinskoye (lithium) – 2250-2700m; in Transbaikalia: Chineyskoye (copper, iron, palladium) – 2000m, Udocan (copper) – 1400-2100m; in Yakutia: Vysokogornoye (manganese) – 2500-2900m; in Northern Caucasia – Tyrnyauzskoye (molybdenum, tungsten) – 2000-3200m; in the Far East: Dalnegorskoye (boron) – 1400m; in Murmansk Region: Khibinskoye (phosphate) – up to 1750m and some others [1, 3, 4].

The majority of the above mentioned deposits are not being developed nowadays, in spite of the occurrence of considerable mineral reserves, mainly due to the inaccessibility and harsh exploitation environment. The factors impeding the development of mountainous deposits include:

- extremely nonuniform geologic structure and irregular occurrence parameters of reserves [5];
- severe topography and steep slopes;
- pergelisol occurrence;
- major seismicity;
- remoteness from infrastructural facilities;
- more inclement climatic conditions (low and erratic temperatures, fog and rime) [6, 7].

With the elevation marks being raised, the amount of precipitations increases (at the average of 12% per 100m of elevation), the percentage of oxygen in the air decreases, wind velocity increases. The other parameters change as well: yearly average temperature falls to 0.5-0.7°C per 100m of elevation, daily fluctuations in temperature range significantly.

In mountainous regions it becomes dramatically difficult to station any technological and productive facilities as well as to construct transportation communications. Under such conditions it is required to centre all technological processes within a small area which is practically impossible for minor deposits. The other option is to dissociate these processes and station the facilities at a long distance away from each other, which becomes very costly for the transportation connections owing to the considerable ruggedness of the surface.

The production waste disposal in the mountains becomes very complicated: due to the steep slopes dump formation for overburden rocks is either impossible or very dangerous. The rock fragments flying-off zone enlarges while performing blasting operations in open pits.

The higher is the deposit location, the more complicated becomes its development techniques. The majority of mountainous open pits are developed by the combined method: the top-ping of the ore body - by using open-cut mining techniques, the bottom part - by using underground techniques. The mentioned circumstances make mining technologies even more complicated.

In view of the aforesaid, the facilities throughput capability at mountainous deposits is 10-20% less than at regular open pits [1], the duration of the working season is a lot shorter, the costs for the minerals extraction are several times greater.

Labour productivity slowdown in mountainous regions is caused by workers overstrain in difficult, stressing environment during production activities.

Besides, the development of mountainous deposits involves higher expenditures for the elimination of negative ecological aftereffects owing to the increased vulnerability of mountainous regions. These circumstances include: lower rates of distressed areas and disrupted ecology reconditioning as well as slower dissociation of contaminants and wastes. Mining operations can be the cause of landslides, avalanches, mudflows, slide-rocks and slumps. The precipitation of dust onto snow and ice accelerate their melting, resulting in slope abrasion, thermokarst and soli-fluction. The ablation of frozen earth can cause ground slumping and rock creeping.

Owing to its immense territory, Siberia has always possessed a sufficient number of mineral deposits with favourable mining-and-geological mode of occurrence. Therefore, there has not been any acute need to explore and develop deposits in hard-to-reach mountainous areas. However, in the last few years due to the depletion of reserves in well developed areas, more and more mountainous deposits are being developed [7, 8]. The proportion of newly developing mountainous deposits is several times greater than the proportion of mountainous regions in Siberia. In the past it used to be only highly scarce and valuable minerals (in the first place – gold), but nowadays they include iron,

quartzites, talcum, graphite, marble, structural stone, etc.

Almost all the newly developing mountainous deposits in Siberia have rather moderate mineral reserves which makes it possible to extract mineral raw materials without major investments, permanent production and residential structures, using small-scale mobile machinery only.

At present IRNRTU has finished the projection of mining operations and started exploitation of one of the most mountainous deposits in Russia. This gold ore deposit is located in the south-eastern part of the Eastern Sayan Mountains, at the slopes and the top of Ostraya Mountain with an elevation mark of 2684m. The deposit is positioned in the Buryat Republic according to the administrative division.

The relief is similar to that in the Alps. The slopes of Ostraya Mountain in its upper and middle parts are cliffy and steep; in its lower parts they are recovered by colluvial talus and pro-luvial apron (Figure 1).



**Figure 1.** Ostraya Mountain, the view from the east side

The western slope of the mountain is more flat, the most part of which is covered by eluvial-colluvial sediments. The level difference from the foot of the mountain to its top accounts for about 600m.

The climate in the region is sharply continental. Yearly average temperature is  $-7.4^{\circ}\text{C}$ . It may be freezing and snowy at any season of the year. The time span with negative daily average temperatures totals to 7 months, the permanent snow cover settles in October and melts away in the first decade of June. Inclement climatic conditions determine all-round development of permafrost, with the depth of the frost retreat at the north slopes not exceeding 0.5m, at the southern slopes – 1.5m. Annual precipitation amounts to 500mm, up to 70% accounts for June – July.

The deposit is located in the seismically active region with the probable earthquake intensity measuring 9 as a maximum on the scale confirmed by the Geophysical Institute of the Academy of Sciences.

The total extension of the ore zone is 9km, the large-scale distributions of gold are found within the interval of 2000-2600m.

Considering hydrogeological conditions of development, Zun-Ospinskoye deposit is characterized as ordinary, because granite and ultrabasite massifs forming the mountain range are waterless. The water inflow beneath the permafrost boundary is not expected either.

The exploitation conditions of this deposit are similar in many ways to the other mountainous deposits. These include unfavourable atmospheric conditions, the complexity of access roads and technological facilities construction, the lack of suitable sites for dump stockpiling.

However, unlike other mountainous deposits the described object has a number of specific characteristics. First of all, the climatic conditions are more severe (especially in comparison with the mountainous deposits in Chile, Kyrgyzstan and Tadjikistan), which makes it practically im-possible to

carry out mining operations in cold periods of year. Secondly, relatively moderate mineral reserves and hard-to-reach location of the deposit do not stimulate mining specialists to establish the necessary infrastructure. Thirdly, the deposit is located far away from the well settled territories (70km off the nearest unimproved earth road and 350km off the nearest railway station).

The very steep slopes covered by combe rocks determine the probability of rocks avalanching, and in winter – snow avalanching. The danger of mudflows and avalanches essentially increases while performing earthmoving works at the slopes.

Nevertheless, mining specialists emphasize some positive characteristics of the deposit, such as the slower increase of the overburden ratio as the open pit depth increases, which is caused by the ore body outcrop at the watershed and by the steep slopes of the mountain. Besides, there is a possibility to in-move to the working areas of the benches directly from the earth surface. And finally, one more positive factor includes the favourable conditions for the open pit aeration.

The development of Zun-Ospinskoye deposit is expected to be carried out by the combined method. The upper part of the ore body up to the level of 2490m will be developed by using open-cut mining techniques, whereas subjacent reserves - by using underground techniques.

Preliminary estimate of the possible open pit depth was calculated according to the contrast of means and marginal overburden ratios. The calculation results showed that at the amount of  $6.5\text{m}^3/\text{t}$  it becomes economically sound to change-over to the underground techniques. Whereas, the deposit development by means of open-cut mining techniques is profitable up to the amount of  $32.7\text{m}^3/\text{t}$ . The final justification for the open pit depth was performed taking into account mining and geological conditions and graphical layout.

While choosing the possible depth of the open pit, the specific lay of land features influencing the transportation facilities location was primarily taken into consideration.

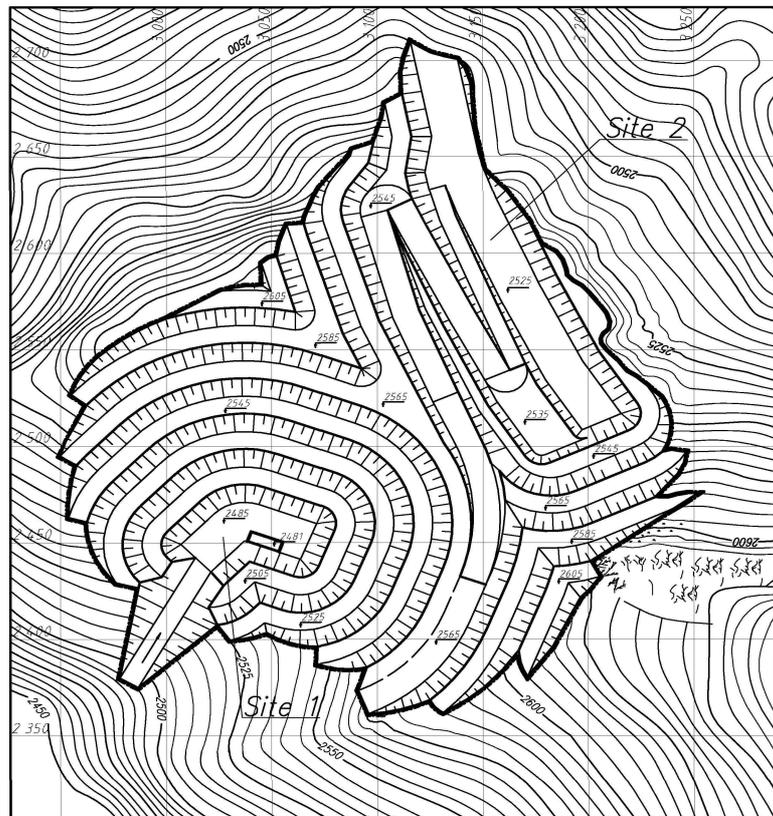
The minimum width of the open pit bottom was calculated according to the tilt-up lorry U-turn capacity and accounts for 20m. The bench height (double benching) at the final stage of bench working – 20m, the bench shelving angle at the same stage –  $65^\circ$ , the width of the safety bench – 9m.

The limiting outlines of the open pit were designed at the geological profiles, taking into consideration the shelving angles of the face and benches, the benches' height and the minimum width of the open pit bottom. According to the determined profiles on the surveyor topographic plan superposed with the plan of exploratory workings (wells, trenches, adits), the design of the open pit was developed. The developed open pit below the horizon of 2565m is divided into two open pit workings which are marked as Site 1 and Site 2. Transportation facilities were included into the developed open pit working. While realizing the transportation layout of the open pit the following facilities were introduced: the cargo transportation connection with the horizons of the Site 1 is accomplished via separate small trenches from the day surface, for the exposing of the horizons below the level of 2515m the outer trench is developed; the cargo transportation connection with the horizons of the Site 2 is accomplished by means of inner trench from the horizon of 2565m at the Site 1 (Figure 2).

High strength and bearing properties of rocks, moderate depth of the workings (up to 100m), the open pit location at the hill slopes and the faces reciprocal interception of the Sites 1 and 2 actually eliminate deformations and faces caving.

The accepted mark for the open pit bottom – 2490m; the maximum depth of the pit – 80m; the height of the highland – 95m; the total pit area –  $67500\text{m}^2$ ; the shelving angles of the working benches –  $75^\circ$ ; the bench shelving angle at the final stage of bench working –  $65^\circ$ ; the maximum face shelving angle –  $50^\circ$ . The balance ore reserves within the open pit outlines equal to  $2550700\text{m}^3$ ; usable ore resources – 440000t; the mean coefficient of capping –  $6.6\text{m}^3/\text{t}$ ; the operational coefficient of capping –  $5.4\text{m}^3/\text{t}$ ; the period of the reserves development – 11 years; the annual productive capacity adopted in the project – 40000t. In all, 85% of the explored reserves are accepted for open-cut mining.

The ore bodies are foreseen to be developed by horizontal layers (benches) with the height of 5m.



**Figure 2.** The design of the open pit by the end its development

The development starts at the common for Sites 1 and 2 horizons, then (at the height of 2565m) the Sites are developed separately. The Sites are developed simultaneously by means of transferring the excavator from one site to another depending upon the availability of prepared reserves. This particular design makes it possible to perform steady lowering mining works at each site, and as required to carry out within-the-pit ore blending.

Vehicular access to the upper highland horizons is executed from the surface which has the marks equal to the working horizon marks. The horizons are developed consecutively top-down; at that, the work front advances northward (Site 1) and south-westward (Site 2). The development of benches is foreseen to be performed via lengthwise advancing.

The overburden rocks are transported to the external dump located southerly, in the ravine, in the barren areas. The transporting distance accounts for 1.8km.

Mining works are carried out by means of the excavation-transportational complex using the drilling-blasting loosening techniques. The rock minerals are transported by tilt-up lorries to the ore storage facilities, located at the foot of Ostraya Mountain in the immediate vicinity of the concentrating plant. The transportation distance for the lode rock is 8.5km.

The choice of the mining equipment and facilities is made according to the mining-and-geological characteristics of the deposit, the mining-technical and climatic conditions of the mine workings, the approved mine working design and the volume of mining work. The deposit is located in remote hard-to-reach area without any power supply or transport infrastructure. That is why besides the compliance of the principal technological characteristics with the deposit parameters, some additional requirements are applied for the chosen equipment: diesel drive unit, the functioning without significant productive capacity loss at the altitudes of up to 2700m above the sea level as well as increased passability, durability of the operational equipment and the un-derrigment, the highest possible reliability and the longest interrepair period.

Taking into consideration the above-stated, the mining-and-transport equipment and machinery produced by Caterpillar Company were approved for the project.

The dragshovel CAT 349D (dipper capacity  $2.1\text{m}^3$ ) is used for the excavation and loading of mineral and overburden rocks. The transportation of the lode rocks to the ore storage facilities for the distance of 8.5km is performed by means of the all-wheel drive articulated tilt-up lorries CAT 725D (load capacity 23.6t). The barren rocks are transported by the same lorries to the external dump located at the hill slope southerly off the open pit, the transportation distance being on average 1800m.

The overburden and lode rocks are subjected to loosening via blasting techniques. The rock-drilling machine CAT MD5075 Track Drill or a similar one with the drilling diameter 110 и 127mm are used for the drilling-off operations.

The excavation and dump formation for the blasted hard rocks in the difficult-to-reach areas are performed by the bulldozer CAT D8R, because it is impossible for other vehicles to safely reach this area (peaks, narrow strips of land at the hillsides). The same bulldozer prepares the work platforms for the excavator and drilling sites for the rock-drilling machine.

The dumping of the overburden rocks is performed by the bulldozer CAT D6R.

Pick-and-place operations at the ore storage facilities are performed by the front-end loader CAT 966H (dipper capacity  $3.5\text{m}^3$ ).

The construction of the technological auto-roads towards the highland horizons of the open pit and the interareal autoroad leading to the ore storage facilities is performed by the bulldozer CAT D8R utilizing mechanical loosening techniques. The excavator CAT-349D equipped with the rigging (ripper and hydraulic hammer) is used in the areas with particularly hard rocks.

According to the results of the preparatory-development works (the first two seasons), the functioning of the used equipment and machinery was excellent. The transportation facilities (the inter-areal auto-road from the top to the foot of Ostraya Mountain), the platform for the concentrating plant as well as the tailing dump couch were constructed.

The external dump, the total volume of which in solid accounts for  $2391000\text{m}^3$ , whereas the realizable volume (considering the retained loosening coefficient) –  $2869000\text{m}^3$  is also provided for.

The vehicular dumping is designed to be located in the ravine. Rather small inclination of the ravine bottom ( $15\text{-}17^\circ$ ) and the occurrence of the holding side surfaces increase the dump stability. The design parameters of the dump are: the height of the dump – 150m, the maximum height of the lower layer – 60m, the height of the following layers – 30m; the number of layers – 4; the width of the inter-layer berm – 30m; the total shelving angle of the dump –  $28^\circ$ .

Exploration works on reserves evaluation below the designed open pit outlines were carried out during the last two seasons and positive results were obtained. In this connection, the mining specialists are giving serious consideration to the issue of increasing the productive capacity of the open pit and the speedy beginning of the underground horizons development.

### 3. Conclusion

Taking into account that Zun-Ospinskoye deposit makes up only a minor share of the licensed allotment of land, where about 20 more probable ore manifestations have been discovered, it can be stated about the formation of the new promising gold-mining region in Eastern Siberia.

The cost composition preliminary analysis of minerals extraction showed that the major share of costs accounts for the transportation of the overburden rocks and ores. Therefore the effectiveness increase in the mountainous deposits development should be realized, first and foremost, through enhancement and search for the new transport communications, including orepasses, cable roads, skips, tracked tilt-up lorries and even airships.

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