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Original Article

Application of strategic stockpile for ore quality stabilization at Erdenet open pit mine

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ABSTRACT

Ore mixing and blending are performed at the mining benches, typically involving 6-8 working benches. However, as the mine deepens, operations across multiple benches become more challenging, and declining copper grades necessitate increased processing plant capacity. Variability in total copper content in the sulfide ore can reach up to 8%, with an allowable range of 0.541% to 0.461% when the average is 0.501%, as per internal Erdenet standard STP-01352-901908085-11:2013. Maintaining this standard within a 24-hour period is difficult, complicating process control. To achieve an 85% metal recovery rate, the processing plant is adjusted to meet the standard ore quality. However, short-term fluctuations exceeding ±8% lead to decreased recovery rates and potential metal loss. Establishing tactical stockpiles close to the primary crushers or along transportation routes can mitigate these issues by stabilizing ore quality before processing. The tactical stockpile project relies on optimizing operational procedures, integrating stockpile construction using mine-sourced waste rock, preparing platforms, utilizing existing equipment capacity, enhancing signage and lighting, and creating guidelines for safe operation and grade averaging. This approach provides a rapid and effective solution to improve blending efficiency and operational stability.

Keywords: accumulation and bedding stockyards, operational data, ore control, fleet management system

INTRODUCTION

The depletion of mineral reserves and a decrease in the content of useful components in them predetermine a sharp deterioration in the economic efficiency of a mining enterprise. The complexity of decision-making on managing the quality of multicomponent ores is due to the significant variability of the geological conditions of the occurrence of the ore body and the distribution of useful components in it, as well as the stochastic nature of the ore mining processes (Otgonbileg, 1996).

Reducing the level of fluctuations in the quality of ore allows you to reduce the loss of copper and molybdenum in the "tailings", increase the yield of concentrate, and stabilize the quality of the ore increases the extraction of metals from it (Davaasambuu, 1995; Delgerbat, 2002).

Stabilization of the quality of porphyry copper ores in open-pit mining depends on a number of factors that affect the processes of its formation, as well as the difficulty of predicting and analyzing this impact, taking into account the mining and geological conditions of the deposit operation and the features of the development technology used (Zhao et al., 2014).

First of all, this applies to intra-monthly intervals of the quarry, since the influence of variability of mining and geological conditions at these intervals is maximum, and the possibilities of control are limited. Characteristic features of porphyry copper deposits, in particular, the Erdenetiin Ovoo deposit, are the complexity of the geological structure, significant variability of ore quality within the deposit and within individual blocks. The alternation of various grades of ores and waste rocks in some cases reaches 3 m, the range of changes in the total copper content in the ore is 0.03-2.25%, molybdene 0.016-0.031% (Ganbaatar, 2003; Ganjargal, 2005).

Since the beneficiation process is set up to receive ore with a certain metal content and qualitative composition, the initial ore in the open pit must undergo preparation, which consists in ensuring the required ore indicators, carried out during the planning of mining operations at prospective, current and operational intervals. At the first and second levels, as a rule, the tasks of ensuring the balance of metals in the mining blocks are solved in accordance with the established directive plans. At operational intra-month intervals, the implementation of the main indicators of ore flows is ensured, especially at the levels of daily, shift planning and management.

MINING BACKGROUND

The Erdenetiin Ovoo copper-molybdenum deposit (104°07'30"E, 49°01'12"N) is one of the most well-known and extensively mined deposits. It is associated with copper-molybdenum stockwork development within the granite-porphyries of the final (third) phase of the Selenga complex. This deposit was exposed through erosion, with the upper part containing oxidized copper ores with a copper content of 0.89% and the lower part containing primary copper ores with a copper content of 0.54%. Total reserves are estimated to include about 7.6 million tons of copper and 216.2 thousand tons of molybdenum (Undrakhtamir et al., 2016; Ivanov et al., 2021).

At the Erdenet open-pit mine, the conventional approach is to directly feed the primary crushers to the processing plant using dump trucks. This method reduces costs by eliminating the need for additional rehandling for ore prior feeding the primary crusher (Battogtokh and Tsogtbayar, 2021).

Erdenet operates two primary crushers, designated as KSI and KKD. Primary Crusher 1, known as KSI, is the original gyratory crusher installed during the initial development of the processing plant. Primary Crusher 2, referred to as KKD, is a more recently added jaw crusher designed to handle increasing ore throughput.

Throughout this paper, these crushers will be referred to by their respective designations: KSI (Primary Crusher 1) and KKD (Primary Crusher 2).

Ore mixing and blending is carried out at the mining benches, typically involving 6-8 working benches, and the process has been maintained without increasing the bucket capacity of excavators. However, as the mine deepens, it becomes more challenging to conduct operations across multiple working benches, and declining copper grade in the ore has necessitated an increase in the processing plant's capacity. This, in turn, requires larger bucket capacities for excavators, making ore averaging at the bench level increasingly difficult.

The ore supplied to the processing plant must meet specific standards: the total oxidized copper mineral content should not exceed 4%, primary copper sulfide mineral content should not exceed 65%, and the levels of harmful impurities, such as lead (Pb) and arsenic (As), should not exceed 0.0075% and 0.012%, respectively (Battogtokh, 2019). Due to the daily ore averaging process and logistical coordination between excavators, achieving the required daily averaging within a 24-hour period is often not feasible.

Variability in total copper content in the sulfide ore can reach up to 8%, with an allowable copper content range between 0.541% and 0.461% when the average content is 0.501% (Baatarkhuu, 2008). As per existing process these variabilities are expected to be limited to six shifts per month. In practice, maintaining this standard within a 24-hour period is challenging, which complicates adherence to these standards. To achieve an 85% metal recovery rate, the processing plant is adjusted to meet the standard ore quality requirements specified above. However, when the metal content in the ore fluctuates within a short period, exceeding ±8%, the processing plant's settings cannot be adjusted accordingly, resulting in decreased recovery rates and potential metal loss (Ganjargal, 2005). Due to the structure of the deposit, the ore grades within benches and blocks are unevenly distributed, which makes averaging difficult within the framework of mining operations planning. In 2016, the mining plan included ores with the following copper content distribution: 36.1% of the ore with 0.25-0.45% copper, 46.7% with 0.45-0.65% copper, and 17.1% with above 0.65% copper, resulting in an average copper content of 0.501% across all extracted ore (Undrakhtamir et al., 2016).

MATERIALS AND METHODS

Ore Blending Practice and Challenges at Erdenet mine

Ore blending refers to quality planning and management activities aimed at minimizing fluctuations in ore quality, stabilizing, and standardizing indicators over a given period as the ore moves from mining to the processing plant. This is achieved through controlled mixing and blending.

The amplitude of fluctuations in ore quality indicators is expressed as variance, defined by dispersion D and standard deviation σ, calculated using the following formulas (Shevelev, 2014; Fomin et al., 2014):

$$D = \sigma^2 = \sum(\alpha_i - \alpha^-)^2/(n-1) \quad (1)$$

$$\sigma = \sqrt{\sum(\alpha_i - \alpha^-)^2/(n-1)} \quad (2)$$

Where, α_i- the flow of quality indicators, α- the average value of quality indicators, n – the number of values in the statistical set.

The effectiveness of the blending process is determined by comparing variability in quality indicators before and after averaging. The more ore batches are mixed, the higher the degree of quality averaging achieved.

The specific quality characteristics used to define ore consistency depend on the characteristics of the ore and the technological scheme of the processing plant. To maintain optimal processing, it is essential to average and stabilize all indicators that adversely affect plant performance. These include the content of valuable and associated components, the presence of harmful impurities impacting process and concentrate quality (Statsenko and Branovets, 2014), the degree of grinding, particle size distribution, fragmentation, and various physical-mechanical characteristics.

If ore with quality deviations from the planned level enters the process, it leads to deviations from optimal processing regimes, reduces efficiency, and changes the flow rate. The greater the quality deviation and the longer it lasts, the more it impacts metal recovery, reagent consumption, and ultimately leads to metal recovery losses. Losses in metal recovery and declines in concentrate quality and productivity due to ore quality fluctuations indicate a mismatch between the processing regime and ore quality (Zarubin et al., 2017).

Significant changes in ore quality within or between shifts, without real-time adjustments to the processing, resulting in the losses mentioned above.

Methods and Types of Ore Blending

There are several methods and processes for ore blending. Planning and scheduling methods utilize annual and quarterly plans based on data collected from orebody exploration. Automated sampling devices are also used to monitor ore quality information and samples taken from the pit and trucks (Assimi et al., 2021; Statsenko and Melkoumian, 2013).

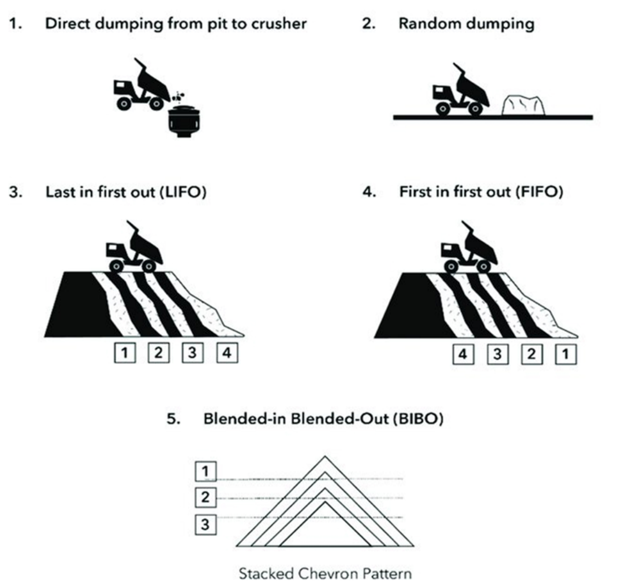

Fig. 1. Five types of Pre-Crusher Stockpiles (Jupp, 2024)

The technological method for ore mixing involves creating layered stockpiles, where ore is dumped and mixed using excavator loading, forming a tactical stockpile.

As is the case with many processes, blending or mixing is a necessary step to ensure optimal product quality. Typically, these blending processes are performed after the primary crusher step. Within mining, pre-crusher stockpiling is often used for its operational simplicity, but it typically lowers the confidence of the ore grade and reduces certainty in feed quality (Jupp, 2024). Following picture (Fig .1) is shown different forms in pre-crusher stockpiling in open-pit mining (Everett, 2010; Jupp, 2024). Erdenet operations' existing practice follows a direct dumping method, where ore is transported from the pit and directly fed into the primary crusher without pre-crusher stockpiling. Just as there are operational differences between iron, coal and base and precious metal mining, there are also differences in how these operations stockpile. For example, iron ore is often shipped directly from the mine to the customer.

Morley and Arvidson (2017) mention that stockpile modelling typically involves arithmetic weighted averages of grade and tonnage values determined from blast hole samples and survey volume records. They also state that spatial modelling of stockpiles is performed manually using engineering software tools.

RESULTS

During construction and development Erdenet Mining Corporation was established, no space was allocated for stockpiling near the primary crushers, as the processing plant was designed with direct feed from the mine. Excluding loader operating space and distances between stockpiles from the total available space, it was determined that the plant could be supplied with a 48-hour feed capacity of 233000 tons of ore.

The primary crusher at the processing plant, the KKD, has a capacity of 2836.37 tons per hour, while the KSI crusher operates at 1120.34 tons per hour. To minimize rehandling and material movement costs, it is recommended to locate the tactical stockpiles as close as possible to the primary crushers or along the transportation route (Elbegzaya et al., 2023). Accordingly, four potential sites for stockpiling near the KKD and KSI crushers were identified (Fig. 2).

Fig. 2. General layout of proposed tactical stockpiles.

Yellow areas in the figure (Fig. 2) represent the proposed back fill required for new stockpiles with blue lines representing handling distance from newly established stockpiles, which are strategically located to improve ore blending efficiency and minimize hauling distances to the crushers.

The red line in the figure (Fig. 2) represents the distance from the tactical stockpiles to the respective crusher feeding points. The abbreviations KSI-DA-A/B and KKD-DA-A/B are used to distinguish the stockpiles allocated for each primary crusher. KSI-DA-A and KSI-DA-B refer to stockpiles designated for the KSI crusher (gyratory crusher), while KKD-DA-A and KKD-DA-B correspond to stockpiles serving the KKD crusher (jaw crusher). These designations help optimize dispatch operations and ensure efficient ore flow management between the two crushing circuits.

The tactical stockpile "DA-A" near the KKD crusher has an area of 13270 m² and can hold 165000 m³ or 420750 tons of ore. "DA-B" has an area of 3100 m² with a capacity of 4400 m³ or 11200 tons. Together, these stockpiles can supply the KKD crusher with 431950 tons of ore, sufficient for 152 hours at a rate of 2836.37 tons per hour. Constructing these sites will require backfilling approximately 8000 m³ of waste rock (Fig. 3).

The KSI-A stockpile near the KSI crusher has a capacity of 10400 m³ or 26520 tons over an area of 6100 m², sufficient for 24 hours of supply at 1120.34 tons per hour. The KSI-B stockpile, occupying 2000 m² with a capacity of 3500 m³ or 8925 tons, can supply 8 hours of operation. Together, these stockpiles can supply 35445 tons or 32 hours of ore to the KSI crusher (Fig. 4).

Establishing the KSI-A site requires 81000 m³ of waste rock fill, while KSI-B requires 12000 m³, totaling 93000 m³ for both. The KKD site will need 8000 m³, totaling 101000 m³ of waste rock for filling across KKD and KSI stockpile sites.

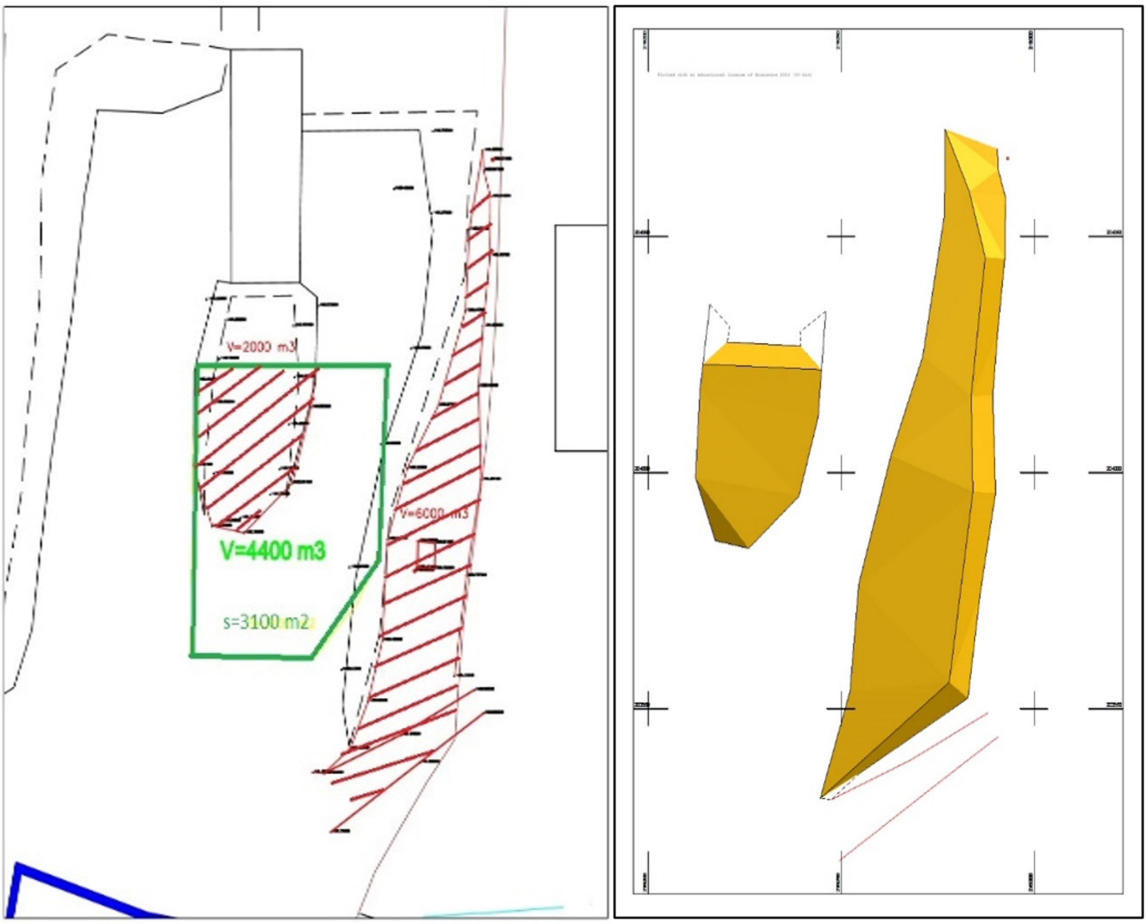

Fig. 3. Plan view of Stockpile B near KKD crusher. Yellow solids represent tactical stockplies, red sections are showing required backfill zones for stockpile pad construction

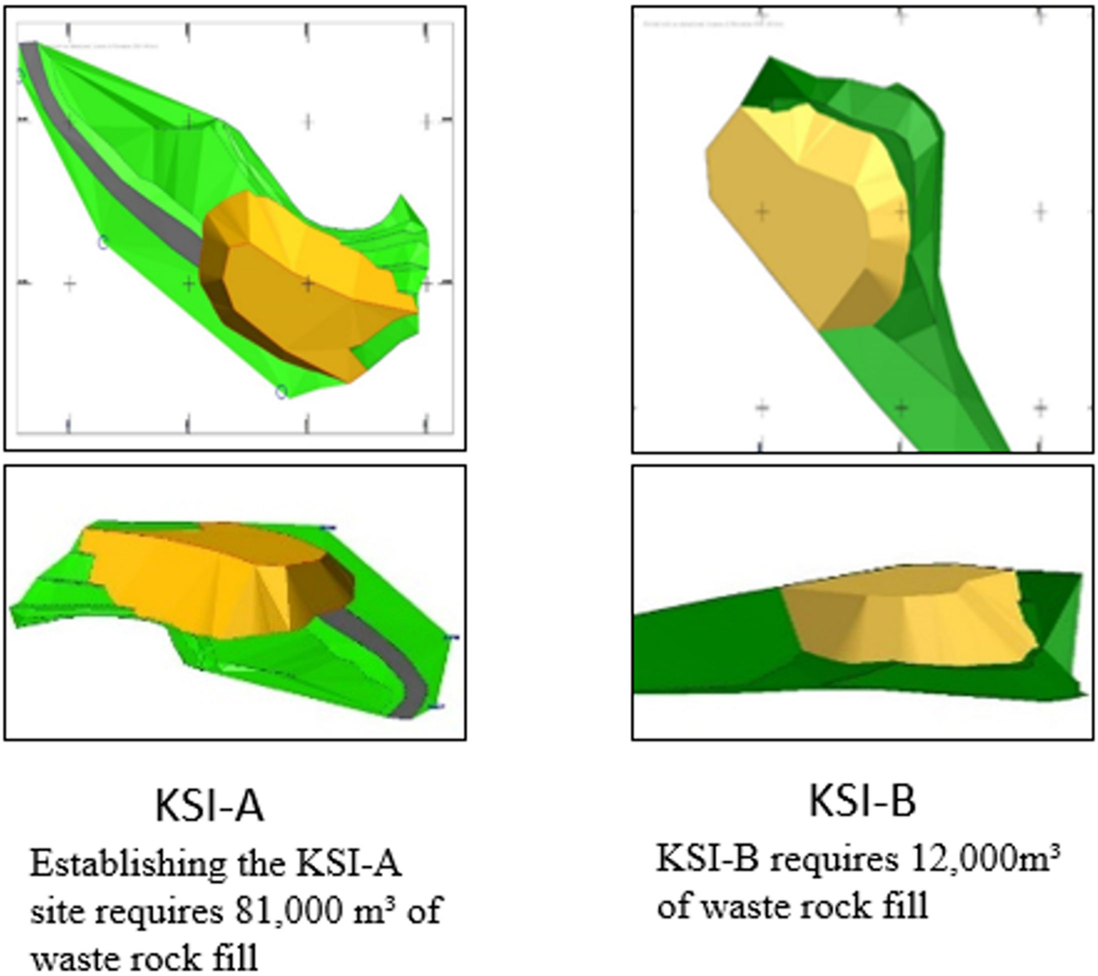

Fig. 4. Plan view of Stockpile KSI-A and KSI-B.

DISCUSSION

The establishment of tactical stockpiles retains the conventional ore blending and mixing scheme while introducing the following changes:

- Conducting survey measurements and determining the stockpile balance at tactical stockpiles, specifying refilling intervals and loading quantities from each block.
- Utilizing tactical stockpiles as backup when direct-loading excavators experience downtime or interruptions, adjusting content levels using short term interval control and the mining dispatch software system.
- In cases where the processing plant declines ore, ore can be diverted to tactical stockpiles.

Since waste rock from the mine will be used to build the stockpile bases, the cost of stockpile foundation work is included in the mine's overburden removal budget. Transport distances for the required 101000 m^3 of waste rock are shorter than current distances to existing waste dumps (4 and 8), hence no additional transportation costs shall be incurred.

For the KKD and KSI areas, two Komatsu WA800 loaders (units 2 and 3) will be assigned from existing mining fleet. The distance from the stockpiles to the receiving bins is 80 m and 340 m for the KKD and 75 m and 130 m for the KSI. For distances over 100 m, additional loading will be required with WA800 loaders. Although this increases costs, productivity will also improve.

As the mine deepens, the ore grade and technological influence of ore on processing will increase, raising production costs. Variability in ore grade, global copper prices, and the need for consistent processing head grade can be managed using strategic stockpiles. Table 1 presents the estimated preliminary economical assessment and costs of establishing tactical

Table 1. Economical assessment and costs of establishing tactical stockpiles

1	Cost	Thousand MNT
1.1	Stockpile site construction costs	17 970
1.2	Costs associated with loader operations	266 834
1.3	Ore handling from intermediate stockpile to crusher	215 707
1.4	Miscellaneous (lighting, signage, mirrors, fences, etc.)	98 000
1.5	**Total cost**	**598 511**
2	Losses	Thousand MNT
2.1	Losses from equipment downtime	8 886 728
2.2	Losses from ore grade variability	4 783 200
2.4	**Total**	**13 669 928**
3	**Potential upside savings from reduced losses**	**14 268 439**

stockpiles, equipment downtime, and losses from copper grade variability.

The future cost savings also include the capital cost of purchasing an excavator, estimated at 15,529 million MNT.

CONCLUSION

Due to the dependence of mining, loading, transportation, crushing, and processing value chain, the Erdenet copper-molybdenum processing plant has experienced production interruptions, issues with ore blending, disruptions in ore supply, operational inefficiencies, metal losses, and imbalances in harmful impurity levels. Based on these findings, establishing a tactical stockpile improves operational efficiency by increasing technical productivity, reducing production costs, stabilizing ore grade, and maintaining the balance of harmful impurities.

The findings demonstrate that improving the sequence, flow, and methods from initial ore extraction through to processing plant significantly reduces inefficiencies. Implementing a tactical stockpile is crucial to mitigating weaknesses caused by operations and reducing waste.

Implementing the tactical stockpile project relies on optimizing operational procedures, integrating stockpile construction using mine-sourced waste rock, preparing platforms, utilizing existing equipment capacity, enhancing signage and lighting, and creating guidelines and regulations for safe operation and grade averaging from the stockpile. This allows opportunity for quick establishment and visible results.

Although the project increases short distance hauling and loading with rehandling costs, the direct and indirect benefits-including reduced metal losses, dilution, time savings, and resource efficiency-outweigh these costs by a factor of 20, making it economically necessary.

By optimizing the direct transportation system based on engineering calculations, the project aims to turn lost time and opportunities into planned, profitable resources. Furthermore, integrating mine and mill processes from the directly of mining operations-known as mine-mill integration-enhances the mining company's competitiveness and promotes economic savings.

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