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CONTACTS

Phone: **+998 50 737 87 88**

Website: https://ist-journal.uz

Email: innovationist2025@gmail.com

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OPTIMIZATION OF WASTE ROCK PLACEMENT SCHEMES FROM A MINING PERSPECTIVE IN THE DEVELOPMENT OF TITANOMAGNETITE DEPOSITS

Ibrohimov Dilshodbek Norimbat oglu
Doctoral Candidate, Department of Mining, Navoi State Mining and Technology University
E-mail: ibrohimovdilshodbek980307@gmail.com

Abstract. This scientific article reviews and analyzes key data on the optimization of waste rock placement schemes in the open-pit development of the Tebinbulak titanomagnetite deposit. The research assesses the geological structure of the deposit, examines its mining and technical conditions, calculates the formation patterns of overburden volumes, and explains external, internal, and combined schemes for overburden placement based on practical field studies. According to the practical results of the research, the use of a combined dumping system was identified as the most effective method, taking into account the geological location and technological characteristics of the Tebinbulak deposit. It has been established that geotechnical requirements based on this approach make it possible to reduce transportation distances by using external dumps at the initial stages of mine development and internal dumps at subsequent stages.

Keywords: Tebinbulak deposit, titanomagnetite ores, waste rock, overburden, dump, open-pit mining, optimization, geotechnical requirements, mine design, geological modeling.

Аннотация. В данной научной статье рассматриваются и анализируются основные данные по вопросам оптимизации схем размещения вскрышных пород, образующихся при открытой разработке Тебинбулакского титаномагнетитового месторождения. В ходе исследования проводится оценка геологического строения месторождения, изучаются его горнотехнические условия, рассчитываются закономерности формирования объемов вскрышных пород, а также на основе практических исследований на месторождении разъясняются внешние, внутренние и комбинированные схемы размещения вскрышных пород. Согласно практическим результатам исследования, с учетом географического расположения и технологических характеристик Тебинбулакского месторождения использование комбинированной системы отвалообразования было оценено как наиболее эффективный метод. Установлено, что геотехнические требования, основанные на данном подходе, создают возможность сокращения расстояния транспортировки за счет использования внешних отвалов на начальных этапах разработки месторождения и внутренних отвалов — на последующих этапах.

Ключевые слова: Тебинбулакское месторождение, титаномагнетитовые руды, пустые горные породы, вскрышные породы, отвал, открытый способ добычи, оптимизация, геотехнические требования, проектирование рудника, геологическое моделирование.

Annotatsiya. Ushbu ilmiy maqolada Tebinbuloq titan-magnetit konini ochiq usulda o‘zlashtirish jarayonida hosil bo‘ladigan chiqindi jinslarni joylashtirish sxemalarini konchilik nuqtai nazaridan optimallashtirish masalalariga oid asosiy ma’lumotlar tahlil qilinadi. Tadqiqot davomida konning geologik tuzilishi baholanadi, kon-texnik sharoitlari o‘rganiladi, qoplovchi kon jinslari hajmining shakllanish qonuniyatlari hisob-kitob qilinadi, shuningdek, konda olib borilgan amaliy tadqiqotlar asosida qoplovchi jinslarni joylashtirishning tashqi, ichki va kombinatsiyalashgan sxemalari izohlanadi. Tadqiqotning amaliy natijalariga ko‘ra, Tebinbuloq konining geologik joylashuvi va texnologik xususiyatlarini inobatga olgan holda, kombinatsiyalashgan ag‘darma tizimidan foydalanish eng maqbul va samarali usul sifatida baholandi. Ushbu yondashuvga asoslangan geotexnik talablar konni o‘zlashtirishning dastlabki bosqichlarida tashqi ag‘darmalardan, keyingi bosqichlarda esa ichki ag‘darmalardan foydalanish orqali tashish masofasini qisqartirish imkoniyatini yaratishi ilmiy-amaliy jihatdan asoslab berildi.

Kalit so‘zlar: Tebinbuloq koni, titan-magnetitli rudalar, chiqindi jinslar, qoplovchi jinslar, ag‘darma, ochiq usulda qazib olish, optimallashtirish, geotexnik talablar, konni loyihalash, geologik modellashtirish.

INTRODUCTION

Interest in titanomagnetite deposits is growing year by year due to the development of the metallurgical industry, the increase in steel production volumes, and the rising demand for high-strength alloys. In the

industrial-scale development of such deposits, one of the most important scientific and practical challenges, along with ore extraction technology, is the disposal of large volumes of overburden and waste rock generated during mining operations.

In large open-pit titanomagnetite mines, vast quantities of overburden are extracted together with valuable minerals. In some cases, the stripping ratio may reach 2–5 m³/t or even higher. As a result, millions of cubic meters of rock are generated as waste during mining operations. The size of the areas allocated for the disposal of this rock, haulage distance, transportation costs, environmental impact, and influence on the progress of mining operations are all directly related to the overall economic efficiency of the mine.

The Tebinbulak titanomagnetite deposit is one of the largest iron ore deposits in Central Asia. The geological structure of the deposit, the wide distribution of ore bodies, its suitability for open-pit mining, and its vast reserves make this area one of the key raw material bases for the region's metallurgical industry. The main issue that arises during the development of the deposit is the selection of the most economically and environmentally optimal scheme for the disposal of large volumes of overburden.

In traditional approaches, waste rock is placed in external dumps located outside the mining area. However, in modern mining practice, the use of internal dumps, combined dumps, and progressive reclamation schemes is becoming increasingly widespread. These approaches help reduce transportation costs, ensure the rational use of land resources, and minimize environmental impact. Particularly in large open-pit mines, the use of mined-out areas for waste rock disposal provides significant economic and technological advantages.

A specific characteristic of titanomagnetite deposits is that they often consist of large, massive ore bodies and are mined by open-pit methods over a long period. At such deposits, the management of waste rock flows is closely linked not only to transport and logistics, but also to pit slope stability, the geotechnical condition of dumps, hydrogeological conditions, and environmental safety.

The primary objective of optimizing waste rock disposal schemes is to achieve maximum technological and environmental efficiency at minimum cost. This requires a comprehensive analysis of the mine's geological structure, topography, location of ore bodies, prospects for open-pit development, transport system parameters, and economic indicators [1]. During the optimization process, it is important not only to reduce haulage distances, but also to consider possible future geotechnical and environmental risks.

Preliminary analyses conducted at the Tebinbulak deposit show that the correct selection of a waste rock disposal system can significantly reduce mining costs. According to some estimates, each kilometer reduction in haulage distance may provide an economic benefit amounting to millions of dollars. For this reason, the optimization of dump management should be considered a specific object of scientific research from the earliest stages of mine design.

In mining practice, there are several basic schemes for waste rock disposal. The first is the external dump system, in which all overburden is transported to specially designated areas outside the open pit. The second is the internal dump system, in which the mined-out part of the pit is backfilled with waste rock. The third is the combined system, which involves the use of external dumps at the initial stage of mining operations, followed by a gradual transition to internal dumps. Each scheme has its own advantages and limitations, and the most optimal option is selected based on specific mining and geological conditions.

The geographical location of the Tebinbulak deposit also plays an important role in waste rock disposal. The region's dry continental climate, the risk of wind erosion, limited availability of surface water, and topographical features require special attention when developing overburden disposal projects. Improper placement of dumps may lead to increased dust levels in the area, inefficient use of land resources, and higher costs for subsequent reclamation.

Modern digital mining technologies are creating new opportunities for optimizing waste rock disposal schemes [2] (Figure 1).

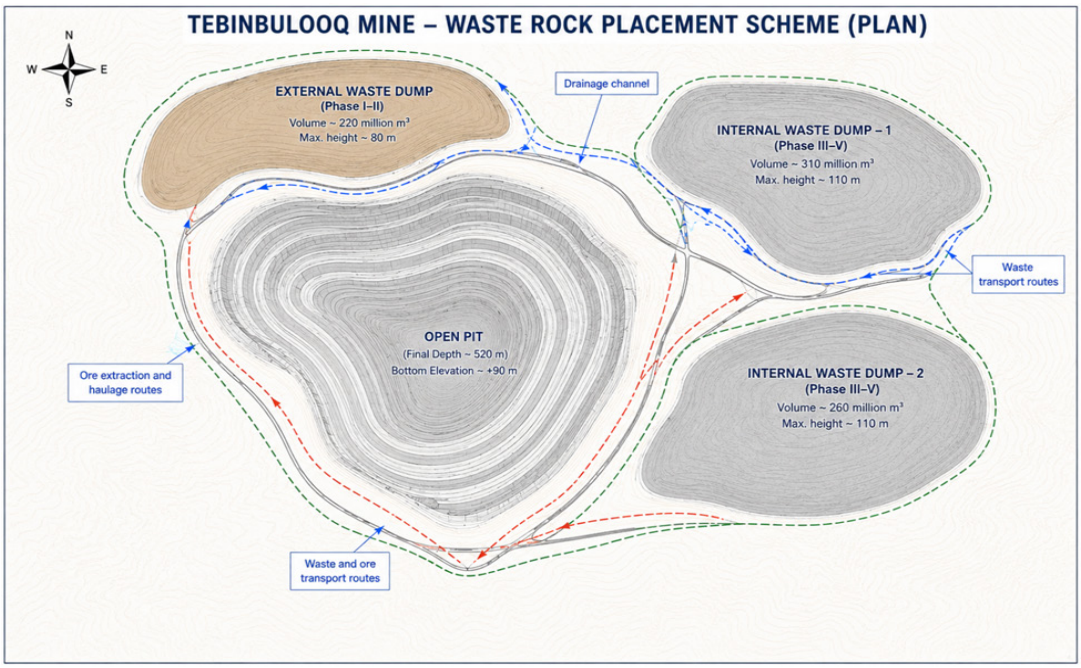

Figure 1. Waste Rock Placement Scheme of the Tebinbulak Mine

It is possible to predetermine the parameters of overburden dumps and select the most optimal options using methods of three-dimensional geological modeling, mining geoinformation systems, mining-technical simulation, and mathematical optimization. Within the framework of the sustainable development concept for mining enterprises, the utilization of waste rock is considered not only a technological task, but also an important element of environmental and social responsibility. From this perspective, conducting scientific research on optimizing waste rock placement schemes at the Tebinbulak deposit contributes to ensuring the long-term efficiency of the mine.

The research results may have practical significance not only for this deposit, but also for the development of other major titanomagnetite and iron ore deposits in Central Asia. The main objective of this study is to analyze various waste rock placement schemes at the Tebinbulak deposit from a mining perspective, evaluate their technical and economic indicators, and develop an optimal placement model. The study examines in detail transportation costs, dump capacity, geotechnical stability, environmental impact, and land reclamation possibilities.

The Tebinbulak titanomagnetite deposit, located in the Republic of Karakalpakstan, is considered one of the most promising iron ore deposits in Central Asia due to its geological structure and mineral reserves. The industrial significance of the deposit is primarily determined by the presence of titanium and vanadium components alongside large volumes of iron ore. This factor makes the deposit a strategic raw material base not only for ferrous metallurgy, but also for enterprises producing special alloys.

When developing technological schemes for the deposit, the volume of overburden and waste rock to be extracted plays as important a role as the mineral itself. Indeed, the economic efficiency of the mine largely depends on the costs of transporting and dumping these rocks [3]. As the scale of mining operations expands, the volume of waste rock also increases, and at a certain stage, the areas allocated for external dumps may become insufficient. Therefore, it is essential to study the possibility of creating internal dumps from the very initial stage of the design process.

In titanomagnetite deposits, ore bodies typically occur as thick mineralized zones. When mining such deposits, the working benches of the open-pit mine occupy large areas. As the quarry deepens, the length of the benches increases, which in turn extends the haulage distance for overburden. An increase in haulage distance leads to higher fuel consumption, increased equipment use, and a rise in overall transportation costs. From this perspective, the correct selection of the waste rock disposal scheme directly affects the overall economic efficiency of the mine.

The volume of generated overburden is typically characterized by the stripping ratio. This indicator represents the volume of waste rock per tonne or cubic meter of extracted ore. The stripping ratio is not uniform across different sections of the Tebinbulak deposit. In the initial stages of quarry development, this ratio may be relatively low; however, as the quarry deepens, the volume of overburden increases sharply. Therefore, applying

a single waste dumping scheme throughout the entire operational life of the mine is not always effective.

The composition of waste rock is also of great importance in mining practice. Some rocks consist of strong igneous materials, while others are composed of weathered and porous layers. When designing waste dumps, the physical and mechanical properties of the rocks must be taken into account [4]. While competent rock can be placed at a steeper angle of repose, unconsolidated materials require a gentler slope. Consequently, the area occupied by the dump also varies depending on the characteristics of the rock.

At the Tebinbulak deposit, the overburden may primarily consist of granite, gabbro, diorite, and metamorphic rocks. Most of these rocks possess high strength, ensuring relative stability in dumps. At the same time, the grain-size distribution and moisture content of the crushed rock significantly affect the deformation properties of the dumps. The settlement and displacement processes occurring within the dump mass require constant monitoring.

The hydrogeological conditions of the mine site are another critical factor in waste rock disposal. Despite the region's arid climate, water flows may form on dump slopes during periods of seasonal rainfall. These water flows can cause erosion of rock material and reduce slope stability. Therefore, drainage systems for dumps should be designed, and water flow management measures must be implemented.

The dynamics of quarry development is one of the primary criteria for selecting a waste rock disposal scheme. Since mining operations are conducted within a relatively limited area during the initial stages, the excavated void has not yet reached a sufficient volume to allow the formation of an internal dump. Therefore, the use of external dumps is necessary during the first stage of operation [5] (Figure 2).

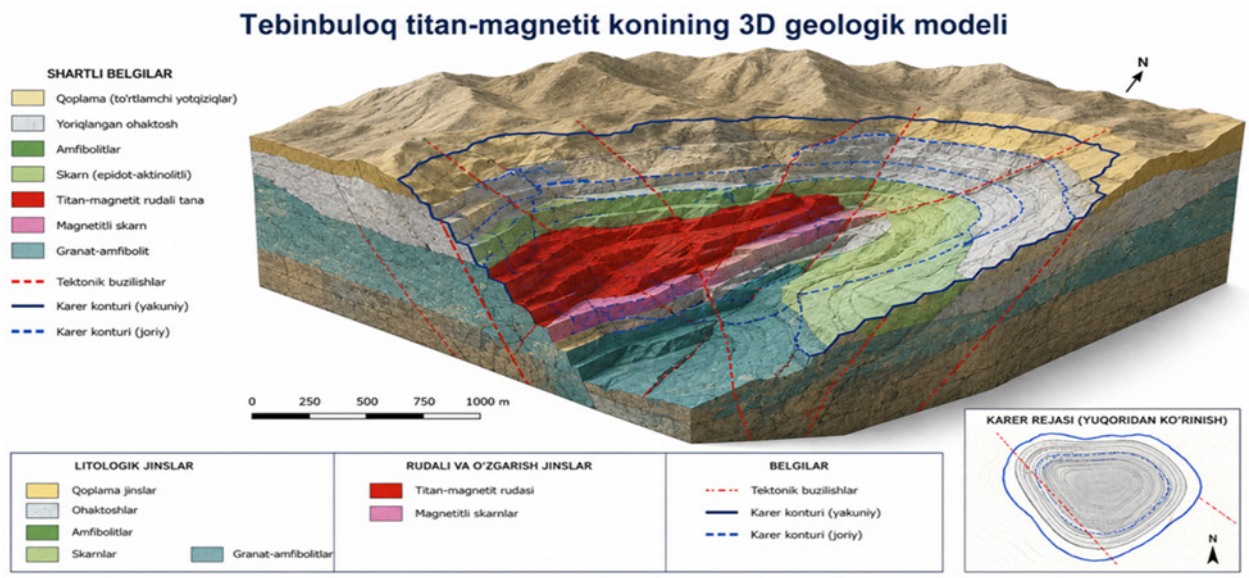

Figure 2. 3D Geological Model and Open-Pit Contours of the Tebinbulak Titanomagnetite Deposit

This, in turn, contributes to increasing operational efficiency. Furthermore, the load is optimally distributed between external and internal dumps, which helps minimize the disadvantages of both systems.

From a mining perspective, the waste rock placement scheme is analyzed based on several key criteria. Haulage distance is of particular importance in optimizing the Tebinbulak deposit. Since millions of cubic meters of rock are planned to be transported during the long-term operation of the mine, reducing the haulage distance by even one kilometer can provide a significant economic benefit. Therefore, it is advisable to introduce elements of internal dumping as early as possible.

Modern mining practice indicates that, for most large iron ore and titanomagnetite deposits, a combined scheme ensures the highest efficiency, as this approach provides flexible management at all stages of production. The geological and technological characteristics of the Tebinbulak deposit also create favorable conditions for applying this solution. As mining operations deepen, the share of internal dumps should be gradually increased. As a result, the growth of external dumps slows down, and the environmental load is reduced. At the same time, lower transportation costs increase the overall economic efficiency of the mine. This approach is also fully consistent with the principles of sustainable mining.

The analysis shows that, under the conditions of the Tebinbulak titanomagnetite deposit, the use of only external or only internal dumping schemes does not provide optimal results. The most effective solution is a combined system based on the extensive use of external dumps in the initial stages of mine development and internal dumps in subsequent stages. This system ensures an optimal balance between economic efficiency,

environmental safety, and technological sustainability.

A comparative assessment of external, internal, and combined waste rock placement schemes was conducted. Although external dumps are technologically convenient in the initial stages of production, they are characterized by high transportation costs and the occupation of large land areas. Internal dumps, by contrast, offer advantages such as reducing haulage distance, ensuring the efficient use of land resources, and facilitating reclamation processes [6]. However, it was determined that the implementation of this system during the initial stages of mine operation is not feasible.

The feasibility study showed that a combined dumping scheme is the most appropriate option for the conditions of the Tebinbulak deposit. This approach involves using external dumps in the initial stages of mine development and internal dumps in subsequent stages. As a result, transportation costs are reduced, the demand for dump areas is minimized, and the environmental performance of the mine is improved.

It was substantiated that ensuring the stability of dump slopes, improving drainage systems, and conducting regular monitoring are among the most important conditions for the long-term safe operation of dump facilities. Overall, optimizing waste rock placement schemes at the Tebinbulak titanomagnetite deposit is an important tool for increasing the economic efficiency of the mining enterprise, reducing transportation costs, minimizing environmental impact, and ensuring the rational use of land resources. The research results have scientific and practical significance for the design and operation of large titanomagnetite and iron ore deposits.

LITERATURE REVIEW

A large anomaly was detected in the Sangruntau Mountains of the Central Kyzylkum using aeromagnetic methods. However, due to the hematite-magnetite geological-industrial type of the ore, its iron content is relatively low, with an average iron grade of up to 13%. Its prospective reserves are estimated at 118 million tons. In 1968, the Tebinbulak iron ore deposit, with estimated reserves of 450 million tons, was discovered in the Sultanuvays Mountains. However, extraction operations were not carried out at that time due to the relatively low quality of the iron ore at the deposit.

According to Polatbaevich, Embergenov Allabergen, Khayitov Odiljon Gafurovich, Eshonqulov, U. Kh., and other researchers, the Tebinbulak deposit is located in the Karauzyak district of the Republic of Karakalpakstan, 75 km southeast of Nukus. The Nukus–Karatov–Turtkul railway line, currently under construction, passes 5–7 km from the deposit area. The Tebinbulak deposit has been known since 1937 and was first studied by I. S. Veskivskiy. Subsequent geological research was conducted by scientists such as G. Yu. Alfyorov, D. A. Rubanov, A. P. Agafonov, A. A. Kulesh, and K. A. Keshishyan.

The industrial significance of the deposit was recognized only after the completion of special geological and thematic studies conducted by V. V. Baranov and V. M. Kormskoy in 1966–1970, after which it was assigned to the Kashkadarya, or Ural, geological-industrial type [7]. It has been determined that the geological structure, composition, and structural complexity of the Tebinbulak deposit are of great importance for enriching the country's iron ore resource base. The main geological characteristics of this deposit, the composition of its intrusive rocks, mineralization zones, and their chemical properties play a decisive role in determining its economic potential. The geological development history of the deposit area is characterized by complex tectonic processes.

According to Dmitriev A. N., Andronova V. I., and other researchers, magmatic and metamorphic rocks are widespread in the region, and titanomagnetite mineralization was formed mainly in association with intrusive rocks. The ore bodies are relatively large and located close to the Earth's surface, creating favorable conditions for open-pit mining. At the same time, the geometric shape and depth distribution of the ore bodies require phased quarry development. As a result, large volumes of overburden are excavated during mining operations, which requires the establishment of specialized waste dump systems for their placement.

The terrain of the mine site consists mainly of low mountains and plains. This topographical feature facilitates the placement of transport infrastructure, while also requiring sufficiently large areas for external waste dumps.

RESEARCH METHODOLOGY

This article presents an analysis based on fundamental research into the management of waste rock flows as extraction volumes increase. In large mines, where tens of millions of tons of ore are planned to be extracted annually, hundreds of thousands of cubic meters of waste rock may be generated daily. Under such conditions, improper organization of dumping operations can lead to overloading of the transport system, equipment downtime, and increased production costs. Therefore, the management of waste rock flows should be considered one of the primary technological processes of the mine.

The long-term development prospects of the mine also directly influence dump design. If the operational life of a mine is planned for several decades, it is necessary to develop a strategic plan covering the entire period of operation rather than limiting the process to the temporary placement of waste rock. This approach reduces future relocation costs and ensures production continuity.

In modern mining practice, waste rock is considered not only as waste, but also as a potential technogenic resource. In some cases, overburden can be used in the production of building materials, road construction, construction of hydraulic structures, or land reclamation activities. Therefore, it is advisable to conduct an in-depth study of the mineralogical and physical properties of the overburden at the Tebinbulak deposit in order to determine its potential use as a secondary resource.

Geological modeling plays a crucial role in predicting the volume of waste rock. Three-dimensional geological models are used to determine the volume of ore bodies and overlying strata, while the annual amount of waste rock is calculated for each stage of extraction. Based on the results obtained, the required capacity of dump sites and the sequence of their development are determined. This approach makes it possible to maintain a balance between mining operations and the management of dumping activities.

Thus, the geological and mining-technical conditions of the Tebinbulak deposit make waste rock placement one of the key tasks in its development. The large volume of waste rock, long-term extraction prospects, high transportation costs, and increasingly stringent environmental requirements necessitate the development of optimized dumping schemes. The following sections provide a detailed technical and economic analysis of external, internal, and combined dumping options and justify the optimal scheme for the Tebinbulak deposit [8].

In the development of the Tebinbulak titanomagnetite deposit, the choice of a waste rock placement scheme is one of the key factors determining the economic efficiency, technological continuity, and environmental safety of the mine. In large open-pit mines, the volume of overburden may be several times greater than the volume of ore itself. Therefore, determining where, how, and in what sequence the extracted rock should be placed is an integral part of mine planning.

In modern mining practice, three main models of waste rock placement are used: external dumping, internal dumping, and combined dumping systems. Each option has its own specific technical, economic, and environmental advantages and limitations. An in-depth analysis of these options, using the Tebinbulak mine as an example, makes it possible to select the most optimal solution.

The external dumping scheme is one of the most widely used methods in mining practice. According to this scheme, all waste rock extracted from the pit is transported to specially designated dump sites located outside the mine boundaries. The main advantage of this method is the simplicity of its organization during the initial stages of production. Since the open-pit mine is not yet deep enough, it is not possible to create an internal dump; therefore, an external dump becomes the only feasible technological solution. Furthermore, external dumps do not interfere with technological processes within the open pit and allow mining operations to proceed without obstruction.

However, the external dumping system also has several limitations. First and foremost, it requires the transportation of overburden over long distances. As the open-pit mine deepens, the haulage distance increases, resulting in higher fuel consumption, greater equipment wear, and increased transportation costs. In some cases, the cost of transporting overburden can account for up to one-third of the total cost of mining operations [9].

ANALYSIS AND RESULTS

Discussions and analytical results show that, in the operation of mining enterprises, external dumps occupy large land areas compared to the extraction process, and additional funds are required for their subsequent reclamation. In large-scale sites such as the Tebinbulak mine, the area occupied by external dumps can reach hundreds of hectares, which reduces the efficiency of land resource use.

Geotechnical risks also increase as dump height increases. In particular, excessive pressure at the base of the dump can lead to deformation and a loss of slope stability. Therefore, geomechanical calculations are of critical importance when designing external dumps.

The internal dumping method is recognized as one of the most economically efficient approaches in modern mining practice. In this method, overburden is placed in the excavated part of the open-pit mine. As a result, haulage distance is significantly reduced, and transportation costs are lowered. After a specific section of the open pit has been excavated, the resulting void is gradually filled with overburden rock.

This approach not only increases economic efficiency but also substantially reduces the need for external dumps. Another significant advantage of internal dumping is its reduced environmental impact, as new land areas are not occupied and reclamation work can be carried out more easily after mining operations are completed. With internal dumping, part of the open-pit area can be reclaimed during the extraction process

itself.

In the case of the Tebinbulak mine, an internal dumping scheme can be particularly effective during the middle and final stages of mine development. As the open-pit mine deepens, a large void is formed, creating an opportunity to use these areas for overburden placement. Preliminary calculations indicate that the use of internal dumps can significantly reduce transportation costs.

Based on the analytical results, the combined dumping scheme is considered one of the most optimal options for mining enterprises. This method combines the advantages of both external and internal dumping. In the initial stages of excavation, overburden is placed in external dumps. Once a sufficient void has been created in the open-pit mine, the main flow of overburden rock is directed to internal dumps. As a result, the volume of external dumps is limited, and overall transportation costs are reduced.

It has been established that the main advantage of the combined scheme is its flexibility, which allows the most appropriate dumping option to be applied at each stage of mine development (Table 1).

Table 1

Comparative Assessment of Waste Rock Dumping Schemes in Open-Pit Mining

Formation of Dumps in Open-Pit Mines	**Mining and Transportation Efficiency Coefficient of the Deposit (%)**	**Main Processes in Mineral Exploitation**
External Waste Dump	60–65%	Lower efficiency due to longer haulage distances, higher transportation costs, and greater land occupation requirements.
Internal Waste Dump	80–88%	Higher efficiency due to reduced haulage distances, lower operating costs, and improved opportunities for land reclamation.
Combined Waste Dump	90–95%	The most suitable option for the Tebinbulak titanomagnetite deposit, providing the optimal balance between economic performance, environmental protection, and operational flexibility.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, it was determined that waste rock placement during the development of the Tebinbulak titanomagnetite deposit is one of the key factors influencing the technological efficiency of the mine. The conducted analyses show that a very large volume of overburden and waste rock is generated during the long-term operation of the deposit. Therefore, the proper selection of a waste rock placement system has a significant impact on the total production costs of the mine and its level of environmental safety.

During the research, the geological structure of the Tebinbulak deposit, the location of ore bodies, the stages of mine development, and the characteristics of transport systems were studied. The analysis substantiated the necessity of using external dumps during the initial stages of mine development due to the limited possibility of creating internal dumps at that stage. At the same time, it was determined that as the open-pit mine deepens and the volume of mined-out areas increases, the transition to an internal dumping system becomes more economically advantageous.

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