ГЕОТЕХНОЛОГИЯ. ГОРНЫЕ МАШИНЫ

DOI: 10.21440/0536-1028-2025-3-8-15

Assessing the economic efficiency of using combined pillars when mining near-edge ore reserves

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Abstract

The research objective *is to carry out an economic comparison of possible methods of near-edge ore reserves mining to select the most profitable one.*

The methodology *for selecting the optimal technology for near-edge reserves extraction is based on selecting the best possible mining method. There are two main classes of mining methods for near-edge reserves, and the choice depends on a number of factors, the main ones being technological and economic. Technological factors include geological, mining and geomechanical conditions of extraction. Economic factors include ore content, value, and production cost. Technologically, it is possible to apply both classes of mining methods, however in order to select a more efficient option, an economic assessment is required.*

Research results. *By the example of the mining method applied to the near-edge part of an ore pillar at the Molodezhnoe deposit, the article considers the process of economical assessment and selection of an efficient technology. Such an assessment made it possible to change the initially designed method of near-edge reserves mining and develop the site's reserves fully.*

Conclusions. *Taking into account such factors as the content of useful components in the ore, the current price of metals and the production cost, allows for choosing a more efficient mining method in cases where technological options are equivalent.*

Research relevance. *The methodology presented in the article allows for choosing the most efficient method of mining near-edge reserves and takes into account ore content, value, and production cost.*

Keywords: *near-edge reserves; combined pillar; economic comparison; mining method.*

Introduction. When carrying out final extraction of near-edge reserves at deposits developed by combined technology, it is essential to create effective and safe process flow schemes for reserves located in the near-edge and bottom parts of the open pit [1–11]. Such process flow schemes should be based on the principles of an optimal combination of flow processes, economically optimal mining methods and safe conditions for ore extraction.

As a rule, the development of near-edge and bottom reserves requires a special technology for ore extraction which usually differs from the standard technologies adopted in mines. The technology is to take into account a number of conditions, such as the safety of mining, the economic efficiency of extraction and the minimum possible indicators of ore loss and dilution.

Methods of research. According to professor V. N. Kalmykov's classification [12, 13] of 1992, there are two main classes of mining methods for near-edge reserves. Class 1 is a mining method with pit's undermined edges caving; class 2 is a mining method with pit's undermined edges preservation. In class 1, the method of managing the open pit

edges is based on either their artificial caving or natural spontaneous caving. Here, the main mining methods are level, sublevel and layer caving, as well as chamber methods with subsequent pillar recovery. In class 2, the method of managing the open pit edges is based on leaving pillars (barrier, inter-chamber, crown), backfilling voids and goaf under the pillars with hardening or bulk mixtures. Main mining methods for class 2 are chamber methods with remnant pillars, as well as chamber and layer methods with backfilling.

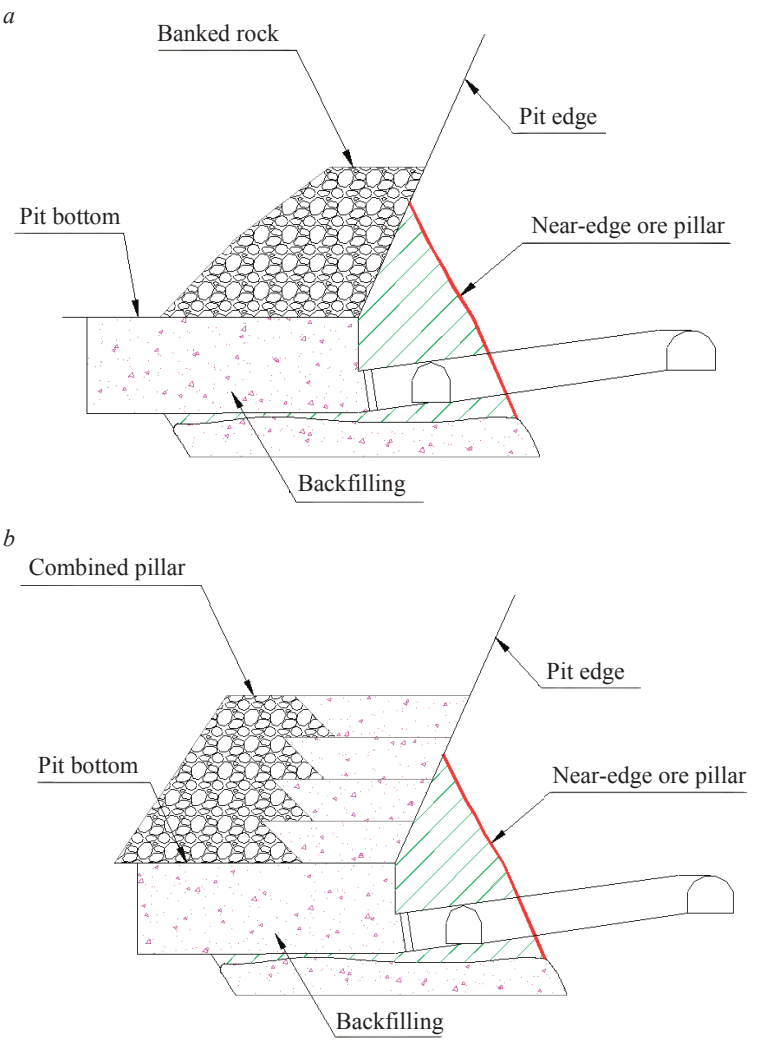

Figure 1. The general design of a pit edge loading with a banked rock – *a*, an option with forming a combined pillar along the pit edge – *b*

Рисунок 1. Проектный вариант пригрузки борта карьера породной насыпью – *a*, вариант формирования вдоль борта карьера комбинированного целика – *b*

There are two main classes of mining methods for near-edge reserves, and the choice depends on a number of factors, the main ones being technological and economic. Technological factors include geological, mining and geomechanical conditions of extraction. Economic factors include ore content, value, and production cost.

At the initial stage, the technological feasibility of extracting the considered section of near-edge reserves using one of the classes is to be assessed. This chiefly applies to the technical feasibility of caving a section of the pit edge in case of using class 1 mining method for near-edge reserves, or to the technical feasibility of leaving an ore (rock) pillar or forming an artificial pillar in case of using class 2 mining method for near-edge reserves. In many cases, it is impossible to consider class 1 mining methods as options due to the need to keep a section of the pit edge in a stable state. At the same time, the location or configuration of the near-edge reserves section may not allow for class 2 mining methods.

Table 1. High-level assessment of selecting a class of a mining method
Таблица 1. Укрупненная оценка выбора класса систем разработки

Indicator	Class of a mining method	
	with backfilling	with caving
Commercial resources, th. tonnes	332.00	332.00
Average content of copper in the commercial resources, %	3.10	3.10
Average content of zinc in the commercial resources, %	4.29	4.29
Average content of conventional zinc in the commercial resources, %	14.55	14.55
Ore losses, %	5.0	18.0
Ore dilution, %	11.0	21.0
Ore losses, th. tonnes	16.6	59.8
Diluting rocks admixture, th. tonnes	34.7	57.2
Ore mass production, th. tonnes (ignoring humidity)	350.1	329.4
Content of conventional zinc in the mined ore mass, %	13.1	12.0
Costs for the formation of a combined pillar in the pit edge, mln rubles	187.2	0.0
Ore production costs, rubles per tonne	2850.0	2280.0
Costs for ore mass production, mln rubles	1185.0	751.1
Processing cost price, rubles per tonne	877.0	877.0
Expenditures on processing, mln rubles	307.0	288.9
Recovery of a conventional zinc into a concentrate, % (calculated as a weighed mean for the components of ore at a deposit)	75.8	75.8
Content of conventional zinc in the concentrate, %	50.0	50.0
Production of conventional zinc in the concentrate, th. tonnes	34.8	30.0
Cost of zinc in concentrate, mln rubles per tonne (calculated as 48% from the market cost of zinc)	0.124	0.124
Cost of conventional zinc in the concentrate, mln rubles	4310.1	3720.3
Gain on disposal of concentrate, mln rubles	2818.1	2680.3
Delta, mln rubles	137.7	0.0

In cases when there are no technological restrictions on the use of either class 1 or class 2 mining methods, the economic component becomes the decisive factor in choosing the mining method.

When choosing a class of methods from an economic point of view, on the one hand, the ore value plays an important role – the more valuable the ore, the lower loss and dilution rates must be achieved for a fuller extraction of reserves. This condition is primarily ensured by class 2 mining methods with hardening backfill: chamber and layer methods with either a rock or artificial pillar separating mining operations and the open-pit space. Most commonly, chamber methods with ore pillars have higher loss and

dilution values. On the other hand, backfill methods increase the production cost, which can play a decisive role when mining less valuable ores. With a lower cost of mined ores, class 1 mining methods can become more cost-effective, namely floor, sub-floor and layer caving methods, as well as chamber methods with subsequent pillar recovery.

The results of pilot survey carried out during the development of near-edge reserves in the eastern edge of an open pit at the Molodezhnoe deposit can provide an example of economic assessment to choose the optimal mining method for near-edge reserves.

In accordance with the general design for the final extraction of reserves by the underground method, in order to separate underground operations and the open pit at this deposit, a separating pillar was left at the pit edge. The horizontal thickness of the near-edge section of the ore pillar varied from 40 m at the base to a wedge at the pit edge. The total length of the section from south to north along the eastern pit edge was about 135 m.

According to the general design, the reserves of the separating ore pillar were supposed to be extracted at the final stage of the deposit development by underground mining using a sublevel caving method and obligatory preliminary loading of the developed reserves with overburden rock (class 1 according to V. N. Kalmykov's classification, Figure 1, *a*).

As ore fields are reducing significantly, in order to ensure the planned annual productivity of ore extraction at the deposit, the need has arisen to resolve the problem of developing the reserves of the separating ore pillar at an earlier stage. As an alternative to design solutions, AO Uralmekhanobr institute [14–16] proposed a technology for extracting reserves based on the preliminary creation of a combined pillar along the ore part of the pit edge, which would allow to develop near-edge reserves using a room-and-pillar mining method with backfilling (class 2 according to V. N. Kalmykov's classification, Figure 1, *b*).

The two options were economically compared to select the most effective mining method for near-edge reserves. Gain on disposal of concentrate from the ore mined at the site was the main criterion for comparison. The calculation took into account the content of only two main components: zinc and copper. Other commercial components in the ore (gold, silver, etc.) were not taken into account to simplify the calculation. The calculation took into account the extraction rates for mining methods and the costs of forming a combined pillar part made of hardening backfill, for the option of near-edge reserves extraction using a mining method with backfilling.

Research results. Based on the comparison, it was decided to abandon the design option of the caving method due to the high value of the ore and increased losses and dilution in favor of the technology for extracting reserves based on the preliminary creation of a combined pillar along the ore part of the pit edge, which would allow to develop edge reserves using a room-and-pillar mining with hardening backfilling.

Analysis of Table 1 showed that the following factors have a significant impact on the choice of a mining method, all other conditions being equal: the price of metal, reserves and content of commercial components in the ore, and production cost, including the cost of backfilling operations during the construction of a combined pillar. Any changes in any of these factors can change the preferred extraction scheme.

Based on the data presented in Table 1, a graph (Figure 2, *a*) was constructed. The graph shows the dependence between the final gain on disposal of concentrate in accordance with the selected mining method and the metal price behavior.

Thus, with other input data being unchanged (content of commercial components, production costs, etc.), both technologies can be equally applied for the area under

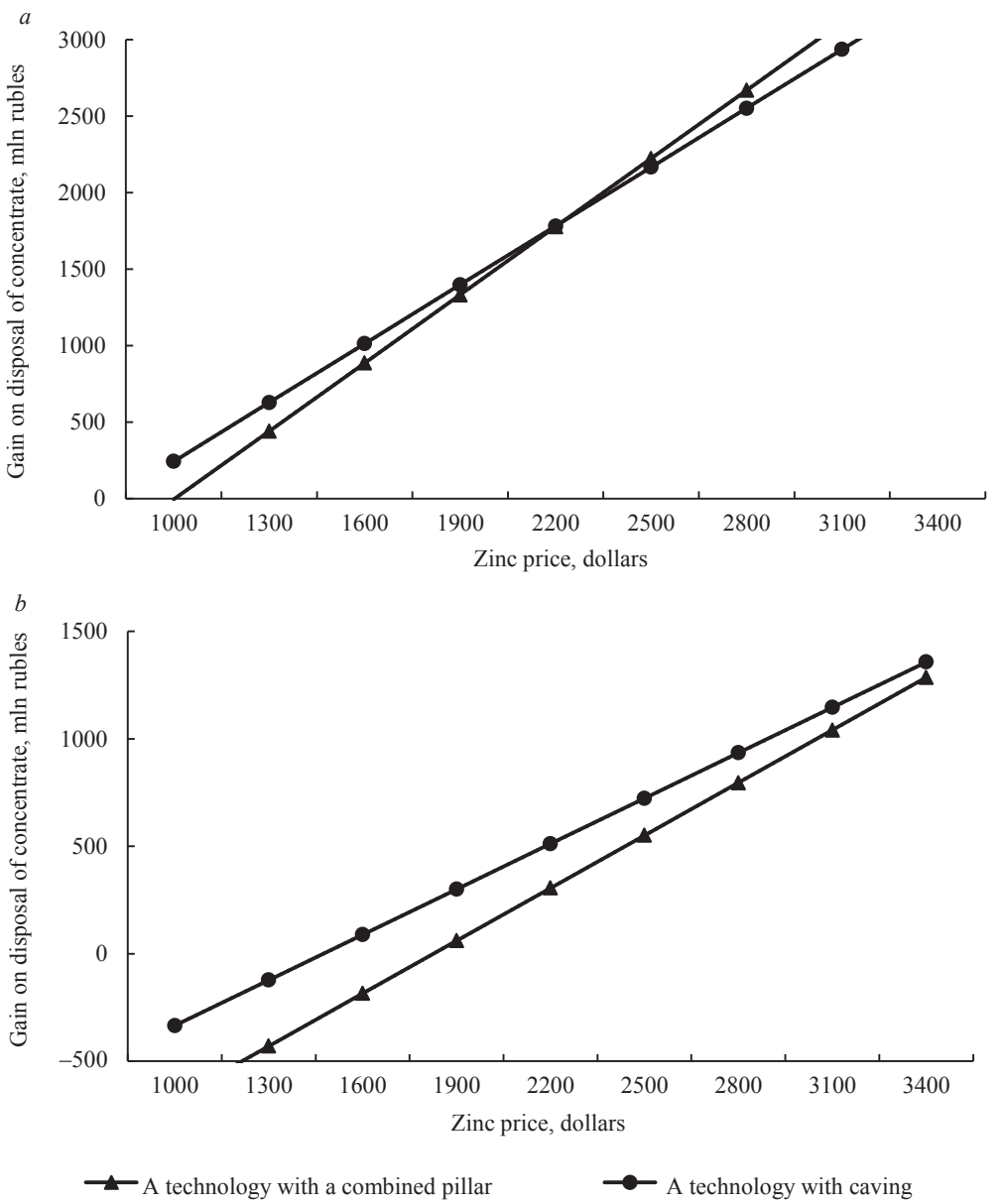

Figure 2. A graph of dependence between the final gain on disposal of concentrate in accordance with the selected mining method and the metal price behavior: under the content of a conventional Zn 12.45 % – *a*; Zn 8.0 % – *b*

Рисунок 2. График зависимости итоговой прибыли от реализации концентрата в соответствии с выбранной технологией и изменения цены металла: при содержании условного Zn 12,45 % – *a*; Zn 8,0 % – *b*

consideration under a zinc price of 2,200 dollars per a tonne. The content of commercial components in the ore, along with the metal price, seriously affects the choice of the optimal technology. In case the content of commercial components in the mined ore decreases, the combined pillar mining method becomes possible only if the metal price is increased, otherwise the caving methods become more economically advantageous when extracting near-edge ore reserves.

A graph in Figure 2, *b* shows that when the average content of the commercial component (conventional zinc) decreases to 8% over the entire accepted price range and up to the zinc price of $3,400, the caving mining methods are more cost-effective despite higher rates of losses and dilution. In this case, the break-even point for the method with a combined pillar is at the zinc price of $1,800. For the caving method, the break-even point is at the zinc price of $1,450.

The choice of a mining method is largely affected by the increased costs of constructing a combined pillar, which in turn increases the cost of mining the near-edge reserves, and makes this option uncompetitive under a low metal price.

Conclusions and application. When choosing an effective mining method for near-edge reserves, not only technical aspects are to be considered. It is also important to take into account the economic aspect, including such parameters as the market cost of the mined metal, its content in the ore, extraction rates in the compared options of mining methods, as well as the production cost. This will allow for the most efficient development of reserves and increase the possible economic effect.

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Received 25 July 2024

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УДК 622.343:446 DOI: 10.21440/0536-1028-2025-3-8-15

Оценка экономической эффективности применения комбинированных целиков при отработке прибортовых запасов руды

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Реферат

Цель работы *заключается в экономическом сравнении возможных технологий отработки прибортовых запасов руды для выбора наиболее эффективной с точки зрения получения прибыли.*

Методология *выбора оптимальной технологии выемки приконтурных запасов заключается в определении оптимальной системы разработки. Существуют два основных класса отработки приконтурных запасов. Выбор того или иного класса зависит от факторов, основными из которых являются технологические и экономические. К технологическим факторам относятся горно-геологические, горнотехнические и геомеханические условия выемки. К основным экономическим факторам – содержание и ценность руды, а также себестоимость ее добычи. Если с технологической точки зрения возможно применение обоих классов систем отработки, то для окончательного выбора более эффективного варианта необходимо выполнить экономическую оценку.*

Результаты исследования. *В статье на примере отработки прибортовой части рудного целика на месторождении Молодежное рассмотрен процесс экономической оценки и выбора эффективной технологии отработки запасов. Благодаря такой оценке стало возможным изменение изначально заложенной в проекте технологии выемки приконтурных запасов, что позволило более полно отработать запасы участка.*

Выводы. *Учет содержания полезных компонентов в руде, текущей цены на металлы и себестоимости добычи позволяет выбрать более эффективную технологию отработки запасов в случае, когда технологически варианты могут быть равноценны.*

Актуальность исследования. *Приведенная в статье методика позволяет определить наиболее эффективную технологию выемки приконтурных запасов с учетом оценки содержания и ценности руды, а также себестоимости ее добычи.*

Ключевые слова: *приконтурные запасы; прибортовые запасы; комбинированный целик; экономическое сравнение; технология отработки.*

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Поступила в редакцию 25 июля 2024 года

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Для цитирования: Танков М. С. Оценка экономической эффективности применения комбинированных целиков при отработке прибортовых запасов руды // Известия вузов. Горный журнал. 2025. № 3. С. 8–15 (In Eng.). DOI: 10.21440/0536-1028-2025-3-8-15

For citation: Tankov M. S. Assessing the economic efficiency of using combined pillars when mining near-edge ore reserves. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = Minerals and Mining Engineering.* 2025; 3: 8–15. DOI: 10.21440/0536-1028-2025-3-8-15