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Determination of Loss and Division of Gold-containing Ores of the Vasylkovskoe Deposit

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Abstract. *Modern large-scale mineral extraction demands a responsible approach to subsoil resources, prioritizing the minimization of ore losses and dilution. High loss levels typically occur at the contact zones between ore bodies and host rock due to discrepancies between mining contours and geological boundaries. This article addresses the standardization of losses and dilution specifically within these near-contact developments. The research proposes a specialized method for calculating standard values within stochastic zones. Investigations established a direct correlation between the geometric form of the contact and the resulting levels of ore loss and dilution. By applying the methodology developed in this study, mining operations can determine standard loss values at contacts with greater simplicity and reliability. This approach provides a scientific basis for enhancing the economic efficiency and sustainability of the mining complex.*

Keywords: *calculation, contact zone, standards, losses, dilution, ore, profit.*

Introduction

The development of the mining industry in Kazakhstan under conditions of resource depletion and increasingly complex geological and technological environments has brought the problem of losses and dilution of ore to the forefront of research and practice. In gold mining, these factors have a decisive influence on the efficiency of resource utilization, the cost of production, and the recovery rate of valuable metals. The Vasylkovskoye gold deposit, one of the largest in Kazakhstan, exemplifies these challenges due to its complex geological structure, irregular distribution of gold grades, and the difficulty of delineating ore boundaries with high accuracy. In such conditions, the issues of minimizing ore losses and dilution are not only of academic interest but also of significant strategic importance for improving the overall efficiency of the industry.

The relevance of this topic is confirmed by numerous studies conducted both in Kazakhstan and abroad. For example, Imashev et al. (2022) emphasize the critical impact of geological and technological factors on ore dilution during the development of steeply dipping, low-thickness deposits using sublevel drifts, highlighting the need for predictive assessment methods [1]. Similarly, Batugina et al. (2021) showed that the ratio of mined mass per unit of metal plays a decisive role in the efficiency of developing placer gold deposits, underscoring the importance of optimizing technological parameters to reduce losses. These works demonstrate that both hidden and explicit forms of ore losses and dilution directly determine the economic feasibility of mining operations.

In global practice, various approaches have been proposed to address these issues. Fomin and Lelen (2024) proposed the refinement of methods for determining ore losses in deposits of cement raw materials mined by layer-by-layer milling machines, showing that technological specificity plays a crucial role in accurate calculations [2]. Istomina and Khatashkeev (2021), analyzing gold content determination methods at the «Nevsky» plant, identified the limitations of current laboratory techniques in reflecting real enrichment efficiency [3]. A number of foreign and Russian researchers also propose different methodological solutions. Kantemirov et al. (2020) highlighted the need for advanced methods of accounting for high ore losses and dilution, stressing that ignoring these effects leads to systematic underestima-

tion of resource potential [4]. Fomin and Chan Dinh Bao (2016) considered optimization of ore losses and dilution during open-pit mining of complex carbonate deposits, while Lapshin (2016) systematized approaches to reducing losses and dilution during the extraction of ore bodies. Kushnarev (2017) focused on hidden losses, which are often underestimated at the design stage but have a substantial effect on the final recovery rate.

Moldabayev et al. (2020) applied stochastic modeling of rock property variation, showing its importance for the design of excavation processes under uncertainty [5].

Ore losses and dilution remain a critical issue for the Vasilkovskoye deposit due to irregular gold distribution, variable ore quality, difficulties in operational ore control, and the need for selective mining. This study aims to analyze ore losses and dilution at the Vasilkovskoye gold deposit and to develop recommendations for their reduction through the systematization of existing assessment methods, identification of key geological and technological factors affecting ore quality, application of advanced modeling approaches for predicting losses and dilution, and development of practical measures to minimize their impact during open-pit mining.

Materials and Methods

The research methodology was designed as an integrated, multicomponent system that combines geotechnical monitoring, numerical modeling, blasting optimization, and mineral processing analysis into a unified framework for spatial and technological investigation. This study is built upon a comprehensive foundation of primary geological data and specialized technical reports from the Vasylkivske gold deposit. Specifically, baseline indicators for ore grades and volumes were integrated from the «Report on Mineral Resources and Mineral Reserves», prepared in accordance with international KAZRC standards by Orient Exploration Team LLP in 2022. Furthermore, industrial safety parameters and quarry ventilation design solutions were verified based on the «Supplement to the Approved Project for Industrial Development», developed by KazTechProject Engineering LLP in 2020. The initial stage of the study involved active georadar monitoring using the IDS GeoRadar system, which enabled the identification of active deformation zones, tracking of displacement dynamics, and localization of potentially hazardous areas within the rock mass. This real-time analytical data served as the basis for assessing pit slope stability under the dynamic conditions of ongoing mining operations. In parallel with the monitoring efforts, geomechanical modeling was conducted to analyze fracture networks and determine fracture density using specialized DIPS and RS2 software. This stage ensured high precision in calculating stability parameters within complex geological environments and provided the justification for an optimal pit slope angle of 45°, which leads to a significant reduction in overburden volumes.

Numerical simulations of drilling and blasting operations were performed in the ShotPlus Premier environment, with a focus on optimizing borehole grids, charge parameters, and initiation sequences. The results of these simulations allowed for the forecasting of the granulometric composition of the blasted rock mass, which was subsequently compared with both industry standards and in-situ analytical data collected directly at the deposit. The final stage involved a comparative techno-economic analysis of various blasting schemes and contour blasting parameters. The findings confirmed that the application of rational blasting technologies not only improves rock fragmentation quality but also reduces downstream processing costs, thereby increasing overall mining efficiency. Collectively, the integration of field data, standardized KAZRC reporting, and numerical validation forms a comprehensive approach to ensuring safety and economic efficiency in large-scale open-pit mining operations.

The research methodology was designed as an integrated and multicomponent system, combining geotechnical monitoring, numerical modeling, blasting optimization, and mineral processing analysis into a coherent framework of spatial and technological investigation. The first component of the study involved georadar monitoring using the IDS GeoRadar system, which enabled the detection of zones of active deformation, the tracking of displacement dynamics, and the localization of potentially hazardous areas within the rock mass of the Vasylkivske gold deposit. This stage was crucial in establishing the baseline conditions for subsequent modeling and served as a foundation for assessing slope stability under dynamic mining conditions.

Results

Structural and Geological Conditions of Ore Body Occurrence

The Vasylkivske deposit is confined to the southwestern flank of the Dongulagash and Vasylkovo-Berezov regional faults, developed within the Altybai synclinal structure. The host rocks are represented by the effusive formations of the Daubai suite of andesite-basalt composition and the sedimentary rocks of the Bukon suite. The ore bodies are mainly localized within the intersection zone of the Dongulagash fault with northeast-trending faults and are associated with the contact of the Upper

Ordovician granitoid intrusion with the enclosing Precambrian formations.

The geological cross-section is characterized by a complex structure including volcanic and terrigenous strata, which indicates the continuation of effusive activity during the Nomurian period simultaneously with sediment accumulation. The lower horizon of bituminous hybrid lavas, previously interpreted as a tectonic breccia zone enriched with carbonaceous matter, plays a key role in the localization of ore bodies. The boundary of the Bukon suite can be traced along the base of this lava package, clearly defined in contact with the Daubai suite effusives, which facilitates mapping in the field.

The structural control of mineralization is determined by a system of major regional faults, well identified through magnetometric surveys. These faults are complicated by numerous secondary dislocations accompanied by zones of fracturing and cataclasis. The most intensive development of higher-order disruptions occurs within the block bounded by major tectonic elements, where the highest concentration of ore bodies is observed. In the southwestern part of the ore field, these zones are separated, whereas in the northeastern direction they converge to form powerful tectonic nodes favorable for ore deposition (Figure 1).

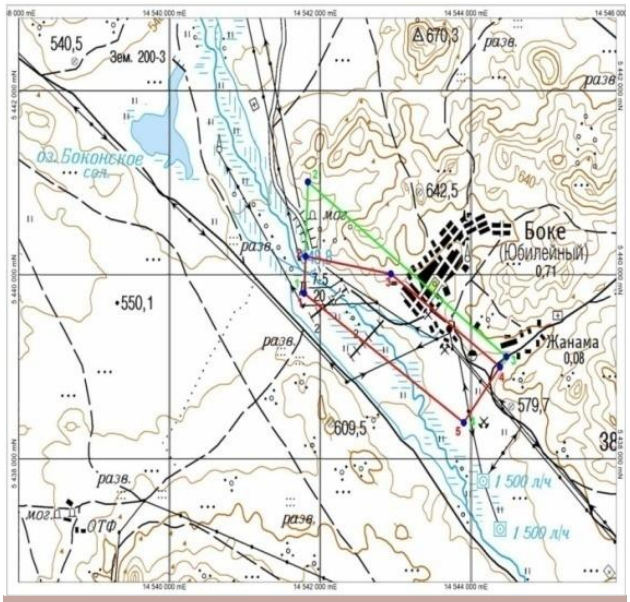

Figure 1 – Overview diagram of the Vasilkovskoye deposit

For the study, the Vasilkovskoye deposit was divided into blocks. Each block has dimensions of 20x20 meters in plan and 15 meters vertically (6,000 m³), or approximately 16,000 tonnes of ore per block. The C1 category reserves in the Vasilkov open pit constitute about 83-84% of the total ore and gold volume in the pit. According to the classification within the pit, the (C1+C2) reserves make up about 70%, with the remaining portion classified as inferred resources.

The deposit reserves are calculated using a block modeling method with geostatistics through the specialized Micromine (MM) software. As of January 1, 2023, balance reserves have been determined. It is also necessary to take into account the estimated off-balance ore reserves:For open-pit mining (C1+C2 categories): Ore – 38,296.3 thousand tonnes Gold – 24,505.2 kg (0.64 g/t). For underground mining (C1+C2 categories): Ore – 30,092.9 thousand tonnes, Gold – 49,952.3 kg (1.66 g/t). To determine losses and ore dilution, ore contours were established. The gold-grade ore contour of the Vasilkovskoye deposit was defined using the Rocscience software.

Standard operating cost indicators, including excavation, loading, transportation, and blasting, were used to determine and normalize ore losses and dilution based on statistical data, industry guidelines, and the project's economic parameters. The calculations were performed using a discretized matrix geological model with block dimensions of 2×2×2 m, ensuring high accuracy in outlining ore bodies. If necessary, the model allows subdivision into 1×1×1 m sub-blocks while preserving the calculation algorithm. Variations in loss and dilution parameters significantly affect mining volumes and the average grade of valuable components in the ore. During open-pit mining of the Vasilkovskoye deposit, the main regulated losses and dilution occur in peripheral zones and at contacts between ore and barren rocks exceeding 10 m in thickness.

Figure 2 presents the schematic of the Vasilkovskoye open pit developed using the Rocscience software.The geotechnical block model plays a key role insolving a number of critically important engineering tasks, as it enables:

- forecasting the degree of ore dilution while taking into account the geomechanical conditions of the deposit;
- reliably determining the maximum allowable parameters of stoping chambers and support pillars to ensure rock mass stability;
- calculating the optimal parameters of cable bolting to maintain the stability of the hanging and footwalls of stoping excavations;
- developing scientifically justified drilling and blasting parameters aimed at reducing the seismic impact of explosive loads on the host rocks under the geotechnical conditions of the Vasilkovskoye deposit.

Figure 3 – During the research years, all the results of geological exploration and oper-

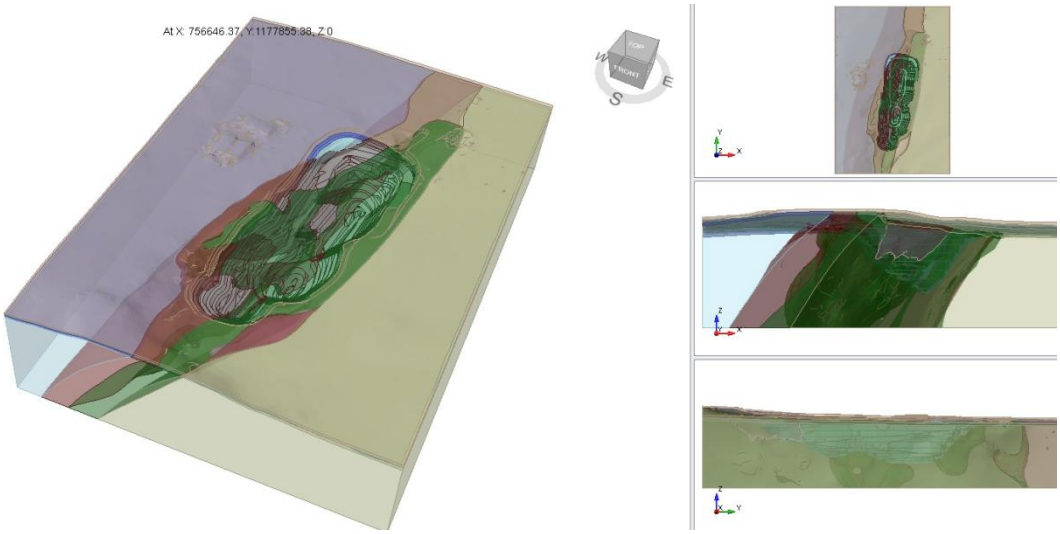

Figure 2 – Schematic of the Vasilkovskoye deposit in the Rocscience software

ational exploration works drilled in the period from 2021 to 2024 were obtained, on the basis of which the resource model of gold-bearing deposits was updated, which led to a change in the contours of ore bodies.

The geomechanical models developed using the software, based on refined data on the physical and mechanical properties of the rock masses, make it possible to:

- increase the reliability of simulated geomechanical processes;
- timely identify zones of elevated rock pressure;
- assess the impact of stoping excavations on adjacent development and main mine workings.

The chart illustrates changes in ore loss, dilution, and profit at the Vasilkovskoe gold deposit during the period 2021-2024 (Figure 4). In 2021, ore losses reached their maximum value of 30%, while dilution was 20% and profit remained at a minimum of 10%. In 2022, both ore loss and profit decreased to 20%, while dilution dropped to 10%, indicating improved mining control. In 2023, ore losses fell to 10% and dilution to 8%, while profit significantly increased to 24%, reflecting higher efficiency in mining and processing. In 2024, ore losses (5%) and dilution (2.8%) were reduced to a minimum, while profit reached its maximum value of 26%.

The results demonstrate a clear trend of decreasing ore losses and dilution, accompanied by an increase in profit. This confirms the effectiveness of implementing advanced monitoring methods, geomechanical modeling, and optimization of blasting parameters, which directly contributed to improving the economic performance of gold mining at the

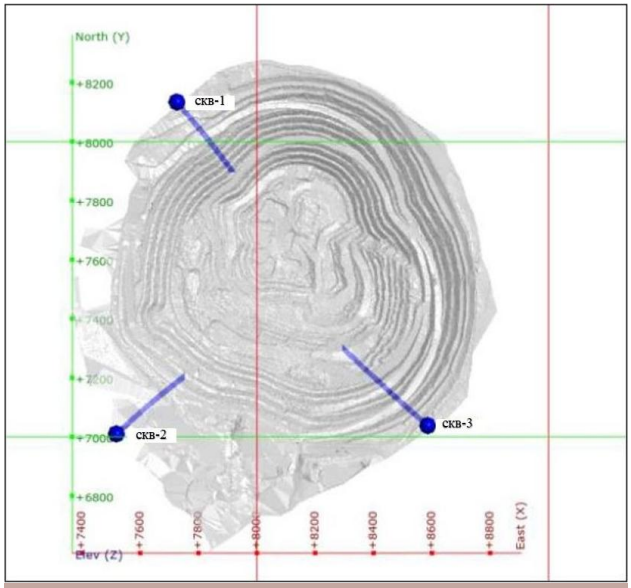

Figure 3 – Geological exploration and operational exploration works of the Vasilkovskoye deposit

Vasilkovskoe deposit. Geomechanical models developed using software based on refined data on the physical and mechanical properties of rock massifs, changes in loss, dilution of gold-bearing ores depending on the period under study.

Conclusions

The objective of this study was to develop a comprehensive methodological approach for assessing the impact of engineering and technological factors on the value chain from mining to processing under conditions of open-pit gold mining. A multi-level methodology was

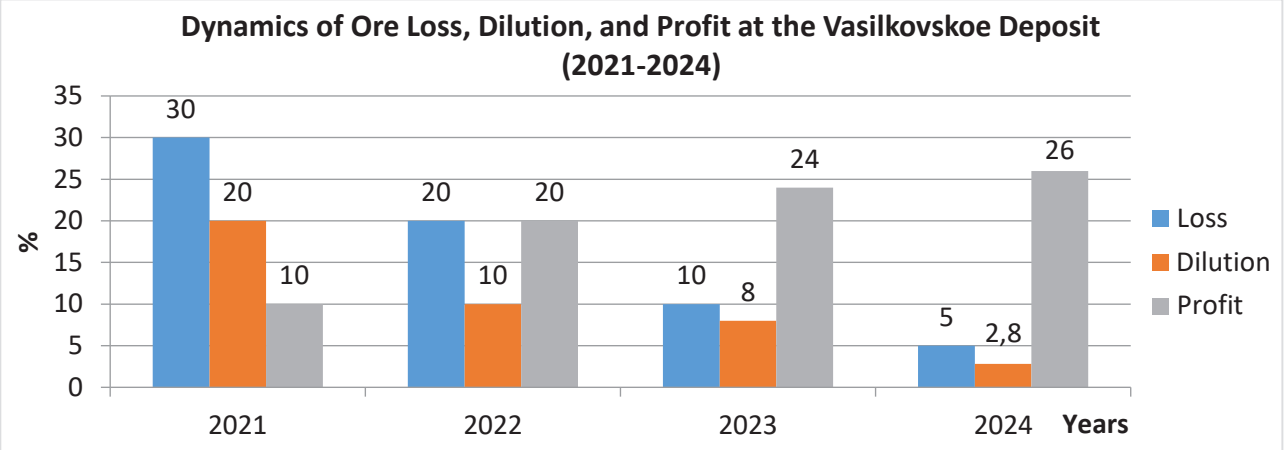

Figure 4 – Change in loss, ore dilution and profit of Vasilkovskoe gold-bearing ore by years

implemented, integrating ground-penetrating radar (GPR) monitoring, geomechanical and numerical modeling, optimization of blasting parameters, and subsequent verification against actual production indicators.

Numerical modeling of the rock mass using the finite element method enabled a predictive assessment of ore dilution during the development of cleaning chambers. Comparison of the calculated data with actual production results demonstrated that the real values of ore loss and dilution significantly exceeded the predicted ones. This discrepancy highlights the critical influence of man-made factors – such as drilling accuracy, blasting parameters, and operational control on the stability of the host rock mass and the overall efficiency of mining operations.

A comparative techno-economic analysis of alternative blasting schemes confirmed that the selection of rational types of explosives and optimization of contour drilling parameters not only improves fragmentation quality but also substantially reduces processing costs.

Overall, the study of gold-bearing ores allowed the following objectives to be achieved: methodological recommendations were developed for assessing the impact of ore loss and dilution indicators on the value chain from extraction to processing, with an emphasis on predictive modeling and the integration of real-time monitoring systems. The proposed methodological approaches were implemented and validated under the conditions of the Vasilkovskoe gold deposit, which confirmed their applicability for optimizing mining operations and enhancing the economic efficiency of ore processing.

The results of this research demonstrate that the combination of predictive modeling, GPR monitoring, and optimization of technological processes forms an effective system for managing ore losses and dilution. This comprehensive approach establishes both a scientific and practical foundation for improving design reliability, ensuring mining stability, and maximizing the economic outcomes of gold mining enterprises.

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Құрамында алтыны бар Васильков кен орнының жоғалым мен кен құнарсыздандыруын анықтау

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***Аңдатпа.** Минералды ресурстарды қазіргі заманғы ауқымды пайдалану кен орындарына жауапкершілікпен қарауды, соның ішінде, кеннің жоғалымы мен құнарсыздануын барынша азайтуды талап етеді. Жоғалымның ең жоғары көрсеткіштері әдетте кен денелерінің сыйыстырушы тау жыныстарымен түйісу аймақтарында, қазып алу контурларының геологиялық шекаралармен сәйкес келмеуіне байланысты орын алады. Бұл мақала түйісу аймақтарын игеру кезіндегі ысыраптар мен құнарсыздануды нормалау мәселелеріне арналған. Жұмыста алтын кенінің ерекшелігіне сай нормативтік мәндерді есептеудің мандандырылған әдісі ұсынылған. Зерттеулер барысында түйісу формасы мен кеннің жоғалымы мен құнарсыздану деңгейі арасындағы тікелей байланыс анықталды. Ұсынылған әдістемені қолдану жер қойнауын пайдаланушыларға түйісулердегі нормативтік көрсеткіштерді қарапайым әрі сенімді түрде анықтауға мүмкіндік береді. Бұл тәсіл тау-кен кешенінің экономикалық тиімділігі мен тұрақтылығын арттырудың ғылыми негізін қалайды.*

***Кілт сөздер:** жоғалым, кен құнарсыздығы, пайда, минерал, тау-кен өндірісі.*

Определение потерь и разубоживания золотосодержащих руд Васильковского месторождения

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Аннотация. *Современное масштабное использование минеральных ресурсов требует ответственного отношения к недрам, где приоритетом является минимизация потерь и разубоживания руды. Наиболее высокие показатели потерь обычно фиксируются в зонах контакта рудных тел с вмещающими породами из-за несовпадения контуров отработки с геологическими границами. Статья посвящена вопросам нормирования потерь и разубоживания именно при разработке приконтактных зон. В работе предложен специализированный метод расчета нормативных значений в стохастической зоне. В ходе исследований была установлена прямая зависимость между геометрической формой контакта и уровнем возникающих потерь и разубоживания. Применение предложенной методики позволяет недропользователям более просто и надежно определять нормативные показатели на контактах. Данный подход создает научную основу для повышения экономической эффективности и устойчивости горнодобывающего комплекса.*

Ключевые слова: *расчет, приконтактная зона, нормативы, потери, разубоживание, руда, прибыль.*

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