

Analysis of Modern Methods for the Construction and Evaluation of Block Models of Solid Mineral Deposits

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Abstract. Block modeling is a crucial tool in modern mining for evaluating mineral deposits and planning their development. This paper analyzes methods for constructing and assessing block models, focusing on their practical application in geological and mining decisions. The main stages of block model creation are discussed, including the formation of geological databases, processing drill hole data, geometrization of ore bodies, wireframe construction, and grade interpolation. Special attention is given to sub-blocking techniques and interpolation methods like inverse distance weighting to improve grade estimation accuracy. The integration of geological, technological, and economic data into digital models enhances resource evaluation and mine planning. The paper also highlights the role of block models in mineral quality management, selective mining, and reducing losses and dilution.

Keywords: block modeling, mineral resource estimation, solid mineral deposits, sub-blocking, geostatistical interpolation, mining planning, mineral quality management.

Introduction

The increasing complexity of geological conditions in solid mineral deposit development requires advanced digital tools for geological and economic evaluation and mine planning. Block modeling has become essential for integrating geological, technological, and economic parameters into a unified digital framework for decision-making.

Earlier studies [1] have comprehensively discussed the foundations of geological and technological modeling of mineral deposits, emphasizing the importance of integrating drilling data, sampling results, and cut-off parameters. The development of geoinformation technologies has further strengthened block modeling's role in improving resource evaluation [2]. The reliability of resource estimation is closely related to assessing ore losses and dilution, especially in deposits with variable thickness and dip angles [3, 10].

The introduction of mining software like Datamine and Micromine has expanded the capabilities of three-dimensional geological modeling and resource estimation [4-6, 9].

These systems enable digital block model construction, grade interpolation, and assessment of geological variability. Well-constructed block models serve as a basis for optimizing pit contours, planning underground mining operations, and improving economic efficiency [5, 8].

Sub-blocking is a key aspect of block modeling, allowing more accurate representation of complex ore boundaries and grade distribution [7]. It enhances reserve estimation, especially in irregular deposits. Moreover, modern geoinformation systems allow continuous updates to geological databases during mining, refining block models as new data becomes available [8, 9].

Despite its widespread use, challenges remain in block modeling, including optimal block size selection, validation of interpolation methods, integration of geological uncertainty into economic evaluations, and adaptation to resource classification standards [10]. Block models primarily reflect in-situ resources, neglecting technological recovery factors and operational constraints, making the refinement of modeling techniques a key task.

This study aims to analyze modern methods for constructing and evaluating block models, identify their features, strengths, and limitations, and determine directions for further improvement in the context of the mining industry's digital transformation. Special focus is given to block model structure, formation stages, sub-blocking techniques, and the role of digital modeling in mineral quality management and mining optimization.

Research methods

A block model is a digital representation of the subsurface, structured as a three-dimensional array of blocks of defined size, where each block is assigned specific geological and economic attributes [1]. In practical terms, it serves as a structured database of the deposit, integrating spatial information with parameters such as grade, density, lithology, and other relevant properties.

The primary purpose of a block model is to provide a comprehensive evaluation of the mineral resource and to support the development of the most rational mining scenarios, taking into account geological complexity, technical constraints, and economic considerations. By linking geological interpretation with quantitative assessment, the model becomes a decision-making tool rather than merely a visualization instrument.

Block modeling is widely used in the preparation of documentation for state reserve evaluation, as it ensures a complete and reliable representation of the deposit. Under current regulatory and industry standards, increasing emphasis is placed on the transparency, reproducibility, and statistical validity of resource

estimates. As a result, government authorities are progressively prioritizing submissions that incorporate geostatistical methods, reflecting international best practices in mineral resource reporting.

At the Kistas deposit, the resource estimation was carried out in accordance with the KazRC Code (Figure 1).

Main Stages of Block Model Development

Block model development in Datamine includes several key stages. First, a geological database is created, with exploration data digitized for compatibility with the mining information system (MGIS) [2]. Data quality control is essential at this stage.

Next, drillhole data is consolidated, assigned spatial coordinates, and composited for grade and geological analysis.

The third stage involves spatial modeling of ore bodies and constructing wireframes for volume estimation. Block size is selected based on ore morphology, and cut-off parameters like grade and ore thickness are applied for reserve estimation [3].

Grade estimation is done using interpolation methods, such as inverse distance weighting [4]. Host rock models are created using nearest-neighbor interpolation, and hybrid methods may be used for structurally variable areas.

The final stage involves reserve estimation, mining optimization, pit boundary optimization, and regulatory compliance.

Structure and Attributes of the Block Model

A block model is a 3D representation of the subsurface, made up of blocks with geometric and qualitative parameters [5]. It describes

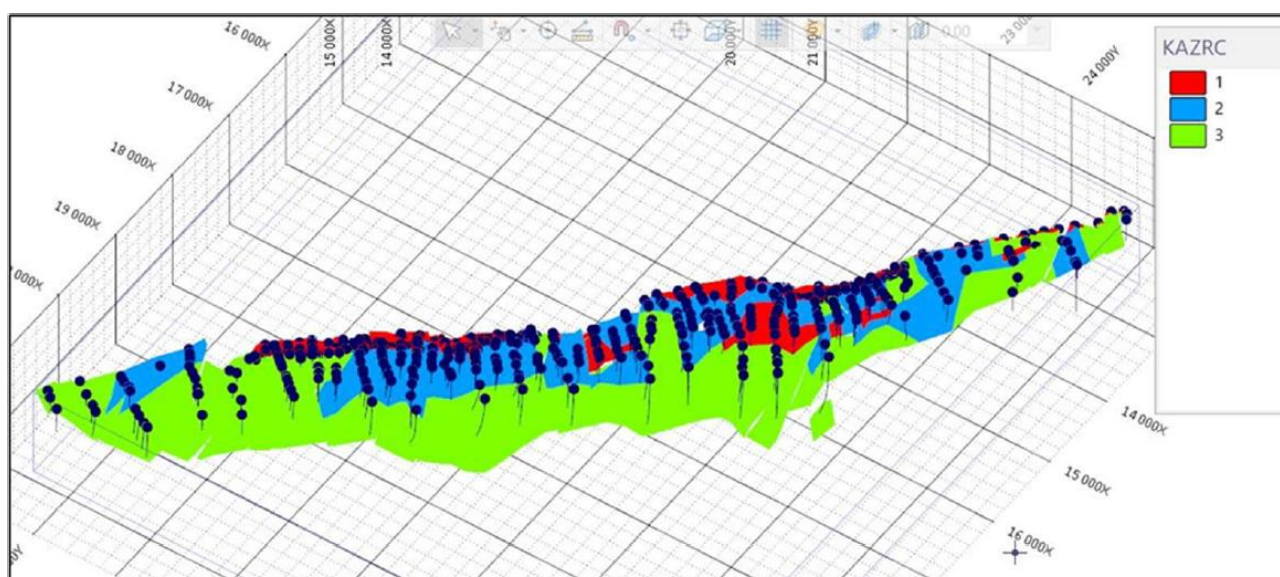


Figure 1 – Block Model of the Kistas Deposit

the mineral body, grade distribution, and occurrence conditions.

The model is structured on a 3D grid defined by coordinate limits and block dimensions. Block size is determined by XINC, YINC, and ZINC, and the number of blocks is represented by NX, NY, and NZ.

Each block contains attributes such as lithology, grade, and density for resource estimation and mine planning.

The principal structural components of a block model include deposit boundaries, ore body limits, mining zones, and spatial constraints. These elements are defined using specialized parameters and commands such as BOUNDARY, SECTION, STRING, and ZONE. They enable precise delineation of geological domains, grade zones, and the limits of planned mining operations. Through these tools, the model reflects not only the geometry of mineralized bodies but also the operational framework within which extraction is planned.

A critical aspect of any block model is its attribute structure. Attributes represent the set of characteristics assigned to each individual block and may be geometric, geological, technological, or economic in nature.

Geometric attributes include the coordinates of the block centroid along the X, Y, and Z axes (XC, YC, ZC), as well as block dimensions and its position within the spatial grid. For indexing and computational convenience, each block is assigned an identifier based on its position within the three-dimensional array, typically expressed in IJK notation.

Geological attributes comprise grade values of valuable components, ore or host rock type, lithology, moisture content, rock strength parameters, and other relevant physical or mechanical properties. These parameters enable quantitative evaluation of mineral quality within each block and support classification according to established reporting standards.

All structural and attribute information of the block model is stored within specialized Datamine databases. Data are organized in model files (MODEL), model parameter files (ESTRAM), and prototype definitions (PROTO). This structured approach allows efficient handling of large datasets during resource estimation, mine design, and operational planning.

In this way, the structure and attributes of the block model form a digital representation of the deposit, serving as a technical foundation for planning, design, and resource management. A high-quality block model underpins sound engineering and economic decision-making throughout the life cycle of mineral resource development.

Subblocking represents an important stage in the refinement of geological detail during

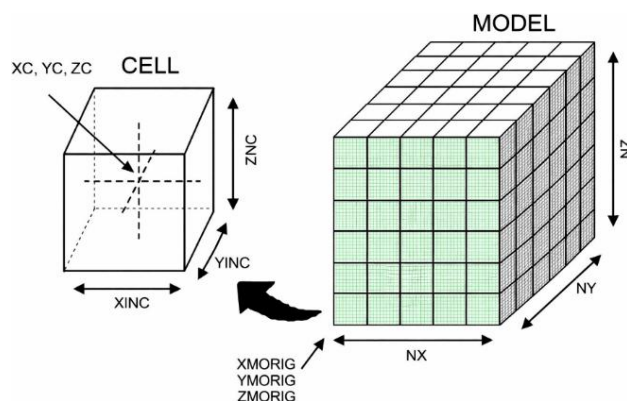


Figure 2 – Prototype of the Block Model

block model construction and resource evaluation [7]. The purpose of subblocking is to increase estimation accuracy by subdividing a parent block into smaller subblocks. This approach is particularly relevant in deposits characterized by complex ore body geometry, sharp lithological contacts, or highly variable grade distribution.

By introducing subblocks, the model can better honor geological boundaries and reduce artificial dilution or loss during resource calculation. This leads to improved precision in reserve estimation and a more realistic representation of the mineralized zones.

An example of subblocking of a parent cell at the ore-waste contact is shown in Figure 3.

Scientific results

Mineral Raw Material Quality Management

Geoinformation technologies are widely used in research and mineral deposit development, enabling rapid geological and technological evaluations. These technologies support the modeling of occurrence conditions and quality parameters, aiding in the selection of optimal access locations, mining development parameters, and appropriate equipment and operating modes.

Computer modeling helps plan the sequence of pit working zone formation, identifying areas for selective mining and blending during ore preparation. Accurate forecasting of geological and quality parameters improves mining performance by reducing losses and dilution, while stabilizing product quality.

Modern geoinformation systems incorporate the physical and chemical properties of mineralized and host rocks, updating the database with new information from exploration and mining operations [8, 9]. These systems ensure continuous refinement of the geological model.

Quality management in mining optimizes extraction and processing efficiency, relying on

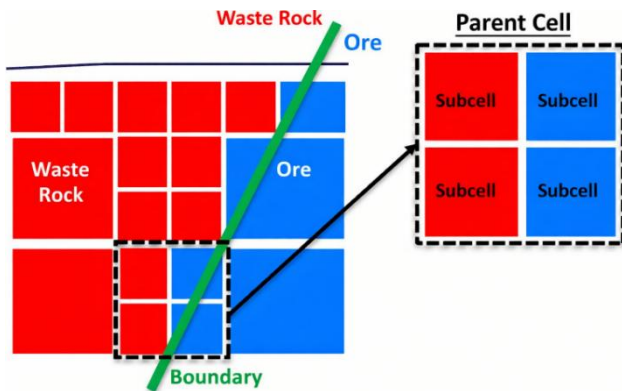


Figure 3 – Subblocking of the Parent Cell

3D geological models to predict grade distribution and quality parameters. These models reduce uncertainty and risk in exploration and mining, allowing for the determination of optimal cut-off parameters and ore body boundaries, maximizing recovery and minimizing losses.

An important aspect of quality management is analyzing grade variability and delineating zones with different quality characteristics, which supports selective mining strategies and optimized blending for consistent feed quality. Figure 4 illustrates selective extraction of high- and medium-grade ore at the Koksui deposit (Block 2), considering variations in quality parameters.

Operational responsiveness to changes in raw material quality during mining ensures stable product specifications and prevents deviations from standards. Software solutions like Datamine and Micromine improve the ac-

curacy and reliability of forecasts related to mineral quality, providing automated quality calculations and rapid data analysis, especially for large-scale deposits.

Geometric modeling results help identify grade distribution patterns, which are used in mine planning and the development of efficient ore preparation technologies.

Summary and Practical Implications

Resource block models are the initial stage of geological and economic evaluation, developed during reserve preparation and approval. They reflect the spatial configuration and quality of ore bodies in their natural state – without considering mining operations or recovery factors.

The main purpose of resource block models is to describe ore body and host rock geometry, as well as mineral quality based on exploration data. These models assess potential resources, including volume and grade, but exclude technological and economic factors related to extraction [10].

It is important to note that resource block models do not differentiate between recoverable and non-recoverable reserves. They represent the total mineral material in the rock mass, without accounting for mining losses and dilution, thus not providing a complete view of reserves that can be practically extracted under real conditions.

Conclusions

The analysis confirms that block modeling is a fundamental tool for the geological and economic evaluation of solid mineral deposits, supporting mining decisions at all project stages. Modern block model construction, based on structured geological databases, wireframe modeling, optimal block sizing, and geosta-

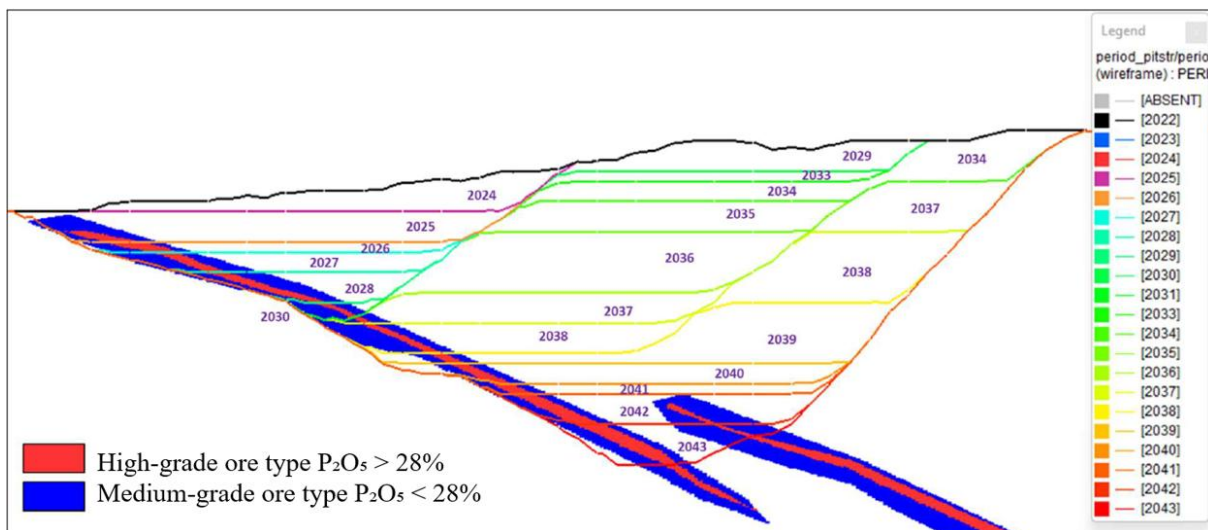


Figure 4 – Mining Plan of the Koksui Deposit with Selective Ore Extraction

tistical interpolation, ensures accurate representation of ore bodies' spatial and qualitative characteristics.

The reliability of resource estimation depends on the quality of primary exploration data, geological interpretation, and the selection of modeling parameters, including block size and interpolation methods. Sub-blocking improves grade estimation accuracy in deposits with complex morphology and heterogeneous mineral distribution, reducing dilution and enhancing reserve calculation precision.

Well-designed block models are not only for resource quantification but also serve as a platform for mineral quality management, selective mining, blending optimization, and reducing ore losses. Integrating geological, technological, and economic parameters enhances transparency, supports compliance with reporting standards, and reduces geological uncertainty in long-term planning.

However, block models reflect in-situ mineralization and do not account for recovery factors, operational constraints, and economic conditions. Future modeling developments should focus on uncertainty analysis, adaptive model updating, and linking geological models with production indicators.

As the mining industry undergoes digital transformation, block modeling is evolving into a dynamic decision-support system. Its continued refinement and integration with advanced geoinformation and geostatistical technologies will improve the efficiency and sustainability of mineral resource development.

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Қатты пайдалы қазбалар кен орындарының блоктық модельдерін құру және бағалаудың заманауи әдістерін талдау

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Аңдатпа. Блоктық модельдеу қазіргі заманғы кен өндіруде минералдық кен орындарын бағалау және олардың дамуын жоспарлау үшін маңызды құралға айналды. Мақала блоктық модельдерді құру және бағалау заманауи әдістерін, олардың геологиялық және тау-кен шешімдерін қабылдаудағы практикалық қолданылуына назар аударып талдайды. Блоктық модельдерді құрудың негізгі кезеңдері, оның ішінде геологиялық деректер базасын құру, бұрғылау тесіктерінің деректерін өңдеу, руда денелерінің геометриясын қалыптастыру, сымжіптерді құру және сапа параметрлерін интерполяциялау қарастырылады. Арнайы блоктар мен интерполяция әдістерінің маңызына аса назар аударылады, мысалы, кері қашықтықпен өлшеу әдісі, бұл сапаны бағалаудың дәлдігін арттырады. Геологиялық, технологиялық және экономикалық параметрлерді біріккен сандық модельге біріктіру ресурс бағалауды және шахтаны жоспарлауды жақсартады. Мақала блоктық модельдердің минералды сапаны басқаруда, таңдамалы кен өндіруде және жоғалтулар мен қоспаларды азайтуда маңызды рөл атқаратынын көрсетеді.

Кілт сөздер: блоктық модельдеу, минералдық қорларды бағалау, қатты пайдалы қазбалар кен орындары, субблоктау, геостатистикалық интерполяция, тау-кен жұмыстарын жоспарлау, минералдық шикізат сапасын басқару.

Анализ современных методов построения и оценки блочных моделей месторождений твердых полезных ископаемых

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Аннотация. Блочное моделирование стало важным инструментом в современной горной практике для оценки минеральных месторождений и планирования их разработки. В статье анализируются современные методы создания и оценки блочных моделей с акцентом на их практическое применение в геологических и горных решениях. Рассматриваются основные этапы создания блочной модели, включая формирование геологических баз данных, обработку данных буровых скважин, геометризацию рудных тел, построение каркаса и интерполяцию параметров содержания. Особое внимание уделяется техникам субблокирования и методам интерполяции, таким как взвешивание по обратному расстоянию, для улучшения точности оценки содержания. Интеграция геологических, технологических и экономических параметров в единую цифровую модель значительно улучшает качество оценки ресурсов и планирования шахты. Также подчеркивается роль блочных моделей в управлении качеством минералов, выборочном горнорудном деле и снижении потерь и разбавления.

Ключевые слова: блочное моделирование, оценка минеральных ресурсов, месторождения твердых полезных ископаемых, субблокирование, геостатистическая интерполяция, планирование горных работ, управление качеством минерального сырья.

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