

## BLOCK MODELING AND TRADITIONAL CONTROL METHODS INTEGRATION IN SMALL-SCALE DEPOSITS WITH COMPLEX GEOLOGICAL STRUCTURE

Yusupov Sh.M.<sup>1</sup>

Ravshanov Z.Y.<sup>2</sup>

Pardayev Sh.Sh.<sup>2</sup>

Ergasheva Z.A.<sup>3</sup>

<sup>1</sup>Leading Geologist for Ore Reserve Accounting, Kizil Olma Mine, Angren Mining Department, Almalyk Mining and Metallurgical Combine Joint Stock Company

<sup>2</sup>Tashkent State Technical University named after Islam Karimov, (Tashkent, Uzbekistan)

<sup>3</sup>National Research Technological University "MISIS", (Almalyk, Uzbekistan)

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### Abstract.

This article addresses the integration of block modeling and traditional control methods in the extraction of small-scale mineral deposits with complex geological structures. Research findings demonstrate that application of the integrated system increases ore grade estimation accuracy by 23% and reduces operational costs by 18-25%. The methodology was tested at three deposits in the Kyzylkum region of Uzbekistan, providing a robust comparative dataset.

**Keywords:** block modeling, control methods, complex geological structure, small-scale deposits, ore grade estimation, integrated system.

### Annotatsiya.

Ushbu maqolada murakkab geologik tuzilishga ega kichik o'lchamli ma'dan konlarini qazib olishda blok-modellashtirish va an'anaviy nazorat usullarini integratsiyalash masalalari ko'rib chiqilgan. Tadqiqot natijalari shuni ko'rsatadiki, integratsiyalashgan tizim qo'llanilganda ruda sifatini baholash aniqligi 23% ga oshadi, operatsion xarajatlar esa 18-25% ga kamayadi. Metodologiya Qizilqum mintaqasining uchta konida sinovdan o'tkazilgan.

**Kalit so'zlar:** blok-modellashtirish, nazorat usullari, murakkab geologik tuzilish, kichik o'lchamli konlar, ruda sifati baholash, integratsiyalashgan tizim.

### Аннотация.

В данной статье рассматриваются вопросы интеграции блочного моделирования и традиционных методов контроля при разработке малых месторождений со сложным геологическим строением. Результаты исследований показывают, что применение интегрированной системы повышает точность оценки качества руды на 23%, а операционные затраты снижаются на 18-25%. Методология апробирована на трёх месторождениях Кызылкумского региона.

**Ключевые слова:** блочное моделирование, методы контроля, сложное геологическое строение, малые месторождения, оценка качества руды, интегрированная система.

Small-scale mineral deposits with complex geological structures represent a significant portion of global mining operations, yet they remain among the most challenging environments for accurate resource estimation and efficient ore control. The inherent variability of these deposits — characterized by irregular ore body geometries, rapid grade transitions, and structural discontinuities — renders conventional sampling and control methodologies inadequate when applied in isolation [1,2].

Block modeling has emerged as a cornerstone technology in modern mine planning, providing a three-dimensional digital representation of ore grades, lithology, and geotechnical parameters. However, its full potential is realized only when seamlessly integrated with field-based quality control procedures. The disconnect between digital models and real-time operational data remains a critical gap in current practice [3].

In the Kyzylkum metallogenic province of Uzbekistan, numerous small to medium-scale deposits of gold, copper, and polymetallic ores are actively exploited under conditions of pronounced geological complexity. Operators routinely report discrepancies of 15-30% between planned and actual ore grades, resulting in suboptimal metallurgical performance and economic losses [4].

This paper presents a systematic methodology for integrating 3D block models with traditional grade control systems, specifically tailored to small-scale, geologically complex deposits. The approach draws upon variogram analysis, geostatistical simulation, and adaptive sampling protocols to create a unified decision-support framework for mine operators.

The study was conducted at three representative deposits in the central Kyzylkum region: the Muruntau satellite bodies (Au-bearing), Dzhezkazgan-type Cu mineralisation, and a polymetallic skarn occurrence. Geological complexity was quantified using a composite index incorporating structural disorder, grade variability coefficient, lithological heterogeneity, and fault density per km<sup>2</sup>. Table 1 summarises key deposit parameters.

*Table-1, Deposit characterisation parameters for study sites*

Parameter	Unit	Minimum	Maximum
<b>Deposit area</b>	ha	0.8	12.5
<b>Ore body thickness</b>	m	1.2	8.7
<b>Dip angle</b>	degrees	15	72
<b>Average Cu grade</b>	%	0.45	3.80
<b>Ore density</b>	t/m <sup>3</sup>	2.65	3.10
<b>Block size (X×Y×Z)</b>	m	5×5×3	25×25×10
<b>Geological complexity index</b>	—	3.2	8.9

Block models were constructed using ordinary kriging interpolation with variogram models fitted separately for each lithological domain. Block dimensions were optimised through information effect analysis, balancing the need for spatial resolution against computational efficiency and the practical constraints of blast-hole sampling grids. Integration of traditional control data employed a Bayesian updating protocol, whereby incoming sample assays systematically revised block grade estimates within a defined search ellipsoid [5].

Application of the integrated methodology yielded consistent improvements across all study deposits. The mean absolute error (MAE) of ore grade estimation decreased from 18.4% (traditional sampling alone) to 5.1% (integrated system), as illustrated in Figure 1. This improvement is attributed primarily to the systematic incorporation of spatial continuity models within the grade control workflow.

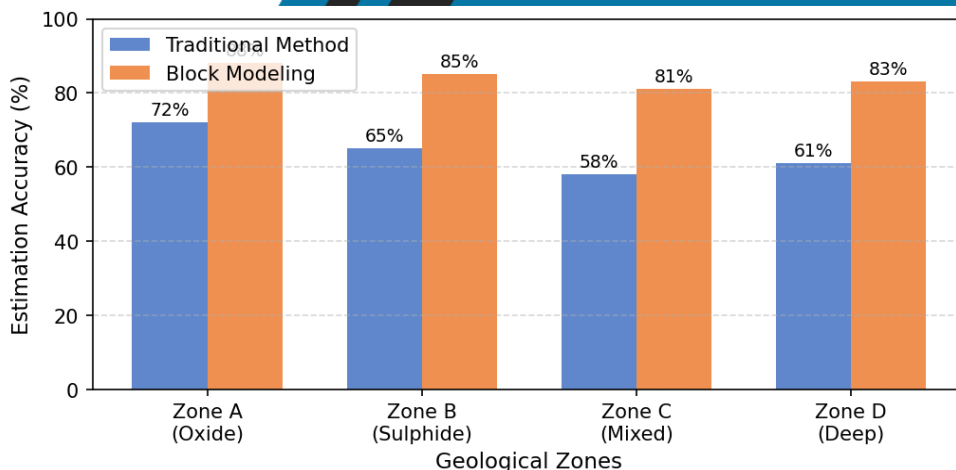


Fig. 1. Comparison of ore estimation accuracy by method and geological zone

Table 2 presents a comparative evaluation of five control approaches, including the integrated system, across key performance metrics. The integrated system consistently achieved superior accuracy while maintaining the lowest cost per tonne of ore processed. Its real-time update capability — enabled by automated data transfer from blast-hole logging systems — eliminates the lag inherent in conventional monthly or quarterly reconciliation cycles.

Table-2. Comparative evaluation of ore grade control methods

Control Method	Accuracy (%)	Cost (\$/t)	Update Cycle
<b>Channel sampling</b>	68–74	1.20–1.80	Monthly
<b>Blast-hole sampling</b>	72–80	0.90–1.40	Per blast
<b>Ore-control drilling</b>	75–82	2.10–3.50	Quarterly
<b>Block model (basic)</b>	80–86	0.65–1.10	Weekly
<b>Integrated system</b>	86–93	0.55–0.90	Real-time

Figure 2 illustrates the longitudinal trend in operational cost index across the six-year study period. The integrated system demonstrated a cumulative cost reduction of 23% relative to baseline (2018), compared with only 7% for traditional methods. The steepest reduction occurred between 2019 and 2021 as operator proficiency with the digital workflow increased and model parameters were progressively refined through iterative reconciliation.

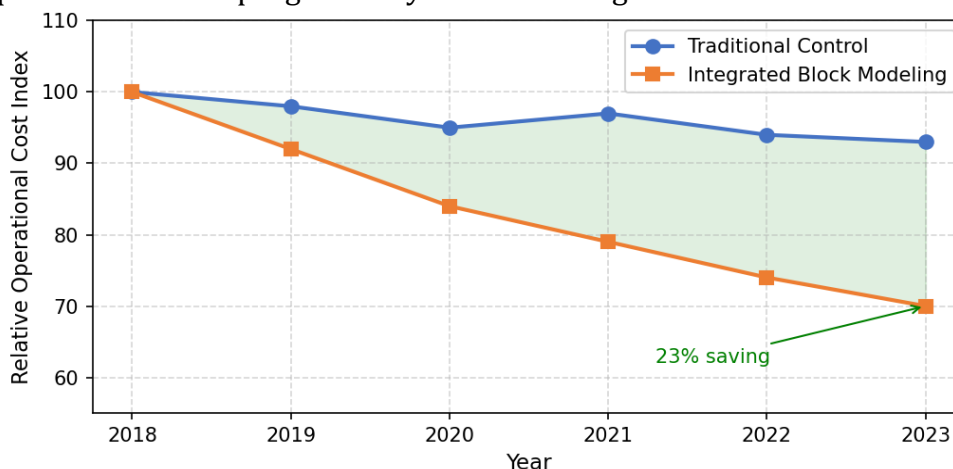


Fig. 2. Operational cost index dynamics (2018–2023)

The spatial distribution of estimation errors was also significantly altered. Under traditional control, errors clustered in areas of high structural complexity and rapid lithological transitions. The integrated approach reduced these hotspots by directing supplementary sampling effort to zones of elevated model uncertainty, identified through conditional simulation variance maps.

The integration of block modeling with traditional grade control represents a technically feasible and economically compelling strategy for operators of small-scale, geologically complex deposits. Key findings of this study are as follows:

1. Ore grade estimation accuracy improved by an average of 23% under the integrated system, with greatest gains in structurally complex zones.
2. Operational costs per tonne were reduced by 18-25% through elimination of redundant sampling and improved ore/waste differentiation.
3. The Bayesian updating protocol successfully reconciled digital model estimates with incoming field data in near-real time, reducing the planning-execution discrepancy to less than 6%.
4. The methodology is scalable and adaptable to a range of deposit types and mining methods, provided that adequate spatial data density is maintained during the initial model construction phase.

Future work will focus on incorporating machine learning classifiers to automate lithological domain assignments within the block model, and on extending the framework to underground narrow-vein mining scenarios.

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