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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
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КАЗАХСТАН
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NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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3D BLOCK MODELING OF GEOMECHANICAL PROPERTIES OF ORE DEPOSITS USING MODERN GMISs

Abstract. Reliable reflection of geomechanical properties of the rock mass in different areas of a quarry or mine is an important factor for safe and efficient mining design. As a rule, at the development of a mine it is impossible to fully study the site and determine geomechanical characteristics of the rock mass. Therefore, it is extremely important to model the spatial variability of geomechanical properties of a rock mass using limited data.

Modern computer software products (Datamine, Micromine, Leapfrog, etc. make it possible to process initial numerical, text and graphic data and obtain digital three-dimensional models of deposits. The standard method of geological modeling consists of interpreting and building a wireframe model for one profile of borehole data at a time, which is time consuming. Modern computer software (Datamine, Micromine, Leapfrog, etc. ensures data processing in several hours with greater accuracy and considering several geological interpretations that may correspond to the input data. As a result, geological interpretation using new software tools requires experience in the field of geology.

The paper covers the stages of building a three-dimensional geomechanical block model (BM, which takes into account the heterogeneity of geomechanical properties as examplified in one of the iron ore open pits of the Republic of Kazakhstan. It contains the building algorithm of the geomechanical BM, which includes the import and preparation of initial data in the GMIS environment, their visualization; modeling of lithology data and structural trends to aggregate them into domains and interpolate the rating data of the rock mass quality and geotechnical characteristics.

Key words: modeling, boreholes, source databases, geological interpretation, domains, statistical analysis, interpolation, geomechanical block model.

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ЗАМАНАУИ ТКГАЖ КӨМЕГІМЕН КЕН ОРНЫНЫҢ ГЕОМЕХАНИКАЛЫҚ ҚАСИЕТТЕРІН ҮШ ӨЛШЕМДІ БЛОКТЫҚ МОДЕЛЬДЕУ

Аннотация. Карьердің немесе шахтаның әртүрлі учаскелеріндегі тау-кен массивінің геомеханикалық қасиеттерін сенімді түрде көрсету тау-кен жұмыстарын қауіпсіз және тиімді жобалаудың маңызды факторы болып табылады. Әдетте, кеніште игеру кезінде тау массивінің геомеханикалық сипаттамаларын анықтай отырып, учаскені толық зерттеу іс жүзінде мүмкін емес, сондықтан шектеулі деректерді қолдана отырып, тау жыныстарының геомеханикалық қасиеттерінің кеңістіктік өзгергіштігін модельдеу өте маңызды.

Заманауи компьютерлік бағдарламалық өнімдер (Datamine, Micromine. Leapfrog және т.б.) бастапқы сандық, мәтіндік және графикалық деректерді өңдеуге және кен орындарының сандық үш өлшемді модельдерін алуға мүмкіндік береді. Геологиялық модельдеудің стандартты әдісі – бұл бір уақытта ұңғыма деректерінің бір бөлігін түсіндіру және қаңқалы моделін құру көп уақытты қажет етеді. Қазіргі заманғы бағдарламалық қамтамасыз ету (Datamine, Micromine. Leapfrog және т.б.) деректерді бірнеше сағат ішінде және дәлірек өңдеуге, бастапқы деректерге сәйкес келетін бірнеше геологиялық түсіндірулерді қарастыруға мүмкіндік береді. Нәтижесінде жаңа бағдарламалық құралдарды пайдалана отырып, геологиялық интерпретацияны анықтау кезінде геология саласындағы тәжірибе маңызды болып табылады.

Мақалада ҚР темір кені карьерлерінің бірінің мысалында геомеханикалық қасиеттердің әртектілігін ескеретін үш өлшемді геомеханикалық блоктық модельді (БМ) құру кезеңдері қарастырылған. Геомеханикалық БМ құру кезеңдерінің алгоритмі келтіріледі, ол тау-кен ГАЖ ортасына бастапқы деректерді импорттау мен дайындауды, оларды визуализациялауды; литология деректерін және оларды домендерге бөлу үшін құрылымдық трендтерді модельдеуді және олардағы массив сапасының рейтингтік көрсеткіштері мен геотехникалық сипаттамаларының деректерін интерполяциялауды қамтиды.

Түйін сөздер: модельдеу, ұңғымалар, бастапқы мәліметтер базасы, геологиялық түсіндіру, домендер, статистикалық талдау, интерполяция, геомеханикалық блок моделі.

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ТРЕХМЕРНОЕ БЛОЧНОЕ МОДЕЛИРОВАНИЕ ГЕОМЕХАНИЧЕСКИХ СВОЙСТВ РУДНОГО МЕСТОРОЖДЕНИЯ С ИСПОЛЬЗОВАНИЕМ СОВРЕМЕННЫХ ГГИС

Аннотация. Достоверное отражение геомеханических свойств массива горных пород на разных участках карьера или шахты является важным фактором для безопасного и эффективного горнодобывающего проектирования. Как правило, при разработке рудника полное исследование участка с определением геомеханических характеристик горного массива на практике невозможно, поэтому крайне важно моделировать пространственную изменчивость геомеханических свойств массива горных пород с использованием ограниченных данных.

Современные компьютерные программные продукты (Datamine, Micromine. Leapfrog и др.) позволяют обрабатывать исходных числовые, текстовые и графические данные и получать цифровые трехмерные модели месторождений. Стандартный метод геологического моделирования заключается в интерпретации и построении каркасной модели по одному разрезу скважинных данных за раз, что требует значительных затрат времени. Современное программное обеспечение (Datamine, Micromine. Leapfrog и др.) позволяет обработать данные за несколько часов и с большей точностью, а также рассматривать несколько геологических интерпретаций, которые могут соответствовать исходным данным. Вследствие чего при определении геологической интерпретации с использованием новых программных средств становится важным опыт в области геологии.

В статье рассматриваются этапы построения трехмерной геомеханической блочной модели (БМ), учитывающую неоднородность геомеханических свойств на примере одного из железорудных карьеров РК. Приводится алгоритм этапов построения геомеханической БМ, который включает импорт и подготовку исходных данных в среду ГГИС, их визуализацию; моделирование данных литологии и структурных трендов для выделения их в домены и интерполяцию в них данных рейтинговых показателей качества массива и геотехнических характеристик.

Ключевые слова: моделирование, скважины, базы исходных данных, геологическая интерпретация, домены, статистический анализ, интерполяция, геомеханическая блочная модель.

Introduction. A good 3D geomechanical BM is based on high quality and reliable data and correct interpretation of the geological and structural configuration of the field.

It also includes the distributions of the strength properties of rocks, their changes as well as the hydrogeological model of distribution of the groundwater pore pressure.

The geomechanical BM gives a visual representation of the rock mass condition at various sections of the field, simplifies the selection of design sections for stability calculations, facilitates the optimal technical solution and analysis, especially for complex geological structures with larger number of geotechnical or geological units with different orientations and slopes.

The geotechnical model is a combination of geological, structural, hydrogeological and rock models (Syedina et al., 2018:60-65; Dunn, 2014: 133).

The BM building consists of several stages, and the reliability of data basically depends on the quality of the underlying data. Data reliability is related to the amount of data collected, their spatial distribution, quality of collection and interpretation.

The object of research is mineral ore deposits.

The purpose of creating the geomechanical BM is to store and visualize all the ratings of the rock mass quality and the geotechnical characteristics of the deposit in three-dimensional space with the possibility of updating and correcting the data.

The research methodology. The main research method is the modeling of the digital database of the deposit using one of the geological and mining information systems (GMIS).

The stages of creating a volumetric geomechanical BM of the field are shown in Figure 1.

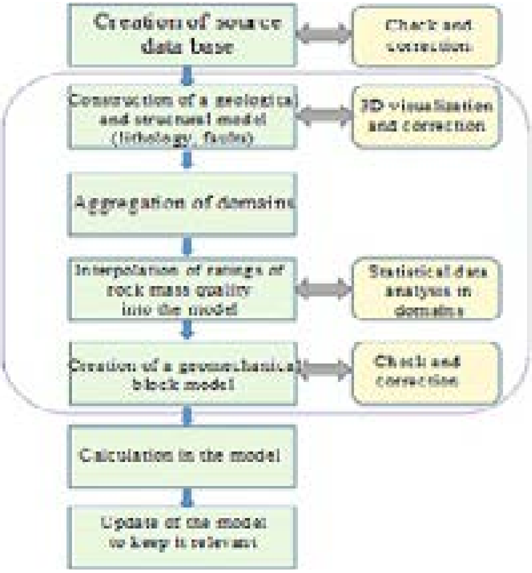


Figure 1. The stages of creating a geomechanical BM

Control is needed at each stage of modeling since a poorly constructed model can cause serious mistakes in technical decisions, which can subsequently lead to serious mistakes and even accidents in open pits (Recommendations, 2015: 87).

Creating a source data base. A digital database (DB) is built on the basis of numerical and text data and consists of many tables, each containing several data fields (vertical columns) and entries (lines). The structure of the source data base for building a block geomechanical database can be represented as follows (Figure 2):

For wells:

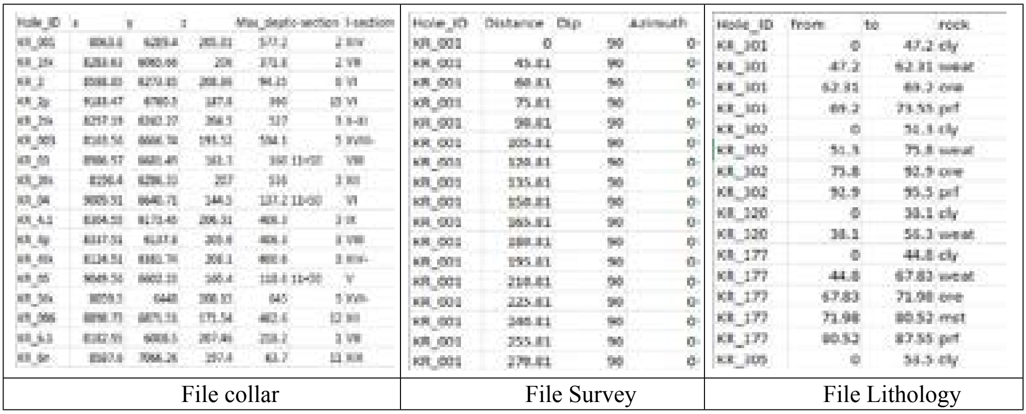
- Collars: data about well locations. Fields: Well (# well); North (X); East (Y); Relative elevation (Z); Depth of the well.

- Directional survey. Orientational data on the deflection of wells in depth. Fields: Well (# well); Survey depth (measurement); Azimuth; Plunge (angle of plunge).

- Lithology. Lithological data, stratigraphy. Fields: Well (# well); From; To; Lithological codes.

- Geomechanical data. Fields: Well (# well); From; To; Fields with indicators (RQD, FF, uniaxial compression strength (UCS), condition of fractures etc.).

When the database joins/is imported into a certain software for 3D geological and mathematical modeling, the data are checked for errors to ensure the preparation of a reliable data set with the least ambiguities and inconsistencies. Error checking is performed automatically in modern 3D modeling programs.



File collar | File Survey | File Lithology

Figure 2. Examples of table structures with source data bases

The source data base can include not only drilling data from exploration and geotechnical wells, but also available historical sections and plans, toposurfaces, restrictions in the form of a quarry or mine, fault surfaces, GIS data, maps and other images with georeferencing.

Geological modeling. A wireframe modeling is the most universal method for determining geological boundaries.

The standard method of geological modeling consists of interpreting and building a wireframe model for one profile of borehole data at a time, which is time consuming. The contours created at the interpretation stage are combined into three-dimensional wireframes that form a wireframe model of the field (Figure 4). Modern computer software (Datamine, Micromine, Leapfrog, etc.) ensures data processing in several hours with greater accuracy and considering several geological interpretations that may correspond to the input data. As a result, geological interpretation using new software tools requires experience in the field of geology (Kaputin, 2022: 600; Baryatskaya, 2019: 57).

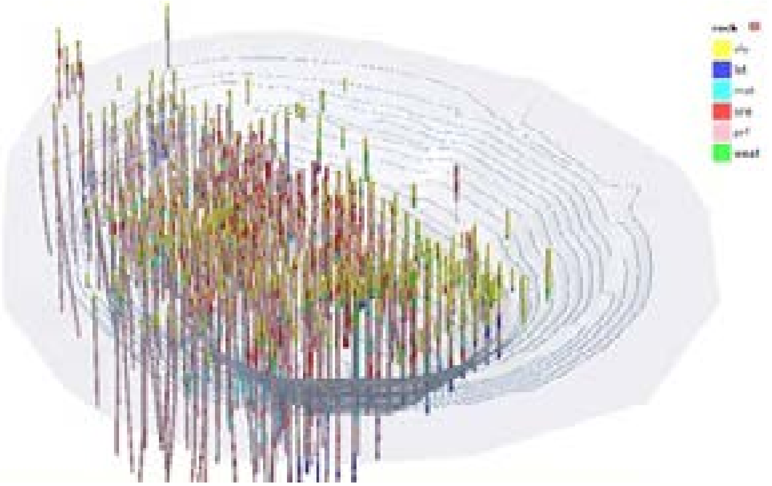


Figure 3. An example of database visualization in 3D according to lithological codes

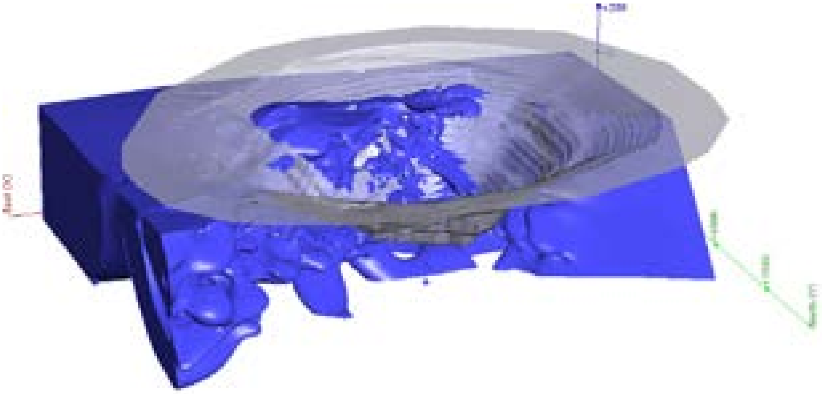


Figure 4. An example of a wireframe model of a domain

The wireframe geological and structural models are created by bringing together all the available information (database with the geological description of the core of exploration wells, geological plans and sections, toposurfaces) obtained at various stages of the deposit study and development. Based on the analysis results, the lithological codes are adjusted to create a reliable geological model. The spatial distribution of the data should be sufficient to define geotechnical areas and to identify critical structures or zones that may be problematic.

Interpretation of geological domains. At the construction of geomechanical BM, defining geological domains is of great importance. The domains have a clear boundary and are geologically and statistically homogeneous zones. The average values of mechanical property parameters obtained from rock sampling for each area are considered to be characteristics of the rock properties in that area.

To define each geomechanical area (domain), it is recommended to comply with the combinations of the following lithological and geomechanical features (Deere, 1967: 302):

- Domain boundaries are based on the main faults documented during the operation of the pit, in the case where the structural orientation is dominant and leads to a change in the geomechanical characteristics within them;
- Stable and slightly variable geomechanical parameters within one lithological type;
- Each lithological type is aggregated into a separate domain according to a geological criterion. Thus, igneous and sedimentary rocks with similar geomechanical properties are aggregated into independent domains;
- If geomechanical parameters within the same lithological type are highly variable, it is necessary to separate them into independent domains.

The choice of domains must be confirmed by static data and variography. After the interpretation of the domains is completed, a block three-dimensional model of each domain is built and a unique domain number is assigned to it.

Block modeling includes filling wireframe models with an empty block model as well as interpolating the data of the ratings of a rock mass quality and numerical geomechanical parameters within the selected geomechanical domains from the actual information (database) into each block (Livinsky, 2017: 55).

Domain data analysis and interpolation methods. Before modeling the distribution of numerical values from well data, it is necessary to study their spatial distribution in each domain. It includes calculating the number of samples used for evaluation in each block and the average distance between them. Statistical analysis (histograms and probability plots) is used to determine the distribution of numerical values from well data (rock mass ratings) for each domain.

Currently, many evaluation methods have been developed and mathematically justified, which are used to interpolate qualitative indicators into block models (Poniewierski, 2019: 33). The evaluation method is selected based on the data completeness and comparative analysis of the modeling with the actual mining and geological conditions of the object. For interpolation are used only the source data that get into the domain shell (Hesameddin, 2016: ; Russell. 2003: 114).

Table 1 shows the main methods for assessing the spatial distribution of quality indicators (Chiles, 2018: 612).

Table 1. The main BM interpolation methods

Nearest neighbor analysis	Assigning the value of the closest sample point to a block
Inverse Distance Weighting (IDW)	Assigning a value to a block using inverse distance weighting
Simple Kriging (SK)	Assigning a Specific Value to Model Blocks
Ordinary Kriging (OK)	Assigning values to a block using kriging with variogram parameters derived from geostatistical functions

Indicative kriging (IK)	Data on the distribution of probable grades in a block are obtained using indicative kriging
Import of centroids	Assigning values to a block from text file data in split or fixed format

At the application of any methods, it is important to choose the area in which samples will be searched for value assignment. If the exploration network has an irregular order, where the well data are a nonuniform sampling (different amount of information), which leads to a shift in the estimated average, it is necessary to take into account the uneven distribution of these data when analyzing the modeling area. This is achieved based on the average distance between wells by splitting the data about the modeling area into elementary units (cells) of space by limiting coordinates (Kantemirov, 2021: 73; Manikovsky, 2021: 14; Mery, 2017: 351).

In the presence of complex domain shapes such as dikes, veins, folds, faults, it is necessary to use a structural trend or a dynamic ellipse. The ability of Leapfrog software to model along complex trends is a distinct advantage over other geological modeling software programs. The use of a dynamic ellipse (Variable Orientation) allows to change the orientation of the evaluation in accordance with the local characteristics of a domain (Shinkarenko, 2021: 538).

After modeling the spatial characteristics of geomechanical properties of domains, a block model is created and filled with the necessary data for further calculations.

Checking the geomechanical BM. After creating the BM, it is necessary to build plans, sections and use three-dimensional images to check the model and compare it with the corresponding drilling data.

Practical implementation of the research. As examplified in one of the ore deposits of Kazakhstan, an empty block model was created for the required model boundaries. The following parameters were used: thickness: 640 m; length: 2,300 m; width: 2,000 m, block size: 15×15×15 m.

When building a three-dimensional geological and structural model of the field, both geotechnical well data and all available historical data from exploration wells for the years 1972-2014 were used. The set of geomechanical well data was cleared to eliminate ambiguities and inconsistencies. To develop the fault model, historical geological transverse and longitudinal sections and plans, and topographic surfaces of faults were used. A total of 7 key lithologies were modelled. Table 2 shows the main rock types classified in the open pit. With the help of structural model frameworks, the codes of the geomechanical domain (Quaternary sediments, limestone, porphyrite, metasomatically altered rocks, ore, tectonic fault zones, weathered rocks) were assigned to the model blocks.

Table 2. An example of geological domains of an ore deposit

Geological domain	Domain code for interpolation	Domain code in the model
Quaternary sediments	1	CLY
Limestone	2	LST
Porphyrite	3	PRF

Metasomatites	4	MST
Weathering crust	5	WEAT
Ore	6	ORE
Tectonic fault zones	7	FAULT

Geostatistical analysis and modeling of sample data of geomechanical parameters were performed for each of the 6 domains of the rock part of the mass. Histograms and probabilistic graphs of the ratings distribution by domains were built (Figure 5).

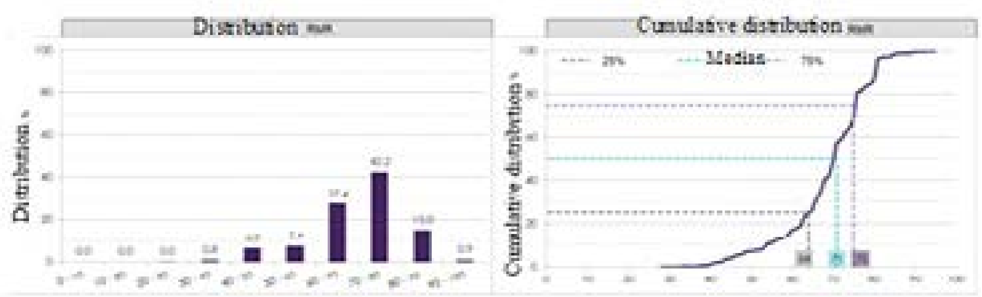


Figure 5. RMR data distributions for domain 2

For geostatistical modeling of spatial characteristics of geomechanical properties of the rock mass (RQD, RMR, FF, GSI, Jn, Jr, Ja, Jw, UCS, UTS) based on well data, an RBF interpolant was used.

Due to the relatively limited number of wells used to obtain data to determine RQD and RMR, a probabilistic approach was used to estimate their values in the block model. The RQD and RMR values were evaluated in three stages, with sequentially increasing search radii used at the second and third stages (Table 3). The search ellipses were oriented to match the dip angle and azimuth of the domains.

Table 3. RQD and RMR evaluation parameters.

	Search parameters		
Search	1	2	3
The size of the search ellipse (X/Y/Z)	120 m/120 m/60 m	240 m/240 m/120 m	480 m/480 m/ 240 m
Minimum number of composites	8	8	8
Maximum number of sample composites	16	16	16
Minimum number of wells	2	2	2

The data were not interpolated over a longer distance. And the blocks that were not filled in by the third interpolation were assigned median values in accordance with the domain code in the model. Statistical and visual verification of the RQD and RMR calculated values in the block model was done to confirm that the well test data and the resulting estimates are in line with expectations. In general, the verification confirmed a good correlation of RQD and RMR values with well test data (Table 4).

Table 4. RQD statistical demonstration.

Domain code in the model	RQD preliminary average value	RQD median value	RQD average estimated indicator	RQD median estimated indicator
LST	87.47	91.00	83.57	89.23
PRF	79.27	84.13	80.12	85.46
MST	79.64	83.04	78.80	87.83
ORE	83.88	92.00	83.88	83.88
WEAT	55.18	32.54	25.41	13.31

As more and more geological and geotechnical information becomes available, domains are reevaluated and the model is updated.

A general view of the geomechanical block model of the ore deposit with the distribution of the RQD rating is shown in Figure 5.

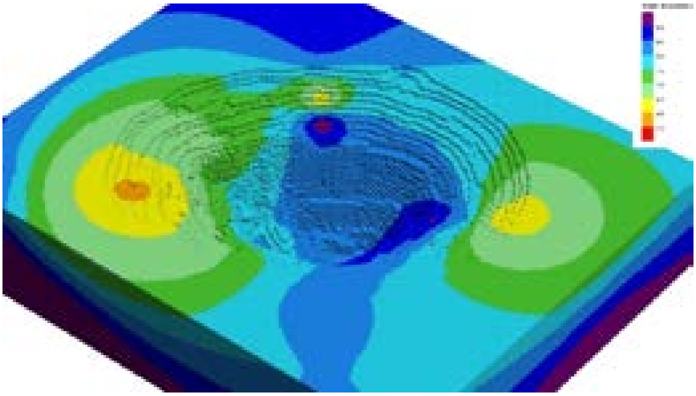


Figure 5. An example of a block model of one of the RK ore deposits with a visualization of the RQD rating distribution in the Leapfrog Mining software.

Conclusion. Thus, the geomechanical BM is a computer image of the field indicating the geological zones filled with blocks, which are assigned the values of the ratings of the rock mass and other characteristics. The combined use of traditional and modern interpretation and modeling methodology at the construction of a geomechanical BM provides realistic predictions of the geomechanical properties of rock masses in different sections of an open pit or mine and makes it possible to develop field design parameters for a particular area.

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