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Modelling of natural stone extraction

It is obvious that at such rates of use of mineral resources, the main share of explored reserves of minerals will be exhausted from the subsoil within the next 30 years. Of course, a partial solution to the mineral-raw material problem can be achieved thanks to scientific and technical achievements, the implementation of which will allow reducing the volume of raw material consumption or replacing certain types of it with less scarce ones. However, the main way of meeting the needs for raw materials remains the development of existing deposits and the search for new ones. Therefore, an important task of our and other countries is to develop methods that make it possible to obtain the most reliable information about deposits in order to make the most effective decisions for their development.

Keywords*: modelling; geometrization; deposit development.*

Relevance of the topic. When assessing the prospect of development of non-ore mineral deposits, the most important task is reliable forecasting of the spatial variability of quality indicators. One of the main approaches to the analysis and processing of spatially distributed data is geostatistical modelling [1]. The shape of the deposit, its size and the conditions of bedding of the mineral have a great influence on the choice of methods of development and technical and economic performance of mining enterprises. At the same time, the presence of reliable information about the deposit, its structure, the nature of the placement of useful components in the deposit directly affects the correctness of decision-making on the above-mentioned issues. The main part of the tasks in this direction is solved by the surveying and geological services of the mining enterprise. It is worth noting that the most important tool for studying the described problems is the geometrization of deposits, since knowledge of the forms, elements of bedding and placement of the main indicators of deposit quality are extremely important when choosing a method of working out and drawing up a project for the rational exploitation of a deposit. The ultimate goal of geometrization of the deposit is to identify patterns of spatial arrangement of forms and properties of the deposit. Most accurately, with a minimum number of observation points, the indicator placement function is revealed using geometrization methods [2].

Analysis of the latest research and publications on which the authors rely. The relationship between fracturing and structural features of gabroid massifs is most fully covered in the works of A.O. Kryvoruchko [3–5]. The founder of the classical school of subsurface geometry is the outstanding scientist P.K. Sobolevskyi. His works, as well as the works of P.M. Leontovskyi and V.I. Bauman at the beginning of the 20th century laid the foundations of mining geometry for mathematical modelling of mineral bodies. Later, P.K. Sobolevskyi developed geometric (mathematical) methods of studying and expressing the spatial location of geological indicators.

Sobolevskyi P.K. developed the theoretical foundations of the study of the deposit based on ideas about the subsoil as a set of geochemical and geotectonic fields. It is characteristic that for the study of such fields, he proposed as the main method of isolines, which makes it possible to express the placement of a geological feature in space in any plane section. Proposed by P.K. Sobolevskyi point palette and the apparatus of mathematical operations with topographic surfaces made the grapho-analytical method developed by him universal in the study of the subsoil. It should be noted that P.K. Sobolevsky's ideas served as a theoretical basis for the geometrization of various mineral deposits: layer sedimentary and vein, mono- and polymetallic ore, placer, oil and gas, etc.

The further development of the geometrization technique was spread in the works of the students of P.K. Sobolevskyi – P.O. Ryzhova, I.M. Ushakova [6], V.O. Bukrynskyi [7, 8], V.M. Hudkova [9], D.I. Vilesova, O.O. Trofimova [10], K.F. Yermolaeva [11], V.M. Kalinichenko [12] and others.

In the work of V.M. Kalinichenko [12] the application of mathematical modelling in the geometrization of deposits was analyzed and a classification of mathematical models for the placement of deposit indicators were developed. V. O. Bukrynskyi developed and proposed a predictive and dynamic method of identifying indicator placement functions for rational and more effective deposit processing.

The purpose of the article is to analyze the rational methods of geospatial modelling.

Presentation of the main material. Geometrization of a mineral deposit is a method of studying and depicting on drawings (maps, posters, sections, graphs, etc.) geological forms, conditions of their bedding, properties of the substance that fills these forms, and processes occurring in the subsoil [13]. The main methods of studying and graphically depicting various indicators of the deposit are the method of isolines and the method of geological sections and profiles. Also, in the study of complex deposits, the methods of three-dimensional visual graphs and the modelling method are additionally used. Geological sections are very important structural charts. In some cases, being the result of a graphic summarization of primary documentation, they are final materials, and in other cases they are used in the process of further summarization as intermediate material, for example, when drawing up structural plans in isolines, geological maps, block diagrams, etc. Therefore, when geometrizing deposits, it is necessary to pay very serious attention to the documentation and proper execution of these structural schedules. A feature of the isoline method is a graphical representation of the spatial location of various qualitative characteristics of the deposit, expressed in numerical values. At the same time, isolines display not only real surfaces, but also imaginary ones that do not exist in nature. The reliability of the image of the placement of indicators on plans in isolines depends on the variability of this indicator and the conditions for obtaining the values of the indicator (density of reconnaissance points, sample size, etc.).

Geometrization can be carried out for individual workings, blocks, horizons, deposits or the entire mining area as a whole. The process of geometrization of the properties of the deposit consists of the following stages: testing, processing of measurement data, drawing up qualitative graphs and solving problems based on them. The method of geological sections makes it possible to detect with sufficient accuracy the shape of the mineral resource and determine its position among the host rocks in any cross section. The choice of intersections is determined by the shape and conditions of the ore body. However, with the help of sections, it is sometimes impossible to detect the nature of changes in the content of useful components, therefore, when geometrizing deposits, the method of geological sections is supplemented by the method of isolines.

The method of three-dimensional graphs is used for visual and three-dimensional representation of geological structures. The graph is presented in the form of block diagrams, which are an axonometric (affine, vector) projection of the blocks of the site or the entire deposit.

Geological indicators are divided into features that characterize the shape of the rock mass, its properties and processes in the subsoil. Following types of geometrization are distinguished depending on the field of subsoil study: geometrization of the form of mineral deposits and the conditions of their occurrence; geometrization of physical and chemical and technological properties of deposits and inside rocks; geometrization processes that occurred and are occurring in subsoil. Depending on the stage of the field study, specific problems of mining and geometrical drawings, as well as regional and detailed prospecting, and operational geometrization of fields are distinguished. The regional geometrization is carried out at the scale from 1:50,000 to 1:500,000. The data on prospecting, as well as space, aerophotographic, geological and geophysical surveys are taken into account. It allows making generalizations and general forecasts, and identifying areas which are perspective for further exploration. Detailed stakeout geometrization is carried out at scales from 1:5,000 to 1:50,000 on the basis of detailed prospecting, as well as geological, structural, geophysical and geological surveys.

Various mining-geometric graphs of the conditions of a deposit occurrence and the raw material contained in a deposit are drawn at this stage. Geometrization data are taken into account when evaluating deposits, estimating resources and planning mining enterprise. Operating geometrization of a deposit is carried out at a scale of 1:100–1:5000. It is performed on the basis of detailed prospecting and geological information obtained when performing preparation works and cleaning of mining workings. Operating geometrization allows revealing structural and qualitative patterns which helps to build forecasts on deposits and on their rational development. The methodology of geometrization considers techniques and methods of detection and imaging the field form and properties, the conditions of a field occurrence and the processes occurring in the depths [14].

With the help of the volumetric modelling method, deposit models are created based on the results of geometrization performed by the methods of isolines, geological sections, and volumetric graphs. In its turn, the use of this method makes it possible to visually depict the shape of the mineral deposit, host rocks, tectonic shifts, placement of components and exploration of the deposit. The output of conditioned blocks from the massif depends not only on its natural state, determined by the genetics of the deposit, but also on a number of technical factors that can be controlled. These include the method of preparing the block stone for extraction and the direction of cutting in relation to natural cracking.

After analyzing the structure of geometrization, the continuity of the relationship between geometrization and forecasting methods based on the same approach to processing the initial information is clearly visible, which makes it possible to consider them the basis for solving production issues for rational exploration and development of the field.

At the stage of processing geological exploration data, structurally homogeneous surfaces are formed, which makes it possible to calculate reserves divided into categories. The basic unit of information for accounting for reserves of a decorative stone reservoir is a stock counting figure. The study of decorative stone by geometrizing the deposit based on the method of geological sections allowed researchers to identify the shape of the body and determine its spatial position. However, such a narrow approach to the method of geometrization does not give a clear idea of the nature of changes in the content of qualitative indicators of decorative stone. Therefore, the priority task is precisely to carry out the geometrization of the deposit of decorative stone according to quality indicators using the isoline method. It is obvious that the most complete picture of the deposit, the spatial arrangement of its forms and properties, can be obtained only with the complex application of all the methods of geometrization discussed above. Also, the analysis of literary sources revealed that the study of regularities of distribution of quality indicators can be performed without increasing the volume of geological exploration data based on mathematical methods of geometrization.

Structurally homogeneous surfaces are formed at the stage of processing geological prospecting data, which makes it possible to calculate reserves by category. The basic unit of information for accounting for reserves of a layer of decorative stone is the stock count figure.

The size, shape and position of the layer in the subsoil are determined by a set of linear and angular values, which are called geometric parameters. These include: coordinates of points at the contacts of the formation with the host rocks, in which geometric parameters are installed; extension and dip angle of the surface (contact) of the formation; deposit capacity; depth of bedding; the position in space of the symmetry elements of the studied geological structure.

Coordinates x, y, z on the surface of the deposit are determined by the results of survey shooting, measurements and inclinometer surveying of wells [2]. Inclinometers used in mining mainly apply measuring systems based on a combination of three gravity sensors (separately along the x, y and z axes) and three magnetic (ferroprobe, magnetoresistive) type recorders. The maximum accuracy of the measured parameters for this type of complex of recording elements is ± 0,1° when measuring the zenith angle and ± 0,5–1° for the azimuthal angle [6, 7].

The output of conditioned blocks from the array depends not only on its natural state due to the genetics of the field, but also on a number of technical factors that can be controlled. These include the method of preparing the block stone for removal and the direction of cutting in relation to natural fracturing. The influence of these factors on the yield of block stone from the rock mass was studied at the Dobrynske labradorite deposit.

In most deposits of granite, gabbro and labradorite, there is a multisystem fracturing with a pronounced layering.

On the basis of geological data on wells of the field, the maximum possible yield of blocks at depth intervals was determined. It was determined for each interval separately by dividing the total capacity of the conditioned columns by the total length of the wells in the interval. Based on these data, the average maximum possible block yield for the field as a whole was determined.

When preparing a block stone for excavation, mining machines create additional partition surfaces that are superimposed on the natural fracturing of the massif, so the actual output of the block stone from the mined rock mass always differs from the maximum possible.

During the preparation of block stone for excavation by mining machines, additional surfaces are created, which are superimposed on the natural fissures of the massif, therefore the actual output of block stone from the extracted mining mass is always different from the maximum possible. In most deposits of granites, gabbros and labradorites, there is a multi-system cracking with clearly marked layering.

The ratio of the length of the column (L_l) to the number of cracks in it (N_{nc}) is the cracking modulus:

$$\mu = \frac{L_l}{N_{nc}}. \qquad (1)$$

When the deposit is developed in horizontal layers, the division of the conditioned columns of the core into several layers is inevitable, depending on the height of the ledge being developed, which is equivalent to the imposition of additional artificial fracturing on the massif. In this case, the probability of obtaining large conditioned blocks decreases with a decrease in the height of the mining ledge. For each method of preparation for excavation, the modulus of cracking can be calculated, taking into account the overlay of additional interface surfaces (μ_{ci}).

The ratio of the modulus of cracking for the accepted method of preparing for the excavation of blocks and the modulus of cracking of the massif will be called the coefficient of reduction of blocks output:

$$К_c^i = \frac{\mu_c^i}{\mu_m^i}, \qquad (2)$$

where μ_c^i and μ_m^i – estimated cracking modules in the specified depth interval, respectively, for the adopted method of extracting blocks and natural massif.

The expected output of blocks in a given interval for this method will be determined as follows:

$$К_v^{ci} = К_c^i \cdot К_v^{mi}. \qquad (3)$$

The average yield for a field is defined as the arithmetic mean of the data obtained for well depth intervals

$$К_v^{ci} = \frac{\sum_1^i К_v^{ci}}{i}, \qquad (4)$$

where *i* – number of well depth intervals; K_{vci} – calculated output for the interval.

When calculating the cracking modulus for the extraction method, additional horizontal interface surfaces created during the separation of the stone from the massif should be taken into account. The lowest modulus of cracking and yield of blocks is obtained when cutting the massif with a diamond-rope installation. In this case, each conditional column will be cut horizontally into additional 2–3 parts. It turns out that there will be five gaps in the depth interval for each well. When working out the deposit with 5m-high ledges with diamond-rope stone-cutting machines, only a single additional gap will appear in the interval. The maximum possible average output of blocks in the field is $К_v$ = 0,18 · 17 %.

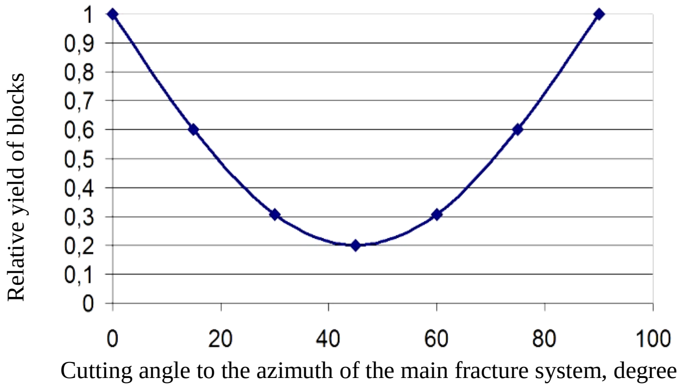

Diagram 1. Dependence of block yield on block chipping direction

Analyzing these data, it can be noted that in preparation for the extraction of blocks by rope stone-cutting machines and a ledge height of 10 m, the maximum possible output of blocks will increase 1,26 times compared to other methods. It should be noted that the high yield of blocks during extraction by rope-cutting machines is possible only if the separation planes of the main crack system are used. It should be noted that a high output of blocks when mining with rope stone-cutting machines is possible only if the planes of separation of the main system of cracks are used. However, if the cutting direction does not coincide with the direction of the main cracking system, the output of blocks decreases. The most favourable is the direction of 45°, when the decrease in output of the blocks is maximum. Based on the performed research, it was found that the real yield of blocks in the field, taking into account its decrease from the direction of cutting the array, can be calculated by the expression:

$$К_v^i = К_v^{cm}\ [1 - 0{,}8 \cdot \cos(90 - 2\alpha)]. \qquad (5)$$

Conclusions. As a result of the conducted research, it can be concluded that the study of the decorative stone by geometrizing the deposit based on the method of geological sections allowed the researchers to identify the shape of the body and determine its spatial position. However, such a narrow approach to the geometrization technique does not give a clear idea of the nature of the change in the content of quality indicators of decorative stone. Therefore, the priority task is the geometrization of the decorative stone deposit according to qualitative indicators using the isoline method. It is obvious that the most complete idea of the deposit, the spatial arrangement of its forms and properties, can be obtained only with the comprehensive application of all the geometrization methods discussed above. Also, the analysis of literary sources revealed that the study of the regularities of the distribution of quality indicators can be performed without increasing the volume of geological exploration data based on mathematical geometrization methods. The most effective criterion for the exit of blocks from the array is the diamond-rope method of extraction. In this case, it is possible to use the natural block of the array by 85,2 %.

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Моделювання видобутку природного каменю

Є очевидним, що за таких темпів використання мінеральних ресурсів основну долю розвіданих запасів корисних копалин буде вичерпано із надр в період найближчих 30 років. Звісно, що часткового вирішення мінерально-сировинної проблеми можна досягнути завдяки науково-технічним досягненням, впровадження яких дозволить скоротити об'єм споживання сировини чи замінити певні її види менш дефіцитними. Проте основним способом задоволення потреб в сировині залишається розробка існуючих та пошук нових родовищ. Тому важливим завданням нашої та інших держав є розробка методів, що дають можливість отримати найбільш достовірні відомості про родовища з метою прийняття максимально ефективних рішень для їх розробки.

Ключові слова: моделювання; геометризація; розробка родовищ.

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