The mining and geometrical methodology for estimating of mineral deposits

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Abstract. Ensuring the correct development of the deposit is a priority production task, which is based on a scientifically grounded assessment of the geometrical characteristics of the mineral deposit and a clear understanding of the nature and quantity of the deposit’s reserves. The aim of the study is a geological and industrial assessment of a mineral deposit, which provides for the correct determination of the quantity and quality of explored reserves, requires the collection and processing of such material, which would be sufficient to draw up a technically correct and economically feasible project for the development of the deposit. The research methodology consists in mining and geometrical modeling and monitoring of subsoil based on progressive and classical methods and techniques for geometrization of the array of minerals and host rocks. This includes a set of measures aimed at collecting and evaluating the initial information, assessing its accuracy, mathematical processing and determining the optimal and most effective methods for solving the problem of geometrization of the field. The results allow us to practically solve the problems of mining operations related to the assessment of reserves of mineral deposits, their genesis, the nature of occurrence, quality, the possibility of sorting, forecasting and industrial development. An effective set of methods has been developed based on the statistical assessment of mineral deposits, as well as the use of the latest geoinformation systems, which provide the possibility of high-quality and accurate calculation and assessment of mineral deposits.

1. Introduction
Of particular importance for ore deposits is the geometrization of the quality and physical and chemical properties of rocks and minerals, which is one of the most important tasks of a mining enterprise. [1–5]. The graphic-analytical method allows you to establish the distribution of the content and create a spatial model of the deposit in order to determine the relationship between the components [6–9]. The development of a deposit requires significant costs, and their effectiveness directly depends on the completeness and quality of information about deposits, their composition, the presence of minerals and, directly, mineral reserves. [10–14]. These problems can be solved on the basis of a set of studies aimed at geometrization, statistical evaluation of the deposit, and modeling and monitoring of its shape, properties and volumes [15–19].
Geometry and subsoil modeling [20–23] is based on information about geological, geochemical, geomechanical and other properties of the deposit that characterize various features and indicators (structure, properties, state) of the mountain massif and sources of georesources [24–27], which are modeled geometrically, including topographic surfaces and different types of projections [28–30]. Geometrization is the methodological basis of subsoil geometry. The complex of geometrization methods consists of collecting and completing the source information obtained during exploration, surveying, testing, geophysical and special research [31–33]; systematization, pre-processing and evaluation of the accuracy of information using variation statistics, the theory of random functions, finite differences; mathematical and geometric modeling and evaluation of model accuracy; using the model to solve problems of exploration and industrial development [34–36], as well as determining the geological and genetic composition of the deposit [37–40].

2. Purpose
The aim of the study is a geological and industrial assessment of a mineral deposit, which provides for the correct determination of the quantity and quality of explored reserves, requires the collection and processing of such material, which would be sufficient to draw up a technically correct and economically feasible project for the development of the deposit.

The task of geometrization of the mineral deposit is to obtain information about the deposits and its systematization in order to further its practical application and solve the problems of mining. One of the applications of geometrization is the estimation of mineral reserves [41–45]. This necessitates the creation of a set of methods [46–49] that will allow to perform with maximum efficiency the calculation of reserves of the mining enterprise.

3. Methods
Geometrization for the purpose of calculating mineral reserves can be carried out using geoinformation systems.

Consider the K-Mine geoinformation system. K-Mine contains a large number of routines to perform these calculations. The module allows you to perform calculations of volumes by different methods (the method of horizontal plans, the method of cross-sections, a modified method of cross-sections using triangulation networks and the like).

When calculating the volume by the method of areas and the average height perform the calculation of the volume of the area of the base, as well as the average height of the excavated layer, set by the user. When calculating the control of the volumes between the excavation and the embankment, the averaging of the height is performed over the entire area.

The calculation of volumes by the method of vertical sections is used to calculate the volumes of complex block figures, consisting of objects of different types, which can be located in several different layers, ledges and have a complex profile of the section. The peculiarity of the calculation of volumes in this way in K-Mine is that at the initial stage the construction of two triangulation surfaces for the new and old positions of the ledge, which have as a dividing line the calculation contour.

Triangulation surfaces are built on the basis of data of all objects included in each category of layers. Next, on the triangulation surfaces is the operation of their intersection with the vertical planes and determine the contours of the figures describing these sections. In the future, the solution of the problem is reduced to the solution of the standard problem of calculating volumes by the method of cross sections. Thus the package of the reporting documentation on a settlement figure is formed and all necessary constructions (construction of sections and their numbering) are carried out. The report contains a calculation table with indicators for calculating the area for each section, as well as a graphical representation of each section at a given scale.
After closing the editor before printing, the objects (frames, section lines and their numbers) on which the report was formed are deleted in the working area of the screen. Thus, K-Mine allows you to quickly assess the volume of mining operations in the design and modeling of mining operations.

Consider the microMine geoinformation system. As an example of deposit geometry, we take the results of calculating the balance reserves of ilmenite Birzuliv deposit in the program. The calculation of ilmenite reserves in the Birzuliv deposit was performed using the MicroMine system using the block modeling method, which is one of the most modern and objective methods of estimating the resources and reserves of minerals used worldwide.

A project based on the Birzuliv deposit database has been created to calculate stocks in the MicroMine environment. It consists of two files: Collar.dat (figure 1, figure 2), which contains information on wells and Assay.dat (figure 3), which contains information on samples.

![Figure 1. The structure of the file Collar.dat database Birzuliv deposit.](image1)

![Figure 2. 3D-visualization of wells drilled at the Birzuliv deposit, according to information from the file Collar.dat.](image2)
Figure 3. The structure of the file Assay.dat database Birzuliv deposit.

In addition, included graphic materials of the preliminary calculation of reserves, namely: the plan of calculation of reserves by the coordinate reference (figure 4). Due to this, if necessary, the results obtained in the process can be easily compared by overlapping and comparing.

Figure 4. Plan for calculating reserves and wells extracted from the database in the MicroMine environment.

4. Results and discussion
At the first stage of work with the database, a statistical analysis of the distribution of values of ilmenite content of Birzuliv deposit was performed. The distribution in the samples is estimated as bimodal lognormal (figure 5). The bimodal distribution of a component in the geological sense is usually explained by two different geological processes (or two different stages of one process). In the case of the Birzuliv deposit, it seems that first an ore stratum was formed with
the primary distribution of ilmenite in it, and then the ore component was redistributed within the stratum, most likely under the influence of gravitational factors. This is evidenced by the increased values of ilmenite content in the lower part of the thickness (closer to the sole is the roof of the weathering crust).

![Histogram of distribution of ilmenite contents in samples by Birzuliv deposit (scale is a natural logarithm constructed in MicroMine environment).](image)

The results of “logarithmic statistics” are used for the lognormally distributed value, namely: \( Ln \) mean \((x)\) \(-4,018\), \( Ln \) standard deviation \((\sigma)\) \(-1,327\). According to the “three sigma” rule, all values of a normally distributed random variable lie within \( x \pm 3 \sigma \) (for the lognormal distribution, the same applies to the logarithms of these quantities). To sample the results of mineralogical analysis of sands of the Birzuliv deposit, the maximum values of ilmenite content should not exceed:

\[
exp(4.018 + 3 \times 1.327) = exp(7.999) = 2977.98.
\]

Thus, we can conclude that among the values of the original sample for the Birzuliv deposit there are no ones that do not obey the laws of a certain distribution. Based on the performed calculations, it was decided not to exclude the maximum values of ilmenite contents when calculating reserves. Further, based on the test results (ASSAY.dat), composites (combined intervals) were created according to the ilmenite content in separate samples according to economically justified conditions. In addition, the concept of metro percentage (product of the content of the useful component and the capacity of the ore layer) was used, which was 20 kg/m\(^3\)×m. The metro percentage is used to account for intervals with a relatively low content of a useful component with a large deposit thickness, or with a low deposit thickness with a very high content of a useful component. With the use of composites on each of the sections outlined the roof and sole of the mineral deposit (figure 6, figure 7).
Figure 6. Roof and sole of the mineral, contoured in section using composites (combined intervals).

Figure 7. Roof and sole of the mineral, contoured by sections using composites (combined intervals).

Using the function to create digital models of surfaces, roof contours and soles of the sections are combined into two surfaces: the roof surface and the sole surface. In the future, they turn into a framework that limits the mineral on all sides (figure 8).

The framework does not include the area of off-balance sheet stocks (limited by the balance-off-balance limit using the polyline line trimming function). An empty block model is created within the obtained framework. The shape of the elementary (single) block of the block model is determined by the shape of the placer (ore thickness). The Birzuliv deposit is characterized by low capacity compared to the area of distribution. According to the available materials, there is no obvious elongated shape in the plan in any of the directions. Therefore, the most optimal shape with a ratio of length, width and power $10 \times 10 \times 1$ m. The size of the elementary (single) block (subblock) of the block model is determined taking into account two main factors. First, there is no need to make a single unit less than the selected mining technology provides
selective mining. Secondly, the unit block must be small enough to accurately describe the configuration of the ore thickness surfaces. The size of single blocks of $10 \times 10 \times 1$ m and sub-blocks of $2 \times 2 \times 0.2$ m was chosen for the block model of the Birzuliv deposit. The created model is "filled" with interpolated values of ilmenite content by the method of inverse distances using the 3D-estimation of blocks function (figure 9). The interpolation occurs in several stages, each of which corresponds to a certain category of reserves (B, C1, C2). One of the important parameters of interpolation is the size of the "search" ellipse, they increase from the highest category of reserves to the lowest and are based on the reasonable parameters of a drilling network ($100 \times 40$ m, $200 \times 60$ m, $400 \times 80$ m, respectively).

To delineate the reserves of different classes and categories, closed contours were created that limit the areas of different degrees of study (figure 10).
5. Conclusions
As a result, a block model of the deposit was obtained, which reflects the distribution of ilmenite. It should be noted that the model allows not only to more accurately estimate reserves and other parameters of the deposit, but also to quickly decide on the direction of extraction work depending on the market situation of ilmenite concentrate or other factors. By assigning category contour indices to each of the blocks, all stocks of the block model were divided into corresponding classes (categories). As a result of creating a report on the block model, the distribution of ilmenite reserves was obtained. The total amount of balance reserves (B+C1+C2) of ilmenite of the Birzuliv deposit amounted to 4526 thousand tons. The error in calculating inventories was 8.3%. The solution of the actual scientific and technical problem of geometrization of the reserves of the mining enterprise, aimed at ensuring the process of mining production, was shown. The set of considered methods is practically applicable, and the researches directed on its improvement are very perspective.

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Figure 10. Distribution of the area of the Birzuliv deposit by classes (categories) of reserves.
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