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3D modeling of the Ag-Mo-Au deposit Babyak in Western Rhodopes: Implications from the geostatistical analysis and spatial distribution of the elements

3Д моделиране на Ag-Mo-Au находище Бабяк в Западни Родопи: изводи от геостатистическите анализи и пространственото разпределение на елементите

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Abstract. The Babyak deposit is situated in Western Rhodopes, about 170 km SE of Sofia. The magmatic-hydrothermal stage of the Rila-Western Rhodopes batholith is characterized by the development of a large quantity of aplites, pegmatites and quartz veins. Ore-bearing zones are with regular thickness, massive structure and consist of grey-white quartz. The 3D geometric features of ore bodies as well as the distribution of Ag, Mo and Au grades in 3D space imply some important information for evaluating the deposit. All ore bodies are vein-shaped and located within or near to the intrusion, suggesting that the intrusion was the most important ore controlling factor. Designed 3D geological and block model describes the spatial features of Ag contents distribution and ore body morphology in Babyak deposit. The 3D modeling is a very useful tool for investigating the shape of complex vein type deposits.

Keywords: Babyak deposit, Western Rhodopes, 3D computational models, Kriging efficiency, variogram modelling.

Introduction

Very important step for understanding and evaluating of ore deposits is modeling in 3D the shape of ore bodies and their grade distribution. Benefiting from the advancement in computer technologies, geostatistical algorithms and computational 3D graphics, computational modeling has also become useful techniques for managing various spatial information. That type of modelling techniques have played important roles in understanding geological systems and exploring mineral resources.

In this study some geostatistical tools for spatial analysis and prediction of contents in the ore bodies are used. The results of geometric and geostatistical modeling gives important information for the better understanding and evaluation of the Babyak deposit.

Geological setting

As a part of the Rhodopes massif, two major stages of the Alpine development (compression and extension) form the modern structure of the region (Ivanov, 2017). The compression stage is associated with the emergence of a system of superposition located thrust plates with south vergence, which caused a significant thickening of the Earth's crust. Within the frame of the Rhodopes, three thrust terrenes are divided – lower, intermediate and upper. The magmatic-hydrothermal stage of the Rila-Western Rhodopes batholith is characterized by the development of a large quantity of aplites, pegmatites and quartz veins. The veins are oriented mainly to the NE or NW following the main geological structures from the region. The established ore minerals are pyrite, molybdenite, galena, sphalerite, chalcopyrite, specularite and wolframite. The contacts of the quartz veins with the hosted rocks are sharp ones accompanying with thick (up to 10 m and more) zone of hydrothermal alteration. Zone 5 is the best developed ore zone in the deposit according thickness and intensity of the ore mineralization. It is composed by quartz-iron oxide-sulphide vein with variable thickness with slope of 45–60°. The vein sinking to the WSW conforming to the metamorphic foliation of the hosted rocks.

Interpolation algorithms and variography

Ordinary Kriging method has been applied. This method (named after the South-African mining engineer Krige who has developed this algorithm in the 1950s) represents a geostatistical interpolation technique that considers both distance and the degree of variation between data points with known values when estimating values in unknown points (Matheron, 1963; Stein, 1999; Wackernagel, 2003). Estimation has been done in a stepwise manner. It starts with a kriging run that used a search ellipsoid matched to the modelled variogram ranges. Cells estimated at this search ware tagged as that they can be differentiated from other cells. A second kriging run have been done using a search ellipsoid double the variogram ranges.

The variogram analysis is an essential part from the geostatistical modeling of ore deposits. The aim of this analysis is a determination of the spatial variability nature for studied geological feature (Matheron, 1967; Rendu, 1981). The variogram function is defined as the relation of average differences between measured values towards distances between samples:

$$\boldsymbol{\gamma(h)} = \frac{\sum_{i=1}^{n_h}(x_i - x_{(i+h)})^2}{2n_h},$$

where $\mathbf{x_i}$-$\mathbf{x_{i+h}}$ are $\mathbf{n_h}$ of number differences between values (e.g. element's contents), measured in samples at average distance h between samples and situated along given direction.

After calculation of average differences in separate directions, represented by experimental variograms, it is very important to select an appropriate theoretical model, to describe adequately a natural structure in variability of data used.

Experimental variograms are approximated with spherical model, represented in general form as:

$$\boldsymbol{\gamma(h)} = \boldsymbol{C}\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right) \boldsymbol{for\ h \le a},$$

$$\boldsymbol{\gamma(h)} = \boldsymbol{C\ for\ h} > a,$$

where C and $\boldsymbol{a}$ are variogram's sill and range respectively, while $\boldsymbol{h}$ is distance between samples.

In this work first were generated omni-directional variograms (Fig. 1a) and then directional ones. As the data are highly skewed – high grades were filter out (start at ~95 percentile down to 90 percentile for Mo and Au) when generating the experimental semi-variograms. Spherical models are fitted in this filtered space, but the nugget (C_0) and Sill variance values has been transformed back to the population variance for the kriging.

Cross-validation routine is performed for estimation of averaged variogram model significance, which is applied later in kriging interpolation modeling. This validation compares true Ag contents measured in raw samples with their kriging estimations by neighbor samples. The results are shown on Fig. 1b, where a high similarity between true values and estimates, with correlation of 0.91, is illustrated. Similarity between real and estimated values confirms the good representation of natural silver variability by the used variogram model, which is condition for precise estimation through ordinary Kriging method.

Result and discussion

In this work ordinary Kriging method was used to generate the 3D block model (Fig. 1c) of Ag distribution by using the Ag assay data of 3807 underground samples from the Babyak deposit. The ore mineralization at Babyak is characterized by particular complexity expressed in different distribution in the space of the 3 economically most important metals – the Ag, Au and Mo. The mineralization control for each element is different. In fact Ag and Mo are similar but Au is very different. For these reasons it was decided that modelling each grade separately for each mineralized zone/vein would provide the best variography models as this approach provided the best stationarity for each. The sample dataset for Babyak deposit was analyzed by comparing grades against rock type and hydrothermal alteration type. Ag grades are very closely matched with veins with minor amounts in gneiss, pegmatite and granite types. With higher Ag grades this association with veins becomes more obviously. From other side the other main components show also significant amounts in granite, pegmatite and gneiss rock types. Higher grades of Au are not necessarily associated with only one of vein, granite or pegmatite type. In this work are presented results from block modeling of Ag grade as they match with the vein.

Next step of works includes basic statistics defining the distributions of Ag, Mo, Au and sample thickness. Since dataset comprised different types of data (trench, channel and borehole) for each domain, cumulative frequency curves were generated or QQ Plots to compare the grade distributions of the different data types inside each domain model and to assess the presence of any bias.

All distributions are positively skewed.

The geostatistical block model of Ag ore body is constructed for the volume with dimensions 720x1200 m in plan and 522 m in depth. Digital elevation model is constructed by topographic map and it is used to remove eroded parts.

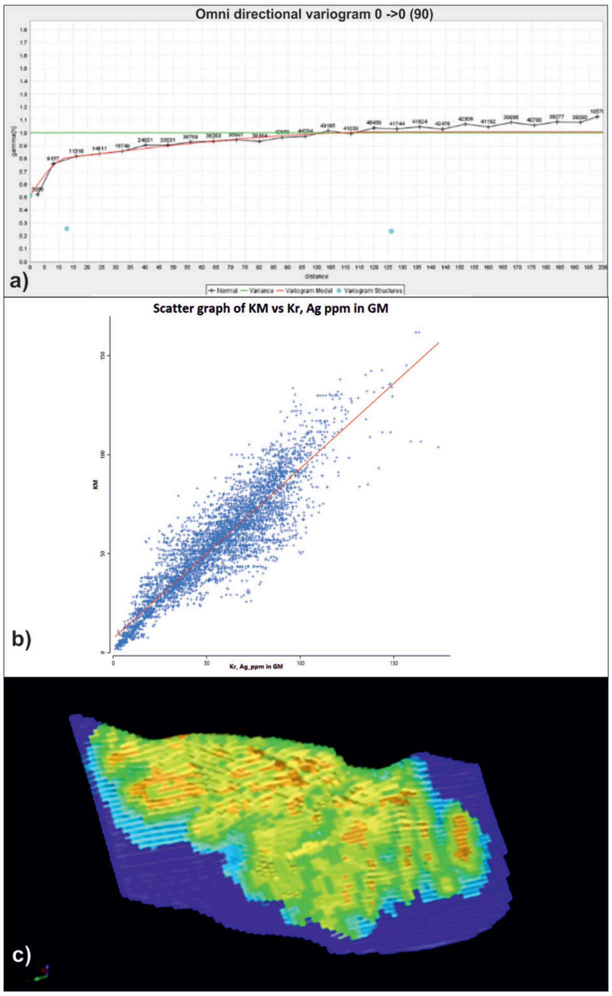

Fig. 1. *a*, omni directional variogram for Ag in Zone 5; *b*, correlation between true Ag contents in core samples and their kriging estimations; *c*, 3D model of the Ag ore body

The Babyak vein zone is divided into 5964 blocks, each of which measures 10 m×15 m×3 m. The ore grades in every block aare estimated by ordinary kriging method. 3x3x3 discretization of cell size is used. During estimation, kriging parameters such as slope of regression, number of samples, kriging variance, block variance, kriging efficiency and others have been checked. Most of the values have positive values for KE and slope of regression close to 1. The resulting digital model represents central coordinates, estimated silver contents and the kriging estimation variance for each block.

Conclusions

Designed three-dimensional model describes the spatial features of Ag contents distribution and ore body morphology in Babyak deposit. The 3D geometric modeling is a very useful tool for investigating the shape of complex vein type deposits. The geometric modeling results not only represent ore bodies in 3D virtual space, but also give more reliable information about ore grades and their distributions. The omnidirectional variogram analysis shows smooth silver contents variance, which is precondition for the precise model design. The major anisotropy axis is oriented either in northeast or northwest direction, parallel or orthogonal to ore body length respectively, in depends of applied method for automated approximation of variogram model. It could be concluded that silver content variances are smoothest in NE-SW direction generally, while highest variance values are observed in NW-SE direction.

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