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3D geological modeling of ore zones in the Sedefche deposit, Bulgaria

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3D геоложко моделиране на рудните зони в находище Седефче, България

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Abstract. In this study, several geostatistical tools have been employed for the spatial analysis and prediction of the ore body contents in the Sedefche deposit, which is located in the easternmost part of the Zvezdel-Pcheloyad ore field. To test the conditions of stationary and to define a domain reflecting this stationarity, the following approach was applied: modeling of the ore bodies (Wireframe modeling); analysis of domain boundaries, and estimation (Variogram models). The resulted three-dimensional model illustrates the spatial characteristics of Au content distribution and the morphology of the ore body within the Sedefche deposit.

Keywords: Sedefche gold-silver deposit, 3D modeling, spatial analysis.

Introduction

A crucial step in comprehending and assessing ore deposits involves the creation of 3D models to depict the shapes of ore bodies and their grade distributions. Thanks to the rapid advancements in computer technology, geostatistical algorithms, and 3D graphics, the computational modeling has emerged as a highly valuable technique for managing diverse spatial information. These modeling techniques have played pivotal roles in enhancing our understanding of geological systems and in the exploration of mineral resources.

In this study, several geostatistical tools have been employed for spatial analysis and the prediction of ore body contents. The outcomes of both geometric and geostatistical modeling yield invaluable insights that significantly contribute to a more comprehensive understanding and assessment of the Sedefche deposit.

Geological settings

The Sedefche gold-silver ore deposit situated immediately north-northwest of the village of Sedefche, is in the easternmost part of the Zvezdel-Pcheloyad ore field of the Zvezdel volcano-plutonic complex (Georgiev, 2012; Popov, Popov, 2022). In particular, the ore filed belongs to the Momchilgrad ore sub-region, which coincides spatially with the Momchilgrad depression. The area of the deposit consists of two complexes, as noted by Georgiev (2012).

The pre-Tertiary metamorphic basement comprises various metamorphic rocks, including biotite and two-mica gneisses, amphibolite-biotite gneisses, marbles, and kyanite-garnet-biotite schists (Sarov et al., 2008; Bonev et al., 2010). The Tertiary volcanogenic-sedimentary cover is composed of sedimentary, volcano-sedimentary, and volcanic rocks. Above the metamorphic rocks lie limestone

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and sandy-clay rocks. Locally, the limestones are partially silicified. Acidic to intermediate dykes (rhyolitic, dacitic and andesitic in composition) are products of an Oligocene volcanic activity.

Geological surveys have identified two gold-silver ore bodies within the deposit – the Northern (central) and Southern one, respectively. The elongated in shape (400 × 60 m) Northern ore body, situated several hundred meters north of the village of Sedefche, is hosted among highly hydrothermally altered pyroclastic rocks and andesites, trending in a N-NE direction (Dragiev, Dragieva, 2006f[1]). The basement comprises marbles, amphibolites, alternating chlorite, chlorite-amphibole and quartz-mica schists and calcschists. The Paleogene rocks built up carbonaceous-sedimentary-tuffaceous series with late Eocene age (organogenic limestone and intermediate tuff, tuffites and tuff-breccias). Oligocene tension dyke complex is presented by gabbro-monzonite, basaltic andesites bodies and rhyolite bodies and dykes covered by Quaternary eluvial-deluvial sediments (Nedyalkov, Mavroudchiev, 1995). The South ore body is located west of the village of Sedefche and is elongated N-S direction. The mineralization is developed within the silica cap overlying limestones and clay-sandy sediments.

The ore bodies of the Sedefche deposit are layer-like and pseudo-conformable in shape (Georgiev, 2012). The deposit is a typical representative of the low-sulfidation epithermal gold-silver type. There are two broad styles of mineralization: base-metal/low gold-bearing mineralization containing abundant sulphides (pyrite and marcasite) and gold-silver bearing silica replacement bodies, which are partially stratabound and controlled by steep N-S structures that overprint the volcanic rocks. The first mineralization is closely related to the Zvezdel-Pcheloyad intrusive complex, which also hosts the Pcheloyad lead-zinc deposit. The second mineralization is later and may be related to the younger rhyolite complex located south of the Sedefche deposit. The gold-bearing mineralization contains abundant sulphosalts and a significant portion of the gold present is considered refractory.

Geological methods

A total of 133 drill holes (81 DD and 52 RC) obtained during the exploration drilling program were used for geological modeling. In order to test for stationarity conditions and define a domain that reflects this stationarity, the following approach was applied:

- *Modeling of ore bodies (Wireframe Modelling)*. For the purposes of 3D modeling, composites of 0.3 g/t Au (minimum threshold content) were calculated and used in delineating and interpreting the ore bodies in the cross-sections. This is made for each mineralized zone. Interpretations across individual sections are linked to create 3D geological models. After the models creation, they are cut according to the topography. Figure 1a shows isometric views of the domains at the 0.3 g/t threshold. A total of 14 ore domains are delineated in different colors, as two-ore bodies are bigger in size. The yellow domain presents the main ore zone 1, and in brown color is ore zone 2 (Fig. 1a).
- *Analysis of domain boundaries*. Two economic bodies are delineated. The analysis of the domain boundaries of ore body 1 was conducted at a threshold value of 0.3 g/t Au. The boundary analysis defines a reference point and then examines how (on average) the estimates change, approaching and moving away from this reference point (Fig. 1b). The left part of the graph shows the distribution of Au contents falling within the domain (inside), while the right part (outside) shows the distribution of contents falling outside the model. Here, the X-axis represents the distance from the domain contact. The estimate is made as the arithmetic mean of intervals with a length of 1 meter. A similar analysis was carried out for ore body 2, where the same trend is preserved. Unlike ore body 1, the average contents are significantly lower, and the distance after which re-enrichment occurs is also smaller.

Results and discussion

For the purpose of estimation process, the Ordinary Kriging method has been applied in this study. This technique is named after the South-African mining engineer Krige who developed it in the 1950s. A geostatistical interpolation method takes into account both the distance and the degree of variation between known data points when estimating values at unknown points (Matheron, 1963; Stein, 1999; Wackernagel, 2003).

- Experimental variograms are created at a 10° lag distance. A contour map of the dispersion derived from the experimental variograms is made. A spherical model variogram with a dual structure was employed, with anisotropy oriented in the plane of the mineralized zone. The range of the variogram defining the maximum distance at which there is a correlation between the samples, does not exceed 40 meters. For silver, no variogram was established, and interpolation was solely carried out using the inverse distance-weighted method.
- Two estimation methods are used – Ordinary Kriging and inverse distance weighting. A com-

[1] Dragiev, H., B. Dragieva. 2006. *Geological Report of Gold-silver Ore with Calculation Reserves and Resources as of 01.01.2006 on the Sedefche Deposit* (in Bulgarian).

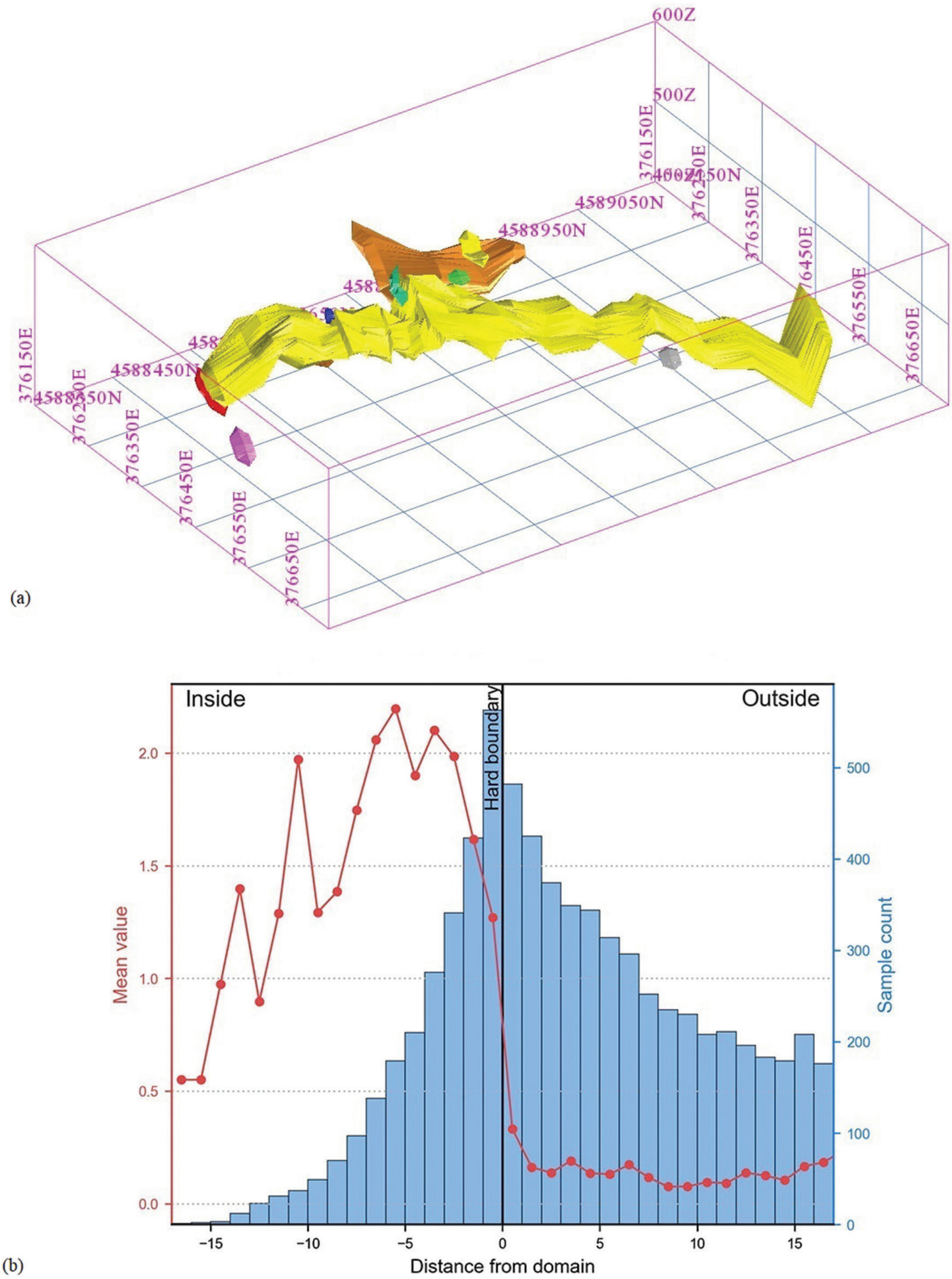

Fig. 1. Isometric views of the 14 domains at the 0.3 g/t Au threshold in different colors, as two ore bodies are bigger in size in yellow and brown color (*a*), and boundary analysis at the 0.3 g/t Au threshold in ore body 1/yellow domain (*b*)

parison has been made between the scores using both methods. The correlation coefficient is above 0.9, with it being 0.95 for zone 1, indicating a very strong positive proportional relationship between the two scores.

- A 3 × 3 × 3 cell size discretization is used.

• Sample count – a minimum of 10 and a maximum of 20 samples are used in the first search ellipse, a minimum of 6 and a maximum of 20 in the second, and a minimum of 4 and a maximum of 20 samples in the third.

• For each block, the number of samples, number of drill holes, kriging variance, and the search ellipse used for estimation were calculated. The use of these parameters allows for model verification and can also be utilized in the subsequent classification of reserves and resources in the deposit.

• Mitigation of nugget effects (Grade capping and cutting) – for ore body 1, a value of 12 was assigned to all samples with contents above 12 g/t.

• Kriging estimation – a search ellipse is used, which was adjusted based on the modeled variogram ranges. The block estimation process was carried out sequentially. For estimation using kriging and inverse distance weighting methods, three search ellipses are used. The first ellipse is aligned with the modeled variogram range values. The second and third ellipses are respectively 2 and 3 times the initial values, with a reduced minimum sample count for estimation.

• Bulk density – the value determined by Gorubso-Kardzhali JSC in the report on the reevaluation of gold-silver ore reserves and resources is used, where the bulk density of the ores is determined during the detailed study phase based on samples taken from the mining works and exploratory drill holes, intersecting the ore bodies. An average bulk density of 2.60 t/m³ was adopted.

Conclusion

The three-dimensional model created here vividly illustrates the spatial distribution of Au content and the morphology of the ore body within the Sedefche deposit. The results of geometric modeling not only offer a visual representation of ore bodies within a 3D virtual space but also provide more reliable insights into ore grades and their distribution. The constructed block model can be utilized to classify the estimated resource quantities in the central section of the Sedefche deposit according to one of the internationally accepted classifications currently in use.

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