Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 31, issue 2, pp. 1-7, selected paper from the First International EnviroMining Virtual Conference 2025

3D GEOLOGICAL MODELING AND GRADE ESTIMATION FOR A GOLD DEPOSIT IN SHANDONG PROVINCE, CHINA

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DOI: 10.2478/minrv-2025-0011
received – 22.01.2025 / revised – 08.02.2025
accepted – 18.02.2025 / published – 18.06.2025

Abstract: *This study focuses on the grade estimation for a hydrothermal altered underground gold deposit in Shandong Province, China. First, the 3D geological model of the deposit was constructed implicitly using the drillhole data and geological maps, while the orebody enveloping surface was built explicitly through the cross sections and vertical sections. Then, within the mineralized alteration domain, the grade estimation was performed using the Ordinary Kriging (OK) and Sequential Gaussian Simulation (SGS). The key steps consist of data exploratory analysis, variogram modeling, Ordinary Kriging estimation, Sequential Gaussian simulation and model validation. For the model validation, the cross-validation was used to assess the parameters of the variogram models and the neighborhood searching, while the global statistics and the variogram of the realizations were compared to those of the original data to check the reproduce. Compared to the explicit orebody model, the kriging estimates present a more precise spatial distribution of the mineralization, and the simulated realizations provide the probability of the ore occurrence. The both models are reliable and valuable to the mining industry.*

Keywords: *Geological modeling, Grade estimation, Drillhole data, Ordinary kriging, Sequential Gaussian simulation, Gold deposit*

1. Introduction

The study area is a hydrothermal gold deposit controlled by fault zones. Mineralization primarily occurs in disseminated, fine-vein, and stockwork forms, with individual veins ranging in width from a few centimeters to several meters. The spatial continuity of the ore bodies is relatively poor. Currently, explicit modeling techniques face challenges in capturing the detailed geometric characteristics of gold ore bodies. In contrast, Geostatistics, with its advantages of efficiency, reproducibility, solid theoretical foundation, and minimal human interference [1], has become the mainstream technique for mineral resource estimation in the mining industry.

This study employs ordinary kriging and sequential Gaussian simulation to estimate the grade of a gold deposit in Shandong Province, China, and compares the results with orebody envelopes generated by explicit modeling. The objective is to demonstrate the complete workflow of geostatistical grade estimation and simulation [2] and to quantitatively assess the uncertainty in delineating ore blocks.

2. Geological modeling

The gold deposit under study is located in the Jiaodong gold field on the southeastern margin of the North China Craton known, as the shown in Fig. 1[3]. The Jiaoxibei gold field is controlled by a series of

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northeast- trending fault zones from west to east, the Sanshandao, Jiaojia, and Zhaoping fault zones, hosting large gold deposits. The study area is situated near the northern side of the Jiaojia Fault zone (Fig.1b). The Jiaojia Fault intersects the intrusive rock contact zone between Linglong granite and Guojialing granodiorite, shaping and positioning the orebodies. The orebodies are tabular and dip gently to the northwest (20–40 degrees).

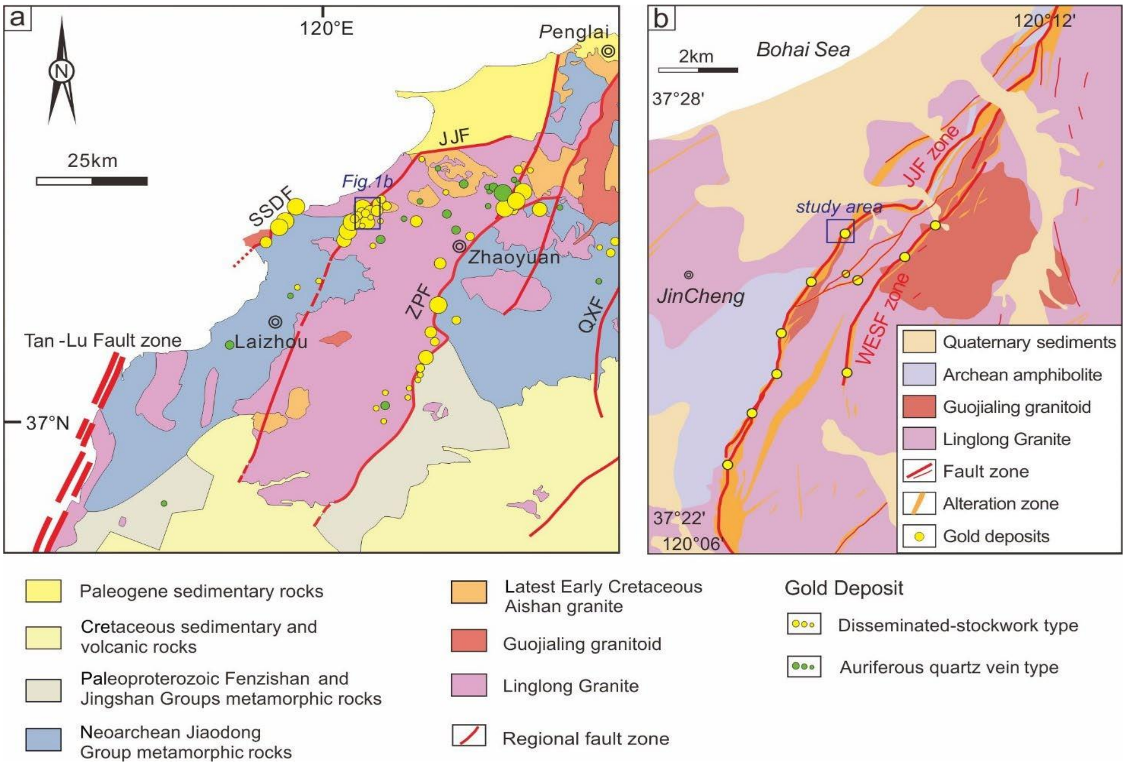

Fig.1. Geology of the Jiaoxibei Gold field showing the regional Jiaojia fracture zone (JJF) [3]

The mineralization has a strong structural control and is spatially associated with a complex alteration pattern. The tectonic alteration zones gradually transitioned, with the degree of structural deformation, alteration intensity, and the enrichment degree of gold minerals gradually decreasing from the center of the Jiaojia Fault Zone toward its surroundings [4].

The drillhole data, surface geological maps, and cross-section maps (Fig.2) were collected to generate the 3D geological model of the gold deposit through the SKUA-GOCAD software [5], consisting of Quaternary sediment, Linglong granite, the alteration zone, Guojialing granodiorite, the Jiaojia Fault, and the orebody model (Fig.3). The alteration zone is selected as the domain for the grade estimation due to the concentration of the gold containments. The orebody enveloping surface was built explicitly using the cross sections from the exploration and mining stage.

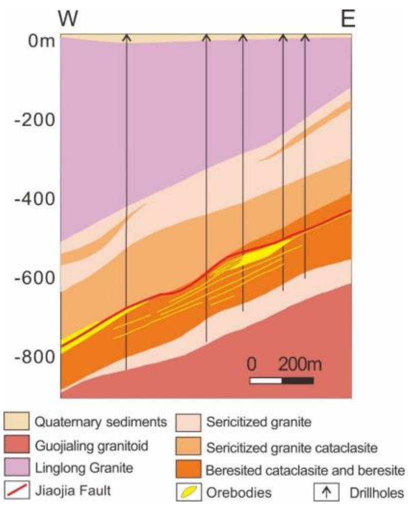

Fig.2. Cross-section of the geology of the deposit [6]

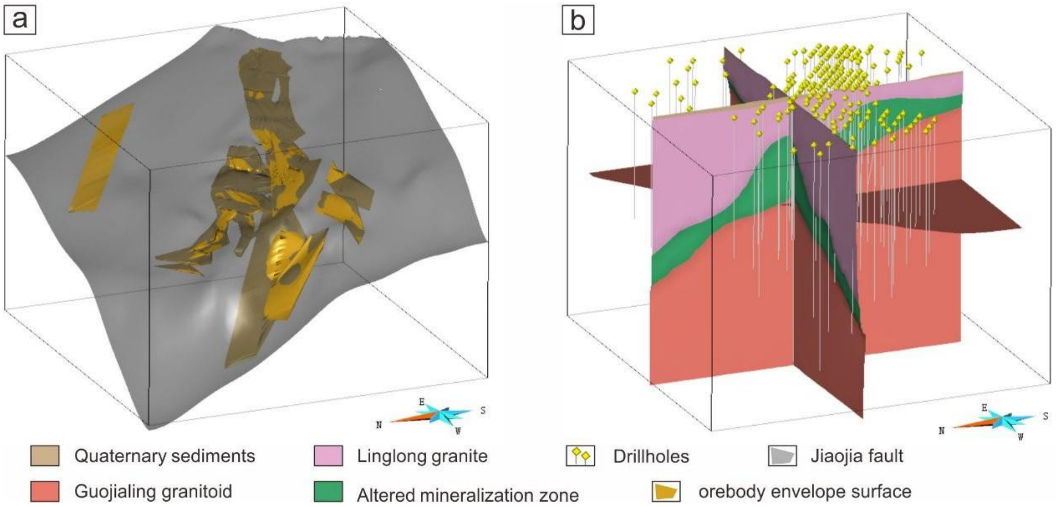

Fig.3. Sectional view of the geological model showing the general trend of the mineralization

3. Exploratory Data Analysis

198 drillholes were horizontally spaced ranging from tens to hundreds of meters. The samples are approximately 1m intervals along the drillholes. To regularize the data support, the samples were composited into 1m intervals. From the histogram of composites (Fig.4, left), the grade distribution exhibits positively skewed long-tailed. A few high-grade outliers can significantly influence the statistics and spatial continuity of the population. Capping method was applied to reduce the overestimation bias caused by the extreme outliers, which means the values exceeding the lower limit of the outliers were replaced with the threshold. Based on the frequency distribution of the composites, 30 g/t value was identified as the outlier threshold.

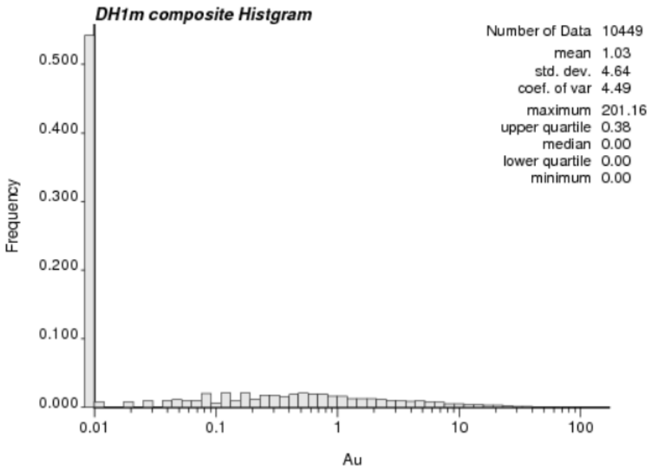

Fig.4. Histograms of gold grades within the mineralization domain for the drillhole composites

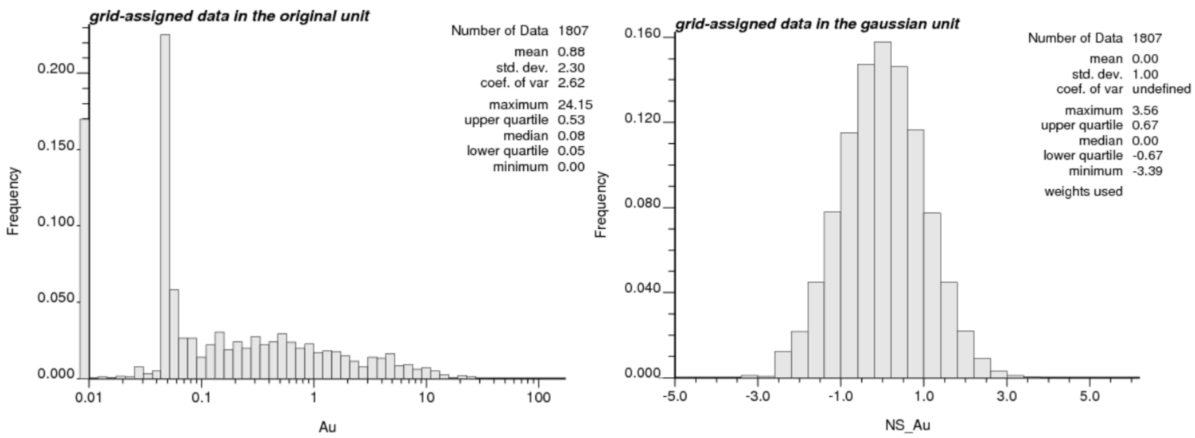

Fig.5. Histograms of gold grades within the mineralization domain for the grid-assigned data in the original unit (left) and the grid-assigned data in the gaussian unit (right)

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The study employs point kriging to estimate the block model, for which the hard data were required to assigned to the modeling block. The block size was set to 25m×25m×7.5m, and the assignment method is the arithmetic mean algorithm. As shown in Fig.5-left, the histogram of the grid-assigned data approximated a log-normal distribution. Next, the cell declustering technique [7] was applied to reduce the bias as a result of the preferential sampling phenomena. Finally, the declustered grid-assigned data were normal-score transformed into a standard gaussian distribution (Fig.5, right) for the Sequential Gaussian Simulation.

4. Variogram Modeling

The grid-assigned data in the original unit and the gaussian unit are used for the kriging and the simulation, respectively. As a result, their variograms were calculated and fitted respectively. A sufficient amount of data was available to obtain a robust variogram model for the mineralization domain. SKUA-GOCAD geostatistical tool was used to assess spatial anisotropy. From the variogram map, the horizontal continuity ranges were similar, hence, horizontal isotropic variogram and vertical variograms were calculated. The nugget effect was determined from the downhole variogram.

The variogram parameters, including nugget value, variogram shape and variogram range, were tested through the cross-validation. The best variogram parameters for the kriging estimation and the simulation are shown as Fig.6 and Table 1. The obtained R2 of both are 0.25 and 0.42, respectively, and the root mean squared error (RMSE) are 2.04 and 0.878, respectively, which are the highest R2 and the lowest RMSE among their respective variogram parameter tests.

Table 1. Variogram parameters for the estimation and the simulation

Hard data	**Sill**	**Nugget effect**	**Type**	**Sill contribution**	**Horizontal range (m)**	**Vertical range (m)**
Grid-assigned data in the original units	9	0.5	Exponential	8.4	100	80
			Spherical	0.1	300	80
Grid-assigned data in the gaussian units	1.34	0.2	Exponential	0.96	56	75
			Gaussian	0.18	300	35

Fig.6. Horizontal (red) and vertical (green) variogram fitting for grade estimation (left) and simulation (right)

5. Ordinary Kriging Estimation

Kriging provides the best estimate since it results in the theoretical smallest estimation error, narrowest confidence interval, and highest confidence [8]. On the other hand, the result is highly conditioned by the choice of the correct variogram model. The grid-assigned data in the original unit did not show any significant trends at the scale of modelling and the variograms were characteristic of local stationarity. The block model grades were estimated using OK based on the SKUA-GOCAD platform (Fig.7).

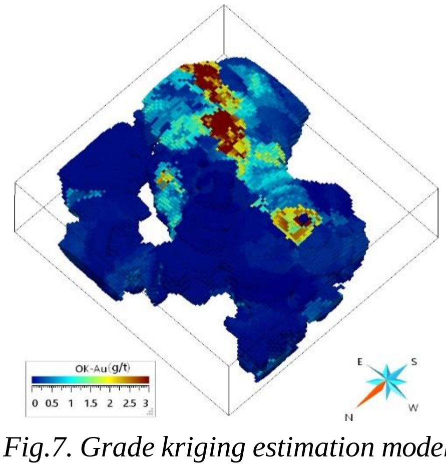

Fig.7. Grade kriging estimation model

6. Sequential Gaussian Simulation

Sequential Gaussian Simulation was conducted using grid-assigned data in the gaussian distribution. 100 realizations of grade data under the Gaussian distribution were generated and subsequently back-transformed to the original distribution (Fig. 8, left). The cumulative frequency plot and directional variogram of the 100 realizations were calculated and compared with those of the input data (Fig. 8, right and Fig. 9), validating that these realizations reproduce the input data.

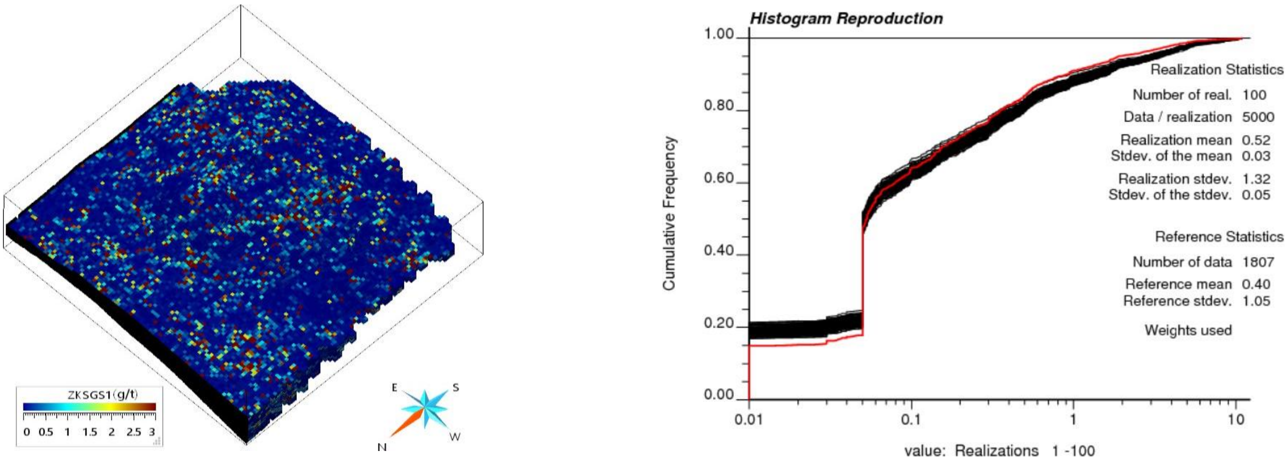

Fig.8. One of 100 grade realizations (left), and cumulative frequency reproduce of 100 realizations(right). The big gap in the cumulative frequency plot is due to a large amount of repeated assays of 0.05 g/t

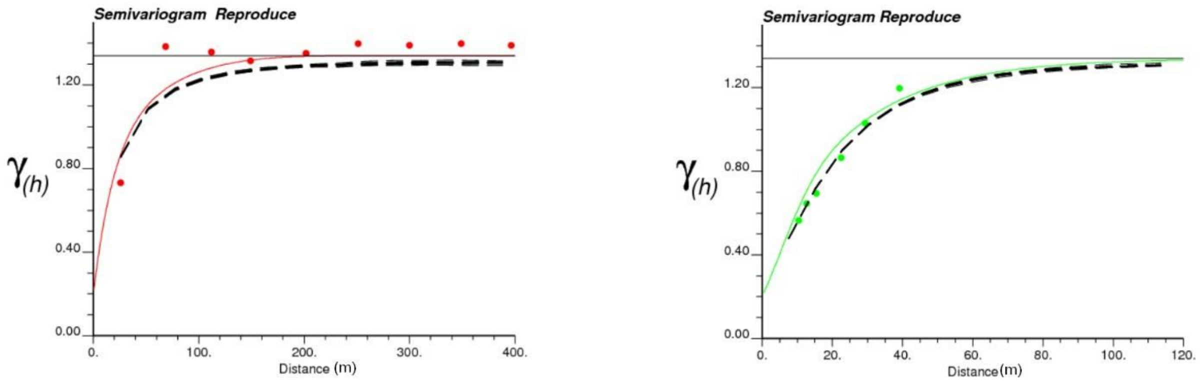

Fig.9. Reproduce of the horizontal variogram (left) and vertical variogram (right)

7. Model validation

The orebody envelope surface was explicitly modelled using data collected during the exploration and mining stages. The orebody model was used to validate the grade estimates and simulated realizations. As shown in the cross-sections (Fig. 10), on the blocks around the orebody envelope surface area, both the estimated and simulated grades are high-value. Additionally, the estimated and simulated grades reveal the thickness of the mineralized zones varies, which is thicker around the shallow portions and thinner around the deep part. It indicates the enrichment degree of gold containment is higher in the shallow regions.

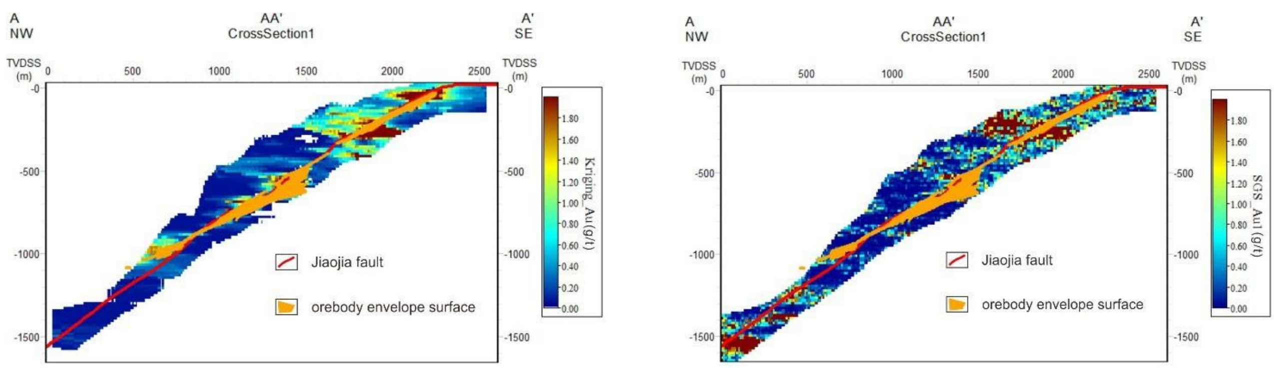

Fig.10. Cross sections of the estimation model (left) and one of the realizations (right)

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The ore blocks (Fig. 11, left) were extracted from the grade estimation block model (Fig. 11, right) based on the cutoff value of 1 g/t. The spatial locations of these ore blocks generally coincide with the orebody envelope, but more discontinuous, reflecting a more practical condition. However, in the deep regions of the orebody envelope, there are almost no ore blocks. This is partly due to the sparse distribution of drill holes in the deep areas, resulting in insufficient samples to delineate the orebody's position. Additionally, the sampled grades in the deep regions are relatively low, with only a few samples exceeding the cutoff grade. However, orebody lines manually inferred tend to be more continuous, leading to orebody envelope appeared to overestimate the actual spatial continuity of the orebody.

Through the 100 simulation realizations, the probability of the simulated grade exceeding the cutoff grade was calculated for each ore block. In areas with high estimated grades, the probabilities for ore blocks tend to be relatively low (Fig. 12, left). Additionally, in area around the orebody envelop surfaces, the probabilities for ore blocks are not always high (Fig. 12, right). Therefore, combining estimated grade values with ore block probabilities can reduce the risk of classifying ore blocks and provide mining companies with more valuable guidance for mining activities.

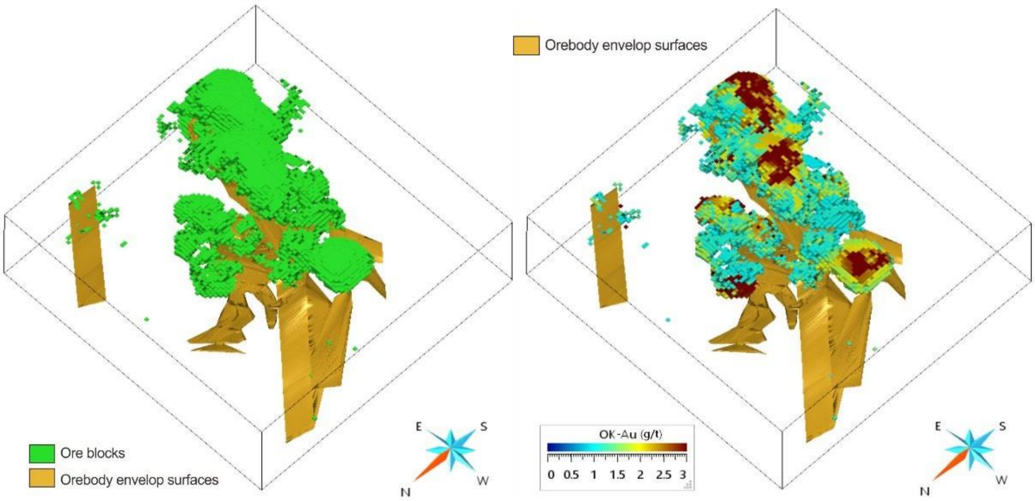

Fig. 11. Left- orebody enveloping surface is superimposed by the ore estimate blocks over the 1g/t cut-off value; Right- estimated grade of ore blocks

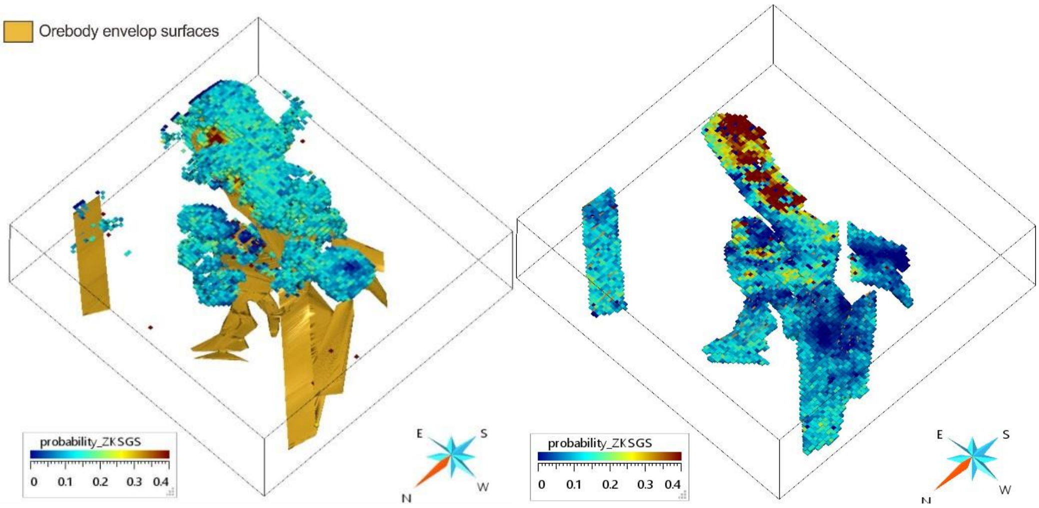

Fig.12. Left- probability of the simulated grade over 1g/t on the ore estimate blocks; Right- probability of the simulated grade over 1g/t on the blocks around orebody envelop area

8. Conclusion

This study described a six-step workflow of grade estimation for a gold deposit in the Shandong province of China based on the 3D geological modelling and geostatistical techniques. The findings of the estimation process revealed that the kriging estimates present a more precise spatial distribution of the mineralization than the orebody enveloping surface informed from the exploration and mining data. Additionally, the multiple simulation realizations measure the uncertainty of the ore block classification. The

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inherent risk associated is as a result of not being able to completely capture the true nature of the geology. From the context of a conventional approach to 3D geological modelling and geostatistical grade estimation, the results were acceptable.

Acknowledgements

This work is supported by the Project on 3D Geological Modeling and Deep Ore Body Extension Prediction of Xincheng Gold Deposits (No. 2019-G-09) and the China Scholarship Council (award to Xiaoning Liu for 1 year's study abroad at the University of Bologna). Participants of this study did not agree for their data to be shared publicly, so supporting data are not available.

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