Mon25-217

Geological modeling of tin placers of Sushchany-Perga zone using Micromine

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SUMMARY

The study focuses on creating a digital geological model of tin placer deposits in the Sushchany-Perga zone of Ukraine using Micromine software. This region contains significant beryllium, zirconium, rare earth elements, and tin resources. The research employed an integrated approach to digital geological modeling, implementing a multi-stage methodology from data preparation to three-dimensional visualization. Analysis of exploration borehole distribution revealed an optimal network with three northeastern-oriented profiles that identified industrial tin mineralization at 60-120 m depths. The SOLID model demonstrated high-grade ores (>0.2% Sn) concentrated in the central deposit area, forming lens-like bodies 2-8 m thick with distinct anisotropy along the northeastern strike direction (azimuth 45-50°). The three-dimensional wireframe model revealed complex ore body morphology with variable dip angles (15-30°) and continuity over 400 meters, covering approximately 45,000 m^2. Several zones of morphological complexity characterized by abrupt thickness variations and structural disruptions were identified, creating horst and graben microstructures that impact ore continuity. The research demonstrates how advanced digital modeling techniques can optimize exploration and development of strategically important tin deposits, contributing to strengthening Ukraine's mineral resource base.

Introduction

The Sushchany-Perga zone represents one of Ukraine's most mineral-rich territories, containing unique deposits of beryllium, zirconium, rare earth elements, and tin. Recent tectonic studies (Mychak, Farfuliak, 2021) have established that the formation of this zone occurred through at least five deformation phases, accompanied by the development of variously oriented shear zones. These researchers determined that the Khmelivska and Sushchanska shear zones share similarities in strike with the Nemyriv and Khmelnytsky fault zones of the Ukrainian Shield, belonging to the Nemyriv stage of fault formation (~1.99 billion years ago). Crystal chemistry investigations (Lupashko, 2017) of fluorite from this tectonic zone have revealed significant variations indicating heterogeneity of rare and volatile components in their parent sources. The growing demand in the global market for rare metals and strategic raw materials makes the exploration of these deposits particularly significant for Ukraine's economic development and resource independence.

Comprehensive geological modeling of the Sushchany-Perga zone's placer tin formations using modern digital technologies is essential for optimizing exploration and resource development. Recent methodological advances (de Kemp, 2021) have shown that spatial agent-based modeling significantly enhances the accuracy of geological surface representation by increasing spatial gradient information density. Similarly, (von Harten, Varga, Hillier, Wellmann, 2021) demonstrated that informed local smoothing in 3D implicit geological modeling reduces modeling artifacts arising from data uncertainty and configuration issues. These innovations enable researchers to develop detailed digital models revealing spatial patterns of mineralization and structural features of ore bodies in the Sushchany-Perga zone while maintaining geological consistency.

The structural-tectonic studies of the region (Pats, Derevska, Kozhenevskyi, Rudenko, 2016) have provided valuable insights into the formation of granite boulder-like rocks in the "Stone Village" geological reserve. These researchers established that most aplite-pegmatite veins are characterized by northeastern strike and nearly vertical dip (60-85°), coinciding with the orientation of numerous tectonic fractures formed during the Sushchany-Perga tectonic zone formation. Modern geological approaches as demonstrated by (Guo, Li, Jia, Yuan, Zheng, Liu, 2023) in ecological geology surveys establish deep interconnections between surface features and geological processes. The creation of an accurate digital model of the Sushchany-Perga zone's placer tin formations will enable the rationalization of exploration activities and ensure efficient development of these strategically important deposits, contributing significantly to strengthening Ukraine's mineral resource base and economic sovereignty.

The materials used in this study are based on geological data and reports obtained during previous exploration activities conducted in the 1960s and do not require additional permissions, as the deposit is currently not being developed and is not subject to a special permit for subsoil use.

Method and Theory

The methodological framework for this research is based on an integrated approach to digital geological modeling of tin placer formations using advanced geoinformation technologies. The study employed specialized tools from the MICROMINE mining and geological information system, which provides a comprehensive workflow from primary data input to three-dimensional deposit modeling and mineral resource estimation (Yan-fen, 2013; Da-chao, 2011; Gang, 2011). A multi-stage methodology was implemented, beginning with the preparation and systematization of source data from the Perzhanske placer tin deposit located in the central part of the Sushchany-Perga zone. This initial phase involved collecting, analyzing, and digitizing geological documentation, with particular attention to creating a structured database containing coordinate information, borehole geometric parameters, inclinometry data, sampling results, and lithological core descriptions.

Database development incorporated a multi-level data quality control system utilizing built-in automatic verification tools to identify and eliminate critical errors such as discrepancies in borehole coordinates, sampling interval overlaps, and missing mandatory parameters. The database architecture was designed according to normalization principles with correct table relationships established. The methodology emphasized the integration of diverse data formats through import and conversion tools, enabling the consolidation of information from various sources including tabular data (CSV, Excel, SQL), vector formats (CAD, GIS), raster images, and remote sensing data (SRTM and LIDAR). Special attention was given to coordinate system management, as MICROMINE provides conversion capabilities between different coordinate systems, ensuring accurate spatial referencing of geological objects—a critical factor for developing a reliable three-dimensional deposit model. The database population process followed a sequential workflow: reference dictionary formation, borehole information and inclinometry entry, sampling data loading, and incorporation of stratigraphic and lithological information, with rigorous data verification at each stage to detect mechanical and logical errors, correct identified inconsistencies, and apply statistical analysis methods to assess information reliability.

For spatial analysis and three-dimensional modeling, the methodology employed advanced geostatistical algorithms and interpolation methods to determine mineralization distribution patterns and ore body morphological characteristics. This approach facilitated the identification of spatial relationships between geological structures and tin mineralization, enabling the construction of an accurate digital model of the placer deposit's geological environment. The developed methodology includes a sequence of operations from primary data input to three-dimensional modeling, with particular attention to the accuracy of spatial referencing of geological objects and data verification at each stage. The use of automatic validation tools and capabilities for conversion between different coordinate systems ensured high precision and reliability of the created deposit model, establishing a foundation for optimizing further exploration activities and rational development of these strategically important deposits.

Results

Analysis of exploration borehole spatial distribution at the Perzhanske placer tin deposit revealed an optimal exploration network consisting of three main profiles with northeastern strike orientation. The distance between profiles (approximately 50 m) and between boreholes within profiles (20-40 m) provides sufficient detail for reliable reserve estimation. Boreholes range from 50 to 150 m in depth, effectively intersecting the entire productive horizon. Detailed analysis of tin content distribution across these boreholes identified industrial mineralization zones primarily concentrated at depths of 60-120 m, forming relatively consistent ore bodies along strike. Advanced SOLID modeling techniques were applied to visualize spatial tin concentration distribution, revealing that high-grade ores (>0.2%) are concentrated in the central deposit area, forming lens-like and sheet-like bodies 2-8 m thick, with tin content gradually decreasing toward the deposit flanks. Several sub-vertical enrichment zones were also identified, likely controlled by fault disturbances, confirming clear structural control of tin mineralization influenced by both lithological factors and tectonic elements. Based on comprehensive analysis of exploration data, a detailed wireframe model of the ore body was created to visualize its spatial characteristics and internal structure.

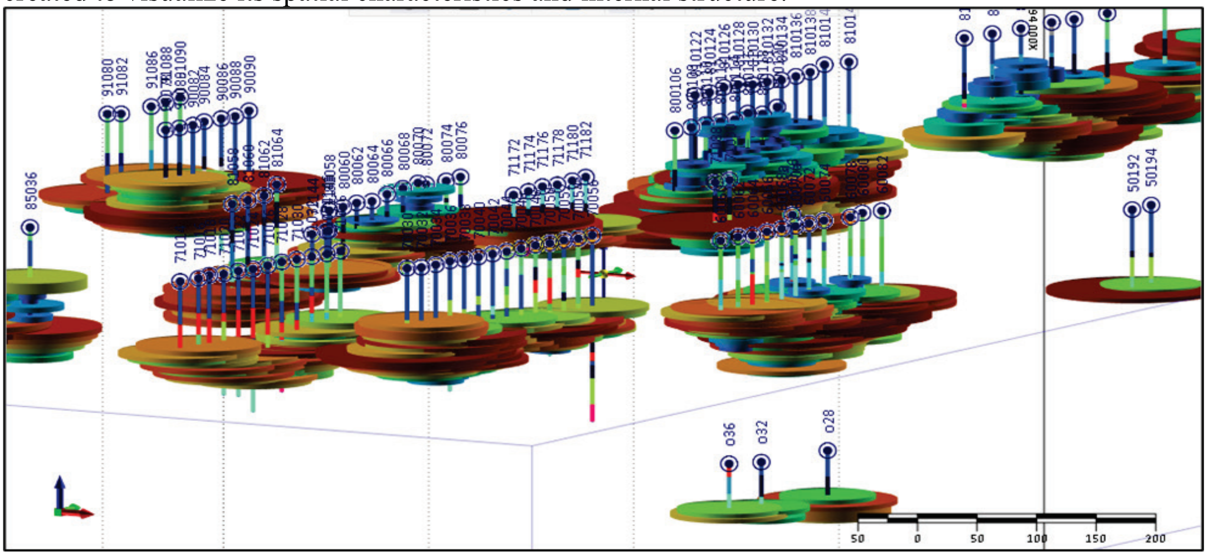

***Figure 1** Three-dimensional SOLID model of tin concentration distribution across the productive horizon showing high-grade zones (red) and low-grade zones (green) with structural control features.*

The SOLID model in Figure 1 provides crucial insights into the spatial distribution of tin mineralization at the Perzhanske deposit. The color-coded visualization employs a comprehensive gradient system where red tones represent high-grade zones (>0.2% Sn), orange to yellow indicate intermediate concentrations (0.15-0.2% Sn), and green shades show lower-grade areas (<0.1% Sn). This detailed representation clearly delineates the economic boundaries of the deposit and demonstrates the heterogeneous nature of mineralization. The model reveals that high-grade zones form coherent bodies with complex internal structure in the central part of the deposit, extending laterally for approximately 200-250 meters with vertical dimensions of 30-60 meters. These zones exhibit strong spatial correlation with specific stratigraphic horizons and structural features. Notably, the enrichment patterns display distinct anisotropy, with preferential elongation along the northeastern strike direction (azimuth 45-50°), consistent with the regional tectonic framework. The transition zones between high and low-grade mineralization show gradational boundaries in most areas, suggesting primary depositional controls, although several sharp lateral discontinuities are evident, particularly in the northwestern section, indicating possible fault displacement or erosional unconformities. The model also captures several isolated high-grade lenses in peripheral areas that may represent satellite ore bodies deserving further exploration attention.

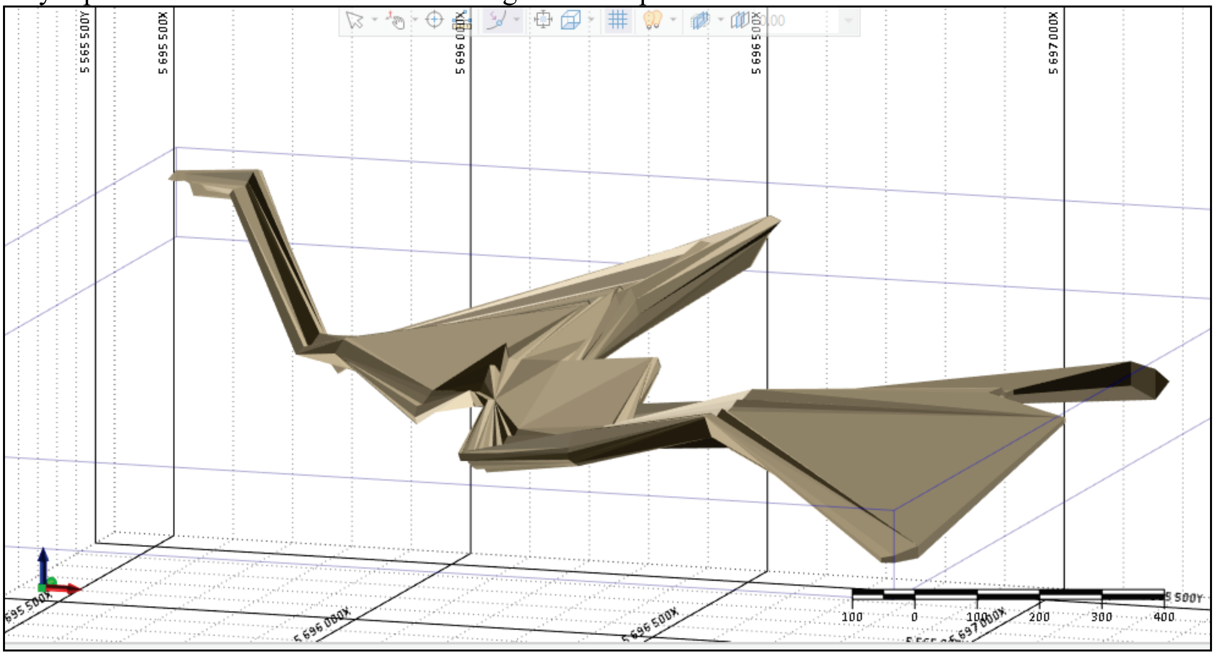

***Figure 2** Three-dimensional wireframe model of the Perzhanske tin deposit ore body showing morphology, spatial localization, and structural complexity features (scale 1:2000).*

The three-dimensional wireframe model presented in Figure 2 constitutes a comprehensive geometric representation of the Perzhanske tin deposit's primary ore body, capturing its intricate morphological features and structural relationships. This high-resolution model, created through integration of drilling data from 37 exploration boreholes, reveals a complex sheet-like structure with pronounced undulatory characteristics and variable thickness. The ore body exhibits a dominant northeastern strike direction (azimuth 40-55°) that closely aligns with the principal structural grain of the Sushchany-Perga tectonic zone, suggesting strong structural control on mineralization. Dip angles display significant variability, ranging from 15° in the southwestern section to 30° in the northeastern portion, with a consistent tendency toward flattening at depth—a feature potentially related to decreasing lithostatic pressure or changes in competency contrast between host rock units. The ore body maintains continuity over a strike length of approximately 400 meters while ranging in width from 50 meters at its narrowest sections to 150 meters in dilation zones, covering a total projected area of approximately 45,000 m². The model clearly delineates a series of asymmetric flexural bends that significantly complicate the overall geometry, with amplitude variations of 5-15 meters and wavelengths of 40-60 meters. These deformation features likely reflect both syn-depositional paleotopography and subsequent tectonic modification. Roof depth varies considerably from 40 meters in the southeastern sector to 80 meters in the northwestern region, demonstrating substantial topographic relief on the upper contact surface. Particularly significant are several zones of morphological complexity characterized by abrupt thickness variations (ranging from 2 to 8 meters), localized structural disruptions, and facies transitions. These complicated zones, highlighted in the model through differential surface rendering, reveal fault-bounded blocks with vertical displacements of 3-7 meters, creating a series of horst and graben microstructures that significantly impact ore continuity. The model's interactive nature allows for real-time geometric analysis, volume calculation, and structural interpretation, providing an essential framework for both resource evaluation and mine planning considerations. Its dynamic architecture enables continuous refinement as additional exploration data becomes available, ensuring ongoing relevance throughout deposit development.

Conclusions

1. The spatial analysis of the Perzhanske tin deposit revealed optimal exploration borehole distribution with three main northeastern-oriented profiles that identified industrial mineralization concentrated at depths of 60-120 m, with high-grade ores (>0.2% Sn) forming lens-like bodies 2-8 m thick in the central deposit area.
2. The three-dimensional wireframe model demonstrated complex ore body morphology with pronounced northeastern strike direction (azimuth 40-55°) and variable dip angles (15-30°), exhibiting strong correlation with the principal structural grain of the Sushchany-Perga tectonic zone and covering a total area of approximately 45,000 m².
3. Application of the MICROMINE system enabled creation of a comprehensive digital geological model that identified several zones of morphological complexity characterized by abrupt thickness variations, structural disruptions, and facies transitions, providing an essential framework for resource evaluation and optimization of further exploration activities.

References

Da-chao, Z. (2011). Application of geological modeling technique with Micromine in a copper-nickel mine. Mining Technology, 11(4), 38-42.

de Kemp, E. D. (2021). Spatial agents for geological surface modelling. Geoscientific Model Development, 14(5), 3527-3549.

Gang, L. (2011). A study on the application of Micromine digital mine model to geological mining. Yunnan Geology, 30(3), 371-374.

Guo, X., Li, J., Jia, Y. H., Yuan, G., Zheng, J. L., Liu, Z. (2023). Geochemistry process from weathering rocks to soils: Perspective of an ecological geology survey in China. Sustainability, 15(2), 1002-1018.

Kapelista, I., Kireitseva, H., Tsyhanenko-Dziubenko, I., Khomenko, S., Vovk, V. (2024). Review of Innovative Approaches for Sustainable Use of Ukraine's Natural Resources. Grassroots Journal of Natural Resources, 7(3), 378-395.

Lupashko, T. (2017). Crystal chemistry and genetic features of fluorite from the Sushchano-Perzhanska tectonic zone (Ukrainian Shield). Mineralogical Journal, 39(3), 31-45.

Mychak, S., Farfuliak, L. (2021). Results of the tectonophysical study in the Sushchany-Perga fault zone of the western part of the Ukrainian Shield. Geoinformatics, 2021(1), 1065-1070.

Pats, R., Derevska, K., Kozhenevskyi, S. R., Rudenko, K. (2016). Tectonic conditions of granite boulder rocks formation in the geological reserve "Stone Village": (northern part of Volyn megablock). Geological Journal, 4(357), 59-67.

von Harten, J., de la Varga, M., Hillier, M., Wellmann, F. (2021). Informed local smoothing in 3D implicit geological modeling. Minerals, 11(11), 1281-1297.

Yan-fen, L. (2013). Micromine 3D geologic modeling and its geological significance. International Journal of Mining Science and Technology, 23(5), 723-728.