УДК 622.2 https://doi.org/10.33271/crpnmu/80.040

© N. Zuievska[1], D. Darmostuk[2], T. Kosenko[1], R. Semchuk[1], O. Ovcharov[1]
[1]National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
[2]Kyiv Regional Employment Center, Kyiv, Ukraine

GIS ASSESSMENT OF COPPER-ZINC DEPOSITS UNDER CONDITIONS OF UNDERGROUND MINING

© Н.В. Зуєвська[1], Д.Г. Дармостук[2], Т.В. Косенко[1], Р.І. Семчук[1], О.О. Овчаров[1]
[1]Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна
[2]Київський обласний центр зайнятості, Київ, Україна

ГІС-ОЦІНКА МІДНО-ЦИНКОВИХ РОДОВИЩ В УМОВАХ ПІДЗЕМНОГО ВИДОБУТКУ

The purpose. The main purpose of the study is the identification of natural and technological types and grades of ores, followed by their spatial zoning within the studied deposit.

Methods. The methods of interpolation and approximation of the initial data were used to display the surface relief and distribution of minerals. The choice of method depends on the amount of initial data and its uniformity. For spatial interpolation, the Kriging and radial basis functions methods were used, which allows us to identify general patterns of distribution of the studied parameters. For fast data evaluation with a large number of points, the methods of minimum curvature and triangulation are used.

The results of the study include the creation of a digital model of the deposit, mapping of mineral deposits with analysis of spatial changes, and estimation of copper and zinc reserves. The use of GIS made it possible to visualize the three-dimensional distribution of minerals in the wells, which simplified the analysis and improved its quality.

Originality. The scientific novelty of the study lies in the improvement of the methodology for analyzing geological results at the stage of mining work planning, when the main strategic decisions regarding deposit development in the product quality management mode are made. The methodology allows for a reliable assessment and zoning of ore deposits based on qualitative characteristics.

Practical implementation. The practical significance of the work lies in the use of GIS in the development of a system for comprehensive technical-ecological-economic assessment of the effectiveness of measures for managing the quality of mineral raw materials in complex conditions, where reserves of valuable mineral raw materials are concentrated in thin and very thin ore veins. The choice of technology for managing the quality of mineral raw materials is based on the results of the assessment of the qualitative characteristics of minerals, the identification of natural types of ores in the ore massif based on geological information, the substantiation of the characteristics of technological types of ores, and their zoning in the underground space using geoinformation modeling.

Keywords: *GIS, deposit, zinc, copper, geological surveys, modeling, quality management, ore, wells, concentration, technology, efficiency, geological cross-section, geodetic monitoring.*

Introduction. The main goal is the selection of natural and technological types and grades of ores and their zoning in space. At the same time, at the planning stage of mining operations, the main strategic decisions regarding the development of the deposit are made in the mode of product quality management [1, 2].

To achieve the goal, the following tasks were defined and solved: a geological model of the deposit was created using geoinformation systems with the determination of the spatial distribution of ore quality.

Research methods. To solve the tasks set in the work, the following research methods were used: review, generalization and analysis of previous theoretical developments and practical experience on the topic research; method of geological mapping; remote methods of obtaining initial information (satellite surveying); methods of mathematical statistics and probability theory; methods of programming and development of geoinformation systems.

The practical significance of the work lies in the use of GIS in the development of a system of complex technical-ecological-economic evaluation of the effectiveness of measures to manage the quality of mineral raw materials [3].

The main methods of managing the quality of mineral raw materials: the separate extraction of technological grades of mineral in many deposits allows to significantly increase the indicators of production during processing, as well as the level of complexity of the use of subsoil and minerals extracted, which is very important for increasing the capacities of enterprises for the production of final products and reducing costs for its production.

The choice of technology for managing the quality of mineral raw materials is based on the results of the assessment of the qualitative characteristics of minerals, the selection of natural types of ores of the ore massif based on geological information, the substantiation of the characteristics of technological types of ores and their zoning in the underground space using geoinformation modeling. Spatial placement of ore types and their quantitative ratio form the strategy of deposit development as management of the quality of mineral raw materials.

Description of the object of research. The Watson Lake mine network is characterized by a volcanogenic array of base metal deposits in an area located in northwest Quebec with high zinc, copper, and silver content [4].

To date, extensive stratigraphic drilling and accompanying electromagnetic studies of the wells indicate that the geological potential is quite large. The discovery of a new, higher grade (>20% zinc) Noranda deposit immediately adjacent to Watson Lake strengthens the case for continued exploration at greater depths.

The Watson Lake deposit is characterized by high variability of the concentration of the useful component in the ore body. It is represented by a massif of rocks, penetrated by a dense network of differently oriented veins and veins containing ore minerals. Therefore, the problem of using separate extraction and separate processing of different grades of ore is relevant. For underground mining, producing selective ore extraction is a challenging task.

With the help of the Google Earth Pro program, the coordinates of the boreholes were obtained (table 1) by combining the map of the area with the selection of the mining zone and the electronic map (fig. 1).

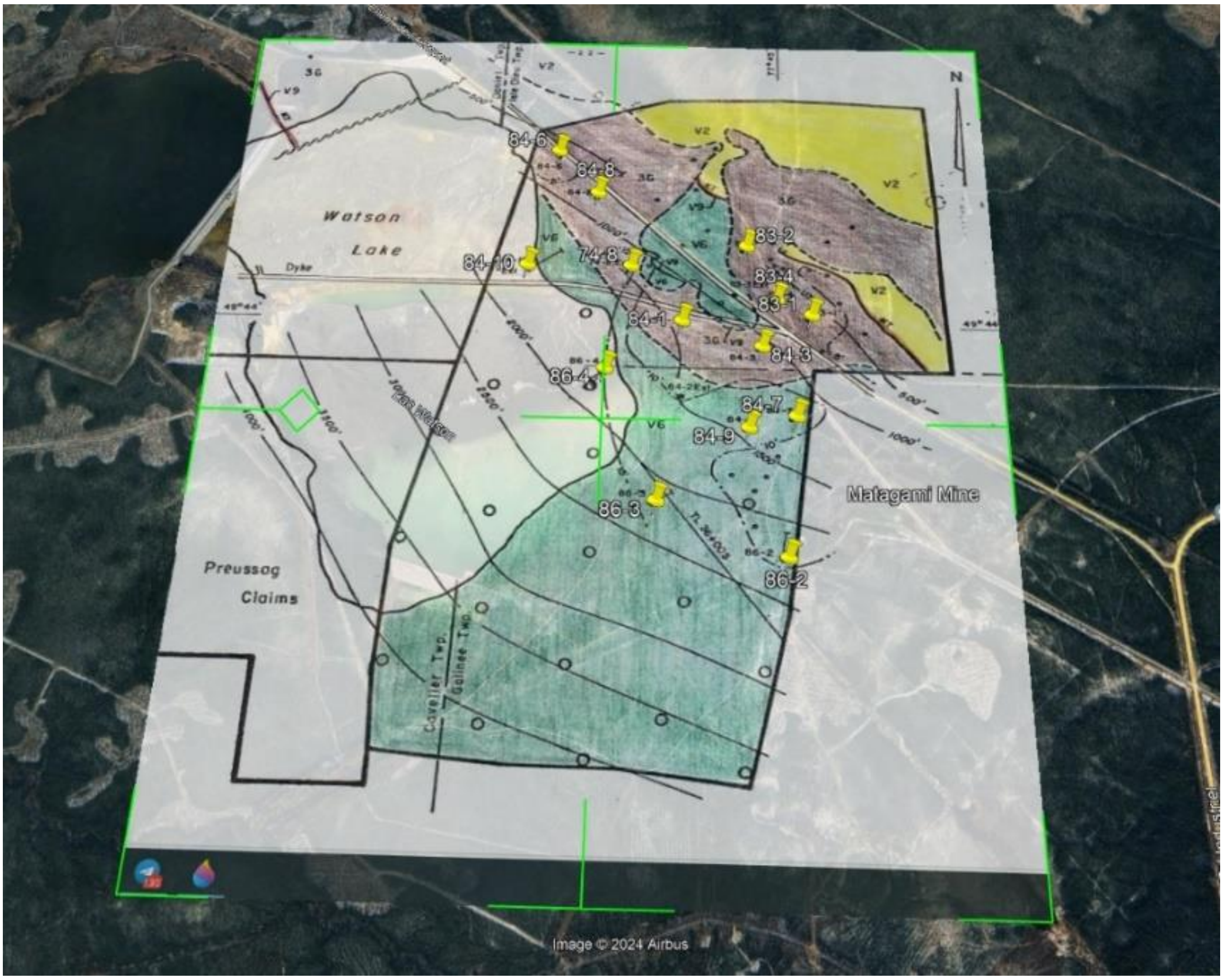

Fig. 1. Map of the Watson Lake field with the extraction zone highlighted

Table 1

Information about drill holes where the Zn layer is present

Drill-hole ID	X UTM	Y UTM	Z	Azimuth	Inclination	Length	Zn concentration
86-2	301817.27	5511699.51	269.90	325.00	5.00	721.77	2.21
86-3	301351.57	5511928,29	269.10	56.00	5.00	728.47	2.02
86-4	301169.66	5512477.43	269.90	232.00	5.00	534.92	0.76
84-2	301474.08	5512371.33	269.90	0.00	0.00	648.00	2.70
74-8	301273.96	5512931.18	270.00	0.00	0.00	605.00	3.10
84-9	301699.48	5512219.39	269.00	0.00	0.00	730.00	3.70

The deposit is characterized by reserves of valuable mineral raw materials, concentrated in thin and very thin ore veins. The development of such reserves by traditional technologies, which include blasting, leads to a significant reduction of the ore mass by waste rock, which increases the costs of processing raw materials and reduces the through-flow of metal. It is advisable to use technologies and equipment for mechanical selective excavation. A promising way to highlight local areas can be their contouring with the help of cutting. It is in such cases that it is extremely necessary to model the deposit using GIS technologies [3].

The technology of local excavation of the richest areas of the vein is used by cutting slits along the borders of the veins with cutting discs and breaking out the obtained core. Then explosive loosening is carried out near the vein rocks. The remaining part of the veins, with a lower metal content in the ore, is mined using traditional technologies based only on the explosive loosening of strong rocks. Separate processing of ores of different grades ensures high rates of metal extraction, which compensates for additional costs associated with local mechanical excavation of rich areas of the vein [5].

In the delineated zone throughout the depth of the wells, there are rock zones with low-quality copper/zinc mineralization. In figure 2, they are represented by wells 74-12, 74-14, 74-15 created by diamond drilling. A large number of wells intersect weak and disseminated copper-zinc mineralization in chloritized acid volcanics.

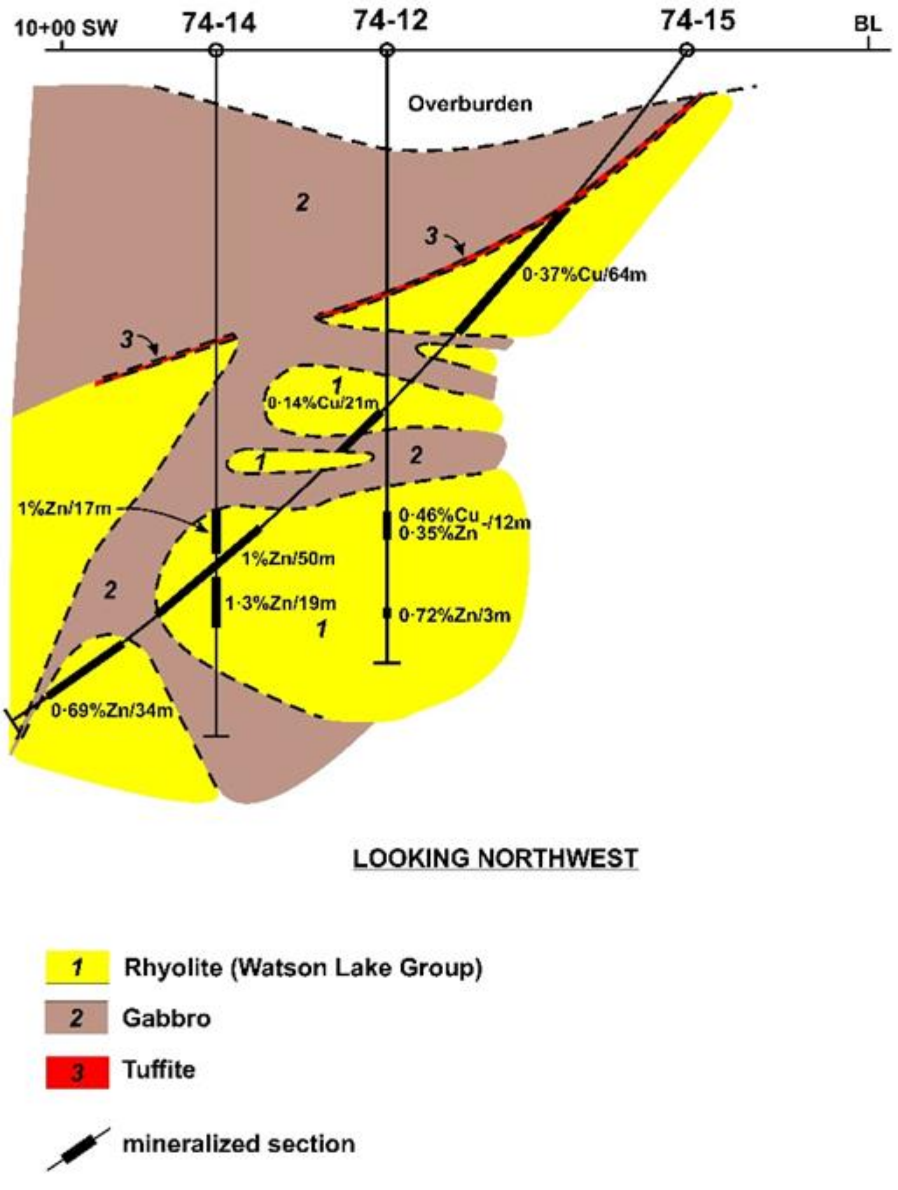

Fig. 2. Research area with wells plotted

The value is represented by the "key tuffite" zone (figures 3, 4), within which there are areas with increased metal content, for example, in wells 84-10 (2.7% Zn), 86-2 (3.1% Zn), 86 -3 and 86-4 (3.7% Zn), the presence of several narrow but well-developed copper and zinc sulfide deposits is observed. Based on the results of research, it can be concluded that mining of minerals is planned to be carried out in difficult conditions, where reserves of valuable mineral raw materials are concentrated in thin ore veins. At the same time, the problem lies in the clear zoning of rich deposits, which is precisely what can be done with the help of GIS technologies [3, 6].

a) b)

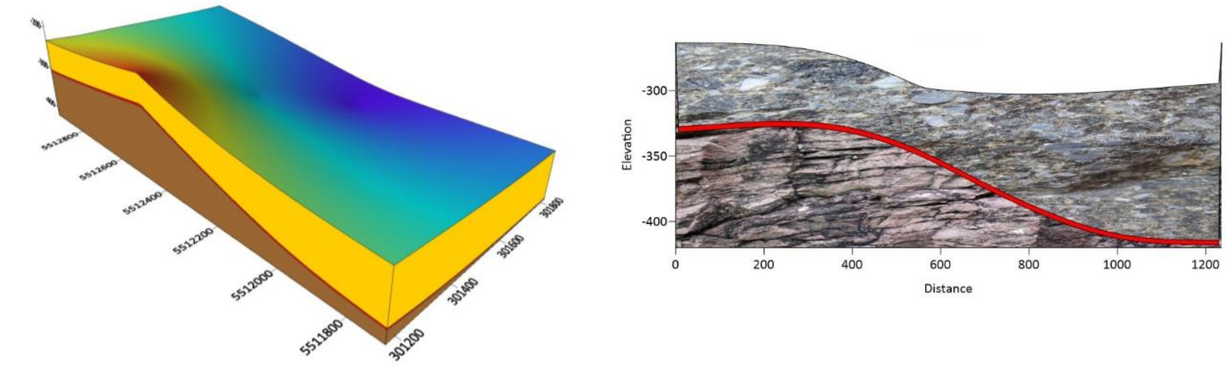

Fig. 3. 3D model (a) and cross-section of the map (b) for the visualization of layers with the highlighting of the layer of "key tuffs" (red color)

The analysis of copper-zinc ore reserves showed that the separation of ores into 2 varieties: copper and copper-zinc, increases the extraction of zinc from copper-zinc ores, and can also significantly increase the extraction of copper during beneficiation. Due to the separation of ores into two grades, copper extraction during beneficiation will increase by 5%.

Calculations show [6, 7] that thanks to the division of reserves into copper and copper-zinc ores, it is possible to increase the production capacity of the enterprise in terms of value by 1.20–1.25 times. In addition, the damage to the environment will decrease by 1.2–1.25 times, respectively. This is significant if we take into account that compensation payments for environmental damage are very high and significant savings can be predicted from increased mineral extraction [8].

Research method. The first stage of the development of mineral raw material quality management systems is a comprehensive study of the qualitative characteristics of minerals based on the data of geological exploration, laboratory research, the results of research and industrial experiments and industrial exploitation of deposits. The next stage is the modeling of qualitative characteristics of minerals using GIS technologies, geometrization of object parameters (ore bodies, distribution of ore-forming minerals in the ore body, indicator of enrichment, contrast, clogging, content of valuable components, etc.). The main goal of this stage is the selection of natural and technological types and grades of ores and their zoning in the quarry space. At the same time, at the planning stage of mining operations, the main strategic decisions regarding the development of the deposit are laid in the mode of product quality management [3, 8–10].

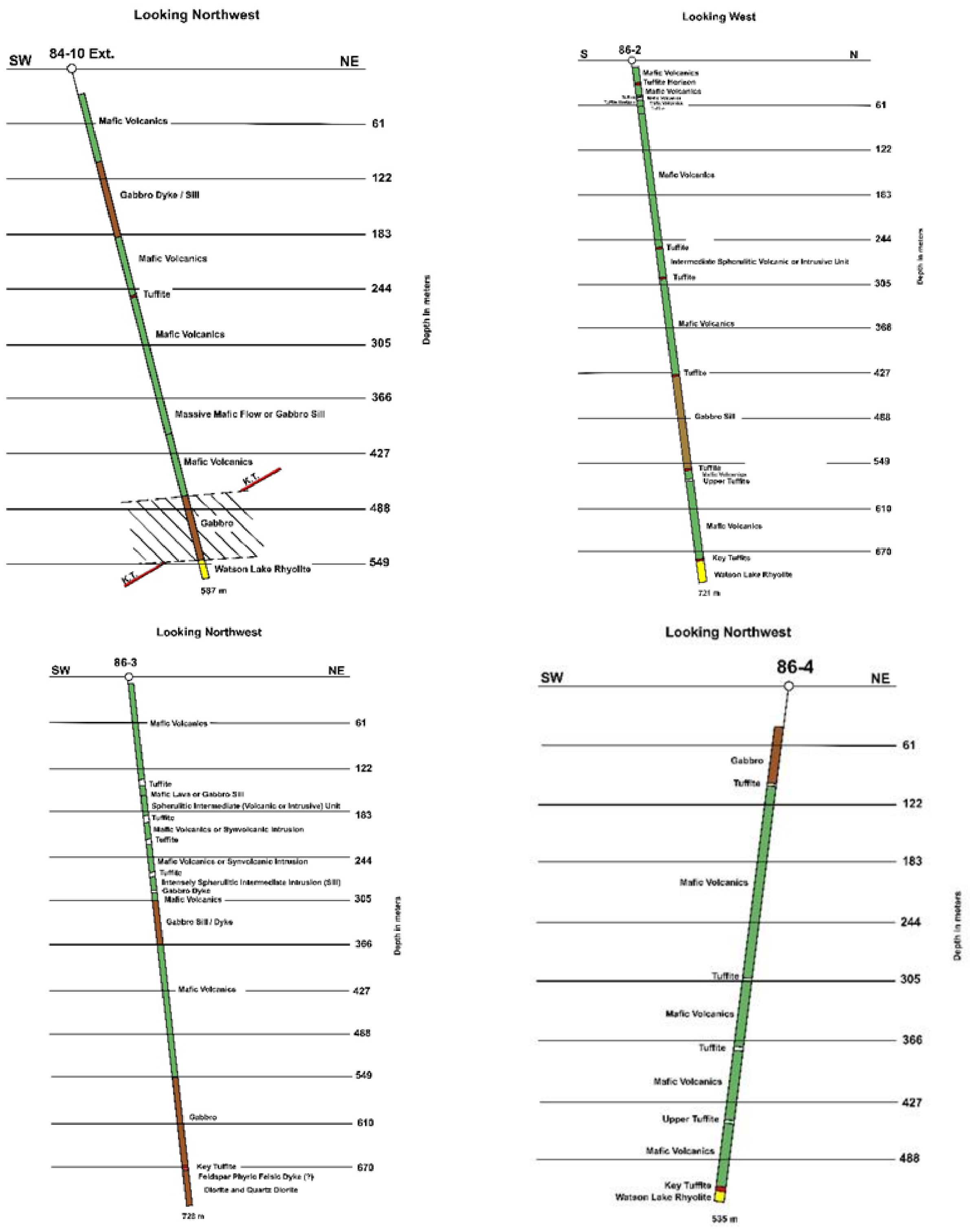

Fig. 4. Geological cross-section of productive wells

The construction of a digital model of the terrain requires a certain form of representation of the initial data (a set of X, Y, Z point coordinates) and a method of their structural description, which allows restoring the surface by interpolation or approximation of the initial data. Data files were created (table 2) and, using the Kriging interpolation algorithm, grid maps were created in the Surfer program as GRID files. As a result, a contour map of the mining zone was constructed, which is presented in figure 5.

Table 2

Coordinates of wells (for constructing the relief)

Drill-hole ID	X	Y	Z
74-8	301273.96	5512931.18	270.00
74-12	302058.63	5512926.62	273.60
74-13	302228.74	5512800.79	269.90
74-14	301977.06	5512874.72	274.00
74-15	302158.42	5512990.29	270.30
83-1	301958.78	5512699.14	269.00
83-2	301723.78	5513015.29	269.00
83-4	301828.85	5512771.62	269.00
84-1	301463.98	5512681.64	270.00
84-2	301474.08	5512371.33	269.90
84-3	301763.32	5512563.51	269.10
84-6	300990.71	5513487.99	269.00
84-7	301877.05	5512264.42	273.40
84-8	301146.74	5513279.43	270.00
84-9	301699.48	5512219.39	269.00
84-10	300871.98	5512945.24	270.00
86-2	301817.27	5511699.51	269.90
86-3	301351.57	5511928,29	269.10
86-4	301169.66	5512477.43	269.90

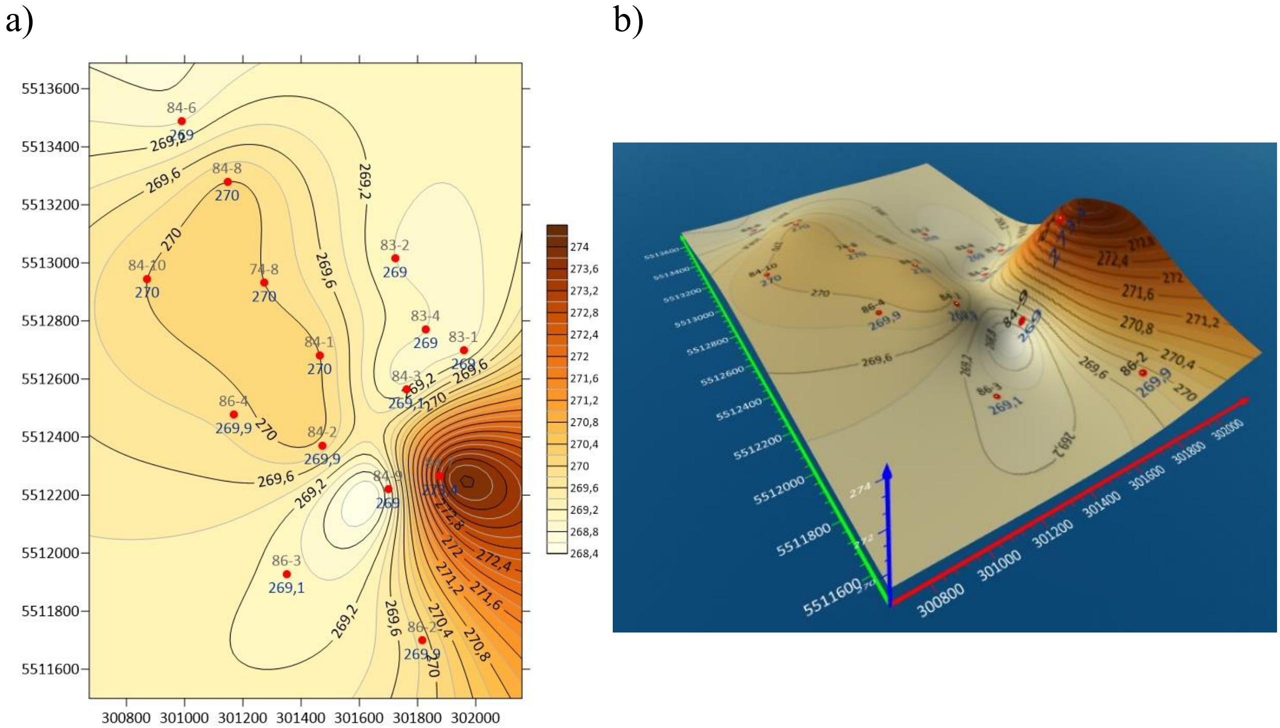

Fig. 5. Relief of the research area: plan (a) and spatial (b) image

With the help of methods of three-dimensional visualization, adding surfaces, combining map types, a complete figure of the final report is created (figure 6). Data bases (tables 2–4) are generated to obtain a map of wells that are loaded into the Drill-hole dialog box. Table 5 is loaded in the grid data dialog as a 3D XYZS data type.

Table 3

Survey

Drill-hole ID	MD	Azimuth	Incli-nation
74-8	570	0	0
83-1	575	0	0
83-2	561	0	0
83-4	610	0	0
84-1	588	0	0
84-2	572	0	0
84-3	563	0	0
84-6	610	0	0
84-7	620	0	0
84-8	598	0	0
84-9	590	0	0
84-10	587	56	15
86-2	721	325	5
86-3	728	56	5
86-4	535	232	5
74-14	560	0	0
74-12	270	0	0
74-15	0	0	0

Table 4

Interval

Drill-hole ID	From	To	Zn
74-8	320	323	3.10
83-1	415	419	4.30
83-2	505	510	4.80
83-4	567	570	3.50
84-1	490	493	0.30
84-2	460	463	1.70
84-3	387	391	2.50
84-6	543	546	2.10
84-7	520	523	3.40
84-8	578	582	2.30
84-9	546	550	3.30
84-10	568	570	0.20
86-2	688	691	2.20
86-3	673	677	2.02
86-4	519	523	0.70
74-14	527	532	5.60
74-12	455	461	5.80
74-15	0	0	6.80

Table 5

Concentration

Drill-hole ID	X	Y	Z	Zn concentration
78-4	301273.96	5512931.18	270.00	3.10
83-1	301958.78	5512699.14	269.00	4.30
83-2	301723.78	5513015.29	269.00	4.80
83-4	301828.25	5512771.62	269.00	3.50
84-1	301463.98	5512681.64	270.00	0.30
84-2	301474.08	5512371.33	269.90	1.70
84-3	301763.32	5512563.51	269.10	2.50
84-6	300990.71	5513487.99	269.00	2.10
84-7	301877.05	5512264.42	273.40	3.40
84-8	301146.74	5513279.43	270.00	2.30
84-9	301699.48	5512219.39	269.00	3,30
84-10	300871.98	5512945.24	270.00	0.20
86-2	301817.27	5511699.51	269.90	2.20
86-3	301351.57	5511928.29	269.10	2.02
86-4	301169,66	5512477.43	269.90	0.70
74-14	301977.06	5512874.72	274.00	5.60
74-12	302058.63	5512926.62	273.60	5.80
74-15	302158.42	5512990.29	70.30	6.80

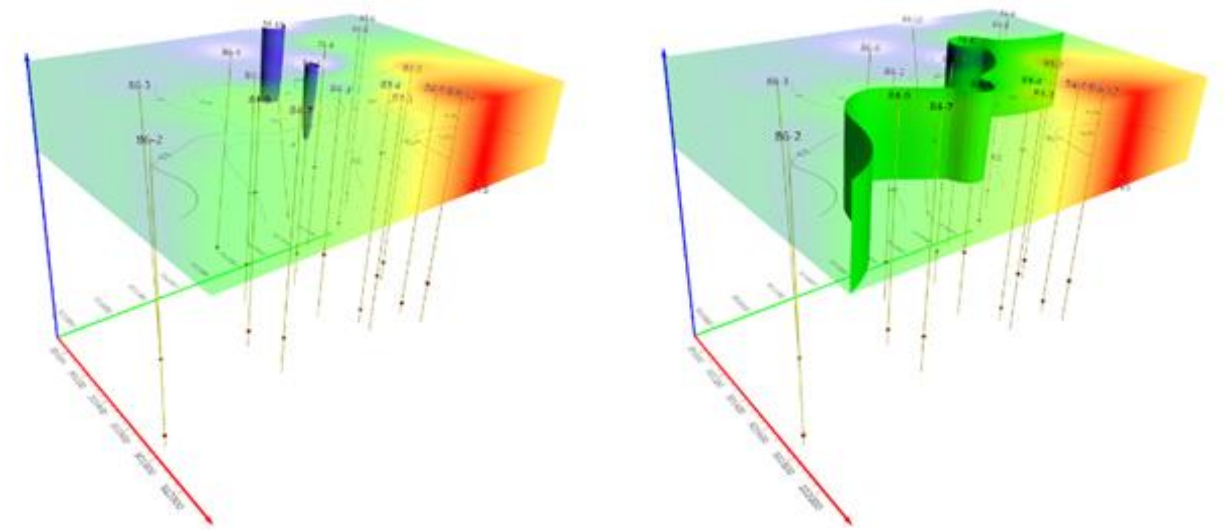

Fig. 6. 3D visualization of the location of the zinc concentration layers in the deposit from the lowest (blue zone), the average concentration (green zone) to the highest (red zone)

Results. The presented studies help to effectively solve the problems of mineral extraction in complex conditions, where reserves of valuable mineral raw materials are concentrated in thin ore veins. A quality management system for mineral raw materials must be provided from the quarry to the beneficiation factory. At the same time, effective management of the quality of ore preparation can be based on the following principles:

– constant clarification of data on the qualitative characteristics of minerals based on the results of operational exploration, magnetic logging of wells, chemical analysis of raw materials at all stages of its processing, etc., implementation of innovative methods to clarify and expand information on the qualitative characteristics of minerals;

– use of GIS when planning mining operations (annual, monthly, weekly-daily, variable), continuous replenishment of GIS with refined data on minerals;

– management of the order of mining of minerals; GPS-positioning of excavation and transportation navigation (taking into account the quality of raw materials in transport vessels);

– implementation of automated systems for managing cargo flows taking into account the quality of raw materials.

Conclusions. Spatial distribution of ore types and their quantitative ratio form the strategy of working out the deposit in the mode of managing the quality of mineral raw materials. In order to implement the existing methods of managing the quality of mineral raw materials during extraction and possible ways of increasing their efficiency through separate extraction, a thorough analysis must be carried out. The method of zoning in the quarry space of technological types of ores in the deposits is given, taking into account the comprehensive assessment of the qualitative characteristics of minerals based on modern geoinformation technologies.

For the interpretation of data in geoinformation systems, a method is proposed that requires the preliminary creation of a geological database and allows reliable assessment and zoning of ore deposits based on qualitative characteristics.

The methodology allows you to adjust the built models depending on the established or changed requirements for the quality of minerals. The mining and geological information system, improved due to the presented methodology, allows with high reliability to zone technological types and varieties of ores in space, which helps to choose the most effective method of ore preparation in the mode of ore quality management for specific mining and geological conditions at the stage of planning mining operations. An example of the zoning of technological types of ores in the conditions of the deposit is given Watson Lake and methodological approaches to the selection of effective methods of managing the quality of mineral raw materials in complex mining and geological conditions of working out deposits and increasing requirements for product quality.

References

1. Mudd, G. M., Jowitt, S. M., & Werner, T. T. (2017). The world's lead-zinc mineral resources: Scarcity, data, issues and opportunities. *Ore Geology Reviews*, *80,* 1160–1190. https://doi.org/10.1016/j.oregeorev.2016.08.010
2. Rostek, L., Pirard, E., & Loibl, A. (2023). The future availability of zinc: Potential contributions from recycling and necessary ones from mining. *Resources, Conservation & Recycling Advances, 19,* 200166. https://doi.org/10.1016/j.rcradv.2023.200166
3. Boszczuk, P., Cheng, L. Z., Hammouche, H., Roy, P., Lacroix, S., & Cheilletz, A. (2011). A 3D gravity data interpretation of the Matagami mining camp, Abitibi Subprovince, Superior Province, Québec, Canada: Application to VMS deposit exploration. *Journal of Applied Geophysics*, *75,* 77–86. https://doi.org/10.1016/j.jappgeo.2011.06.031
4. Cornelious, S. E., & Araque, J. D. (2009). Historical perspective and new developments regarding conversion coatings and seals for zinc deposits. *Metal Finishing*, *107,* 22–25. https://doi.org/10.1016/S0026-0576(09)00017-8
5. Atlin, C., & Gibson, R. (2017). Lasting regional gains from non-renewable resource extraction: The role of sustainability-based cumulative effects assessment and regional planning for mining development in Canada. *The Extractive Industries and Society*, *4,* 36–52. https://doi.org/10.1016/j.exis.2017.01.005
6. Sobolevskyi, R., Zuievska, N., Korobiichuk, V., Tolkach, O., & Kotenko, V. (2020). Cluster analysis of fracturing in the deposits of decorative stone for the optimization of the process of quality control of block raw material. *Eastern-European Journal of Enterprise Technologies, 5,* 21–29. https://doi.org/10.15587/1729-4061.2016.80652
7. Зуєвська, Н. В., Шайдецька, Л. В., Косенко, Т. В., & Матвійчук, І. О. (2024). Прогнозування зон зі змінними фізико-механічними характеристиками ґрунтових масивів. *Збірник наукових праць Національного Гірничого Університету, 77,* 118–125. https://doi.org/10.33271/crpnmu/77.118
8. Ghorbani, Z., Gholizadeh, F., Casali, J., Hao, C., Cavallin, H. E., Loon, L. L. V., & Banerjee, N. R. (2022). Application of multivariate data analysis to biogeochemical exploration at the Twin Lakes Deposit, Monument Bay Gold Project, Manitoba, Canada. *Chemical Geology*, *593,* 120739. https://doi.org/10.1016/j.chemgeo.2022.120739
9. Peck, W. H., Rathkopf, C. A., Mathur, R. D., & Matt, P. D. (2022). Stable isotope (C, O, S, and Zn) geochemistry of marble-hosted exhalative zinc deposits in the Central Metasedimentary Belt, Grenville Province, Canada: Insights into ore deposition and tectonic setting. *Ore Geology Reviews*, *148,* 105057. https://doi.org/10.1016/j.oregeorev.2022.105057

10. Slezak, P. R., Olivo, G. R., Oliveira, G. D., & Dardenne, M. A. (2014). Geology, mineralogy, and geochemistry of the Vazante Northern Extension zinc silicate deposit, Minas Gerais, Brazil. *Ore Geology Reviews*, *56,* 234–257. https://doi.org/10.1016/j.oregeorev.2013.06.014

АНОТАЦІЯ

Мета. Основною метою дослідження є ідентифікація природних та технологічних типів і сортів руд з подальшим просторовим районуванням у межах досліджуваного родовища.

Методика. Для відображення рельєфу поверхонь та розподілу корисних копалин застосовано методи інтерполяції та апроксимації початкових даних. Вибір методу залежить від кількості вихідних даних та їх рівномірності. Для просторової інтерполяції використано методи Крігінга та радіальних базисних функцій, що дозволяє виявити загальні закономірності розподілу досліджуваних параметрів. Для швидкої оцінки даних при великій кількості точок застосовано методи мінімальної кривизни та тріангуляції.

Результати дослідження включають створення цифрової моделі родовища, картографування залягання корисних копалин з аналізом просторових змін, а також оцінку запасів міді та цинку. Використання ГІС дозволило візуалізувати тривимірний розподіл корисних копалин у свердловинах, що спростило аналіз та покращило його якість.

Наукова новизна роботи полягає в удосконаленні методики аналізу геологічних результатів на етапі планування гірничих робіт, коли закладаються основні стратегічні рішення щодо розробки родовища в режимі управління якістю продукції. Методика дозволяє достовірно проводити оцінку та районування родовища руд за якісними ознаками.

Практичне значення роботи полягає у використанні ГІС при розробці системи комплексної техніко-еколого-економічної оцінки ефективності заходів з управління якістю мінеральної сировини в складних умовах, коли запаси цінної мінеральної сировини зосереджені в тонких і дуже тонких рудних жилах. Вибір технології управління якістю мінеральної сировини базується на результатах оцінки якісних характеристик корисних копалин, виділенні природних типів руд рудного масиву на основі геологічної інформації, обґрунтування характеристик технологічних типів руд та їх зонування в підземному просторі за допомогою геоінформаційного моделювання.

Ключові слова: *ГІС, родовище, цинк, мідь, геологічні дослідження, моделювання, управління якістю, руда, свердловини, концентрація, технологія, ефективність, інженерно-геологічний переріз, геодезичний моніторинг.*