https://doi.org/10.33271/nvngu/2024-2/019

S. Bolatbekuly[1],
orcid.org/0009-0003-8676-2574,
G. Umirova[1],
orcid.org/0000-0001-5185-3132,
M. Zakariya[1],
orcid.org/0009-0002-6971-9710,
R. Temirkhanova[1],
orcid.org/0000-0001-8219-0589,
K. Togizov[*2],
orcid.org/0000-0002-4830-405X

1 – Satbayev University, Almaty, the Republic of Kazakhstan
2 – Institute of Geological Sciences of K. I. Satpayev, Almaty, the Republic of Kazakhstan
[*] Corresponding author e-mail: k.togizov@satbayev.university

FORMATION OF PROSPECTING CRITERIA FOR COPPER-PORPHYRY DEPOSITS BASED ON THE CONSTRUCTION OF REFERENCE MODELS

Purpose. To study the modern methodology for forming a list of mineragenic factors and prospecting signs of ore fields and deposits of copper-porphyry type based on reference objects and model constructions on the example of deposits of Jungar-Balkhash folded region.

Methodology. The methodology for identifying the desired factors and criteria is based on the collection and analysis of published and historical data, formation of digital databases using raster and vector geological maps. It also includes the use of modern, advanced specialized technologies and software packages for geophysical surveys and remote sensing data. According to the adopted technology, the results of aerospace methods are used, which include aerial photography, space radar imaging, infrared and spectrozonal surveys and others. The research involves interpretation of WorldView-3 satellite images.

Findings. A list of metallogenic characteristics describing potential copper-porphyry mineralization within the study area has been compiled. Using the Spectral Evolution PSM-3500 infrared spectrometer, characteristic areas of secondary changes in copper-porphyry systems have been identified. ASTER spectral satellite radiometer data have identified mineral spectra, iron hydroxides, propylitic associations, areas of quartzite formation and silicification. By interpreting WorldView-3 satellite images, digital files have been obtained identifying iron ore minerals (hematite, goethite), secondary quartzites (advanced argillizites), varieties of sericite and other clay minerals, silicon, carbonates and propylites (chlorite, epidote). Based on interpretation, “parquet” fracturing in granite bodies and in the area of volcanogenic and sedimentary strata development has been identified, as well as structural lines indicating the strike of rock layers.

Originality. Using the example of an exploration area based on the analysis of a priori and up-to-date data, the nature of a set of relevant criteria and signs for predicting and prospecting has been determined, aimed at increasing the reliability and accuracy of formation of geological-geophysical models.

Practical value. The collected and systematized geophysical data can serve as a basis for developing plans for further geological exploration, identifying promising areas, determining the required volumes and methods of geophysical surveys. They can also contribute to the increase in estimate of reserves and production at mining sites. The prepared models are intended for preliminary assessment of known and newly discovered ore deposits of various types, as well as for determining the directions of geological exploration in the areas of prospecting the Northern Pribalkhash.

Keywords: *Northern Pribalkhash, copper-porphyry deposits, Jungar-Balkhash folded region, geophysical criteria, prospecting signs*

Introduction. The economy of Kazakhstan is still very much dependent on the state of the country’s mineral resource base. As a result of negative tendencies, which do not decrease from year to year, but tend to increase, the mineral resource base of the Republic of Kazakhstan is in a state of decreasing proven reserves, and the rate of discovery of new deposits for their replenishment is extremely low [1]. Since Kazakhstan’s resource potential far exceeds proven reserves, geological exploration companies are faced with the task of converting predicted reserves into balance reserves, and this requires prospecting new competitive deposits. At the same time, it is noteworthy that Kazakhstan is a unique geological province of the world with a complex geological-tectonic structure and associated mineral resources [2]. Oil and gas, ore and non-metallic deposits are truly treasures of the Republic of Kazakhstan territory [3]. Polymetals and gold, copper and zinc, nickel and barite are all concentrated in geological structures of Eastern Kazakhstan [4]. One of the most promising areas for prospecting and exploration of mineral resources is the Jungar-Balkhash folded region. This region has a high potential for prospecting new deposits and further increase in Kazakhstan’s share in the global resource market.

Almost all active proven copper reserves are localized in the fields of Eastern Kazakhstan, which are currently actively exploited. About half of the active lead and zinc reserves are contained in the eastern fields of the Republic that are mined or are about to be mined. Karaganda region is searching for new world-class copper deposits. Geologists expect to discover large copper-porphyry deposits here. Distinctive signs of such deposits are large volumes of ore. The prospect of the Jungar-Balkhash folded region for prospecting and exploration of solid minerals is confirmed by the fact that three major geological exploration projects are currently being implemented in the region jointly with foreign investors.

The Jungar-Balkhash folded region has a unique geological potential, which represents significant prospects for prospecting and exploration of various minerals. This region is characterized by a variety of rocks and structures that contribute to the formation of various fields, including deposits of copper, zinc, nickel ores, as well as gold and other metals. However, despite the potential of the area, its research and exploration require significant investment and scientific efforts [5]. This is due to the fact that the Jungar-Balkhash region has complex and multifaceted geological structure, which complicates the process of exploration and assessment of mineral reserves.

Practically all deposits of the Northern Pribalkhash region have been studied for quite a long time, but the issues of mineralization in the subsurface are still debatable and require further research. This is due to the complex geological structure of the region, as well as ever-changing technologies and research methods [6]. Despite significant advances in the geological survey of this region, new data and modern analysis methods may lead to a revision of existing ideas about the occurrence of minerals in the subsurface of this area. Such research and observations are necessary to fully understand the geological nature and potential of the deposits in the Northern Pribalkhash region [7].

Today it is clear that the ore mining prospects are in one way or another linked to the development of hard-to-recover reserves [8]. The geological exploration experience shows that steadily growing mining and expanded reproduction of reserves can be maintained only by active implementation of innovations not only in the field of studying the physical properties of rocks, but also in the field geophysical techniques, software technologies for processing, interpretation and modeling of promising objects [9, 10]. The reason for this is the active development of digital technologies and the associated increase in the accuracy of processing and interpretation software packages [11]. Another aspect for improving the efficiency of prospecting research is the formation of the most relevant and reliable database of mineragenic factors and prospecting criteria for detecting ore fields and copper-porphyry deposits based on reference objects and model constructions [12]. The scientific predicting and search for hidden, deep-seated deposits require continuous development of research methodology and the use of new technologies. Then an increase in the capabilities of modern predictive-prospecting methods is to be expected [13, 14].

Predicting and prospecting of mineral deposits at the present stage are aimed at building a digital interactive model of the study area, which is intended for mineragenic analysis of the area and selection of sites for further mining, specification of their types and volumes of research [15]. Updating and refining of this model, as new data becomes available, forms the basis for effective management of further geological exploration process [16]. The identified patterns in the genesis and location of mineral deposits allows for more targeted prospecting work.

When performing a geological prediction, not only previously determined, but also modern evolutionary patterns of the geological structure the earth's crust and mantle are used, which can be developed on the basis of in-depth analysis and generalization of historical geological-geophysical information, from which the most informative data is selected to create a digital basis for the area [17, 18]. All field formation patterns, including geological, geochemical, geophysical, metallogenic and tectonic drilling results, are used in the digital basis preparation [19, 20]. A special role is given to regional area interpretation and small-scale identification of spectral anomalies based on the space survey results.

The purpose of this research is to show the modern methodology in compiling the list of mineragenic factors and prospecting signs of ore fields and copper-porphyry deposits based on reference objects and model constructions on the example of deposits in the Jungar-Balkhash folded region. The purpose set is achieved by solving the following tasks:

1. Collection, analysis, and synthesis of stock and published materials to study the structure of the copper-porphyry system to form metallogenic characteristics describing potential copper-porphyry mineralization in the study area.
2. Study predictive-mineragenic surveys to identify mineragenic criteria for prospecting copper-porphyry deposits.

Research methods. In today's world, digital models of natural objects are extremely important for various fields, ranging from scientific research and geological surveys to planning urban development projects and ecosystem analysis. However, it is necessary to conduct thorough research using modern technologies before these models can be developed. One important step is the application of aerospace methods, such as aerial photography, space radar imaging, infrared scanning, and other techniques.

In accordance with the adopted technology, the first stage of the digital model development uses the results of aerospace methods, which may include aerial photography, space radar imaging, as well as infrared and spectrozonal surveys, etc. The data obtained are used for geological and mineralogical mapping [21].

The research the authors would like to focus on involves the interpretation of WorldView-3 satellite images obtained in 2017 for one of the prospecting areas in the Northern Pribalkhash region. The analysis of satellite data, combined with geophysical and geological surveys, allows for a more accurate determination of the earth's crust structure and the distribution of ore deposits.

Based on the results of the processed data, vegetation cover, lithological varieties, and hydrothermal alteration based on the presence of clay minerals have been identified. The research has yielded digital files in the data arsenal identifying iron ore minerals (hematite, goethite), secondary quartzites (advanced argillizites), varieties of sericite and other clay minerals, silicon, carbonates and propylites (chlorite, epidote). Spectral index selection algorithms are presented in Table 1.

Minerals such as pyrophyllite, alunite, dickite, epidot, illite, chlorite, muscovite, paragonite, kaolinite are identified in places where the current and relative wave damping can be compared with certain ranges based on the existing spectral library (USGS Library Spectra, JPL library) (Fig. 1).

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) spectral satellite radiometer data have been successfully used in the global geological exploration practice since the mid-90s of the last century [22].

ASTER interpretation data is an important component of the operational database and provides a wealth of information both in the preparation of field work for the selection of audit sites and field routes. Their result is information on the peculiarities of mineral composition and zonation of hydrothermal-metasomatic alteration fields, which will allow them to be related to certain parts of the copper-porphyry system and significantly reduce the area of field observations. The greatest practical interest for the interpretation of mineral associations of hydrothermally-altered rocks is represented by spectral channels of the short-wave infrared range (channel 4 – 1.60–1.70 μm; channel 5 – 2.145–2.185 μm; channel 6 – 2.185–2.225 μm; channel 7 – 2.235–2.285 μm; channel 8 – 2.295–2.365 μm), in which minerals such as alunite, pyrophyllite, mica, clay minerals, etc. have distinct absorption spectra. In our example, ASTER scene interpretation data has been obtained from a group of promising projects. The dataset is represented by a package of raster scenes of the visible and infrared ranges (composite images of a spectra combination) and a scheme for 25 spectra interpretations, which are a pixel image with a pixel size of 30 m, corresponding to the resolution of the infrared ranges. Spectra of minerals such as alunite, pyrophyllite, kaolinite, mica (sericite, muscovite, illite), iron hydrox-

Table 1

Spectral index selection algorithms

Index	Algorithm
Iron oxides	B5/B2
Ferruginous minerals	B10/B7
Iron content index	(B3*B4)/(B2*1 000)
Clay minerals	B10/B14
Ferruginous mineral content index	(B3/B5)+(B13/B5)
Advanced argillizites	[(B12+B14)/B13]
Argillizites	[(B13+B15)/B14]
Carbonates and propylites	[(B14+B15)/B16]
Silicon	[(B14+B16)/B15]

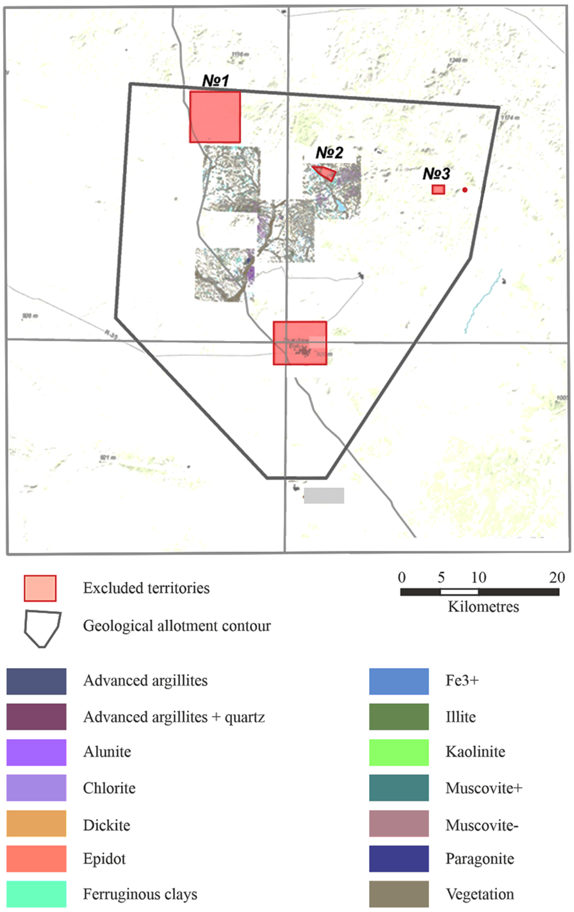

Fig. 1. Results of WorldView-3 satellite image interpretation

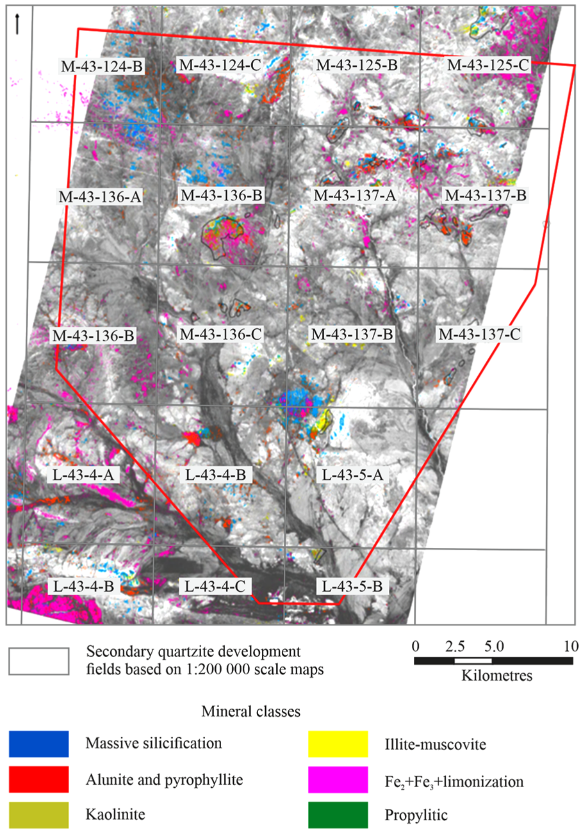

Fig. 2. Results of ASTER spectral satellite radiometer data interpretation

ide, propylitic associations, areas of quartzite formation and silicification have been identified in the study area. The obtained spectral anomalies coincide both with already known masses of secondary quartzites, greisen, and also confirm some areas of weak changes (silicification of sedimentary rocks, external propylites of secondary quartzites, rocks containing increased oxidized iron concentrations) (Fig. 2).

The 1:100,000 scale photogeological frameworks, based on the interpretation of satellite images from OLI (optical range) and TIRS (thermal range) next-generation sensors set on Landsat 8 spacecraft, represents a significant step forward in geological data processing and analysis. A distinctive characteristic of these data is their greater pixel depth (12 bit/pix), which provides higher radiometric resolution than the previous versions. This characteristic allows for more accurate reproduction of different shades of grey on black and white images, and to create more accurate composite images taking into account the color diversity. One significant advantage of the new OLI/TIRS sensors compared to the previous models such as the ETM+ is the availability of additional spectral channels. This provides more complete information on the earth's surface composition and its natural resources, which in turn improves the ability to detect and analyze various geological objects and phenomena. Thus, data from OLI and TIRS sensors set on Landsat 8 provide more extensive information about the earth's surface, contributing to more efficient and accurate analysis of geological processes and phenomena.

In the studies under consideration, interpretation is conducted to identify the structural configuration elements of the area and to determine the material composition of rocks, which will further help in the interpretation of the history of formation of volcanogenic-tectonic structures. When interpreting the structural configuration elements, in addition to lineaments and ring structures, granite intrusions, dikes and dike belts can be identified. Within the boundaries of granite bodies, characteristic "parquet" fracturing has been interpreted, and within the area of volcanogenic and sedimentary strata development – structural lines indicating the strike of rock unit layers.

When interpreting the material composition, all 1:100,000 scale layers are viewed sequentially to determine the interpretation signs of rock complexes and to identify both common and distinctive features. Some important geological structure elements are observed only for 1–2 layers or are unclearly noticeable. However, if they provide important geological information, these structures are also plotted on a composite interpretation scheme after analyzing the geological data set (Fig. 3).

To successfully study and interpret a large amount of geological information, to determine the geological nature of anomalies generated by a particular object, it is necessary to examine this object on geophysical maps [23]. The main method that has proven itself in studying the deep structure of an area is gravity prospecting [24]. Therefore, to solve the problem of updating the digital model based on the collected reports and results of assessing the quality of the newly obtained historical data, geophysical information has been selected in the form of a set of gravimetric maps of 1:10,000–1:50,000 scales. These maps are of good quality and are suitable for providing prospecting work with a high-quality geophysical basis. Surveys performed with relatively low observation accuracy over a loose network of points are excluded from digitization and consideration.

Predictive-mineragenic survey methods include hydrogeochemical, biogeochemical, atmochemical, isotope-geochemical methods in conjunction with geochemical mapping and lithochemical surveying [25, 26]. For the studies under consideration, the main type of field geological work is geological prospecting routes and lithochemical sampling.

Geological routes are focused on identifying copper-porphyry mineralization centers within previously revealed highly promising areas and this task is solved by:

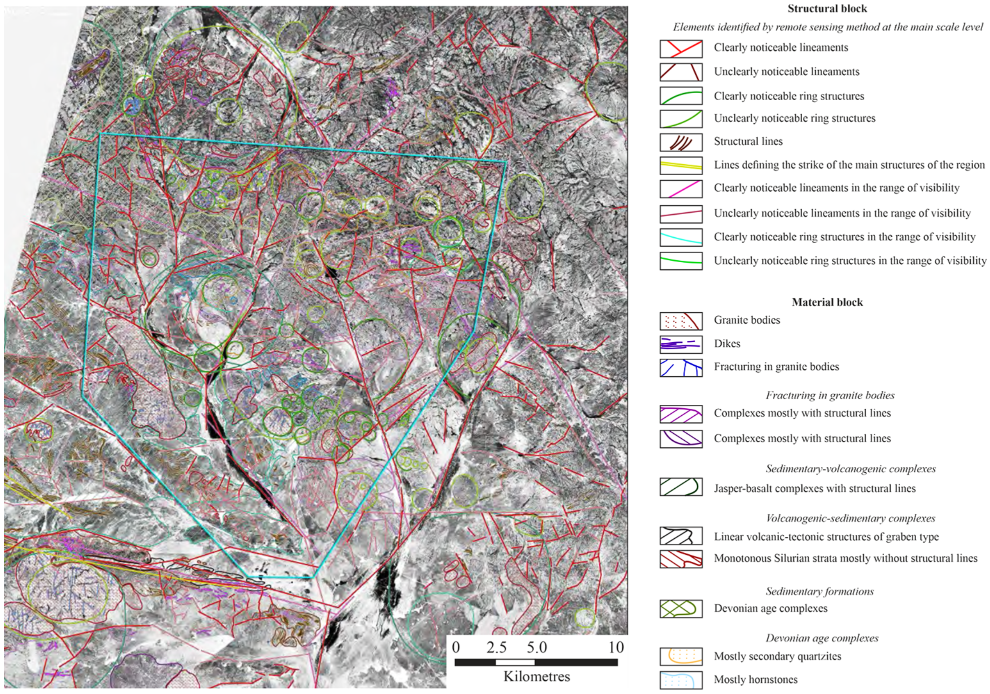

Fig. 3. Results of structural and material interpretation

- studying the zonation of hydrothermal-metasomatic alterations;
- identification, typification and delineation of veinlet (stockwork-type) mineralization;
- identifying and delineating (if present) porphyry intrusions as potential centers controlling porphyry mineralization;
- studying the forms, types, and intensity of ore mineralization occurrences, including oxidized mineralization.

Lithochemical work includes collection-chip sampling, lithochemical sampling of bedrock and soil, as well as RIM-sampling.

Collection-chip sampling is conducted in parallel with the passage of geological routes. Outcrops with vein-disseminated sulphide or oxidized mineralization, veins, vein zones are sampled [27, 28]. After sampling, the samples are subsequently tested with Niton portable field XRF-analyzers from Thermo Fisher Scientific Inc. (USA) to study the content of ore components: copper, lead, zinc, arsenic, etc. Spectral Evolution PSM-3500 infrared spectrometer manufactured by Spectral Evolution Inc. (USA) is used to study the mineralogical composition.

In order to study the fine geochemistry of the resistant minerals of the porphyry systems, RIM testing program is initiated using a methodology developed by Rio Tinto's technology sub-division in Australia. The testing results are considered as the main data for geological and economic deposit assessment when calculating ore reserves. For this purpose, almost 300 propylite samples and 6 age-specific samples from intrusions, altered and mineralized rocks of copper-porphyry occurrences are taken in the study area.

Results and discussion. The distribution of metal contents of Cu, Mo, Pb, Zn, As, Mn, Fe, etc. reflects the main geochemical copper-porphyry system zonation. By using this innovative technology, clear geochemical anomalies of these metals can be identified as early as the sampling stage.

Measurements in rock samples allow in field conditions to determine the ore metal content of Cu, Pb, Zn, As in highly oxidized mineralized rocks, constituting 98 % of the selected bedrock samples.

The Spectral Evolution PSM-3500 infrared spectrometer can be used in the field conditions to identify and delineate secondary alteration characteristic areas inherent in the copper-porphyry system to study the mineralogical composition of rocks and soils.

The ASTER spectral satellite radiometer has identified within the study area the spectra of minerals such as alunite, pyrophyllite, kaolinite, mica (sericite, muscovite, illite), iron hydroxide, propylite associations, areas of quartzite formation and silicification. The obtained spectral anomalies coincide with already known masses of secondary quartzites, greisen, but also confirm some areas of weak changes (silicification of sedimentary rocks, external propylites of secondary quartzites, rocks containing increased concentrations of oxidized iron).

Using the interpretation of WorldView-3 satellite images obtained in 2017, in one of the Northern Pribalkhash prospecting areas, the following can be identified: vegetation cover, lithological varieties, as well as hydrothermal alteration based on the clay minerals present. The research has yielded digital files identifying iron ore minerals (hematite, goethite), secondary quartzites (advanced argillizites), sericite varieties and other clay minerals, silicon, carbonates and propylites (chlorite, epidote) in the data arsenal.

Based on interpretation, the characteristic "parquet" fracturing in granite bodies and in the area of volcanogenic and sedimentary strata development has been identified, as well as structural lines indicating the strike of rock unit layers.

Thus, based on the analysis of cartographic data, reports, as well as with due regard for the refined structure of the copper-porphyry system elements in the study area, a list of metallogenic characteristics describing potential copper-porphyry mineralization in the study area has been compiled. The list includes 21 criteria related to the following classes of copper-porphyry mineralization control:

- lithological-magmatic-volcanogenic formations, calci-alkalic intrusions, bunches of porphyry intrusions, etc.;
- tectonic-buffer fault zones of different strike and their intersection nodes;
- ore mineralization – occurrences of copper-porphyry, skarn gold-epithermal type, as well as polymetallic occurrences forming zonal clusters with copper mineralization;
- geochemical halos, flows, samples with increased concentrations of copper, molybdenum, gold, arsenic, polymetals;
- placer samples of gold, as well as copper, molybdenum, lead and zinc minerals;

- halos of hydrothermal-metasomatic alterations, secondary quartzites, their composition, zonation;
- ASTER spectral anomalies, their composition, zonation;
- positive and negative gravimagnetic field anomalies.

Based on the results of visual expert assessment of the above criteria distribution nature, areas ranging from 1 to 60.5 sq. km have been identified. Further ranking of prospecting areas is based on a simple summation of criteria, the number of which varies from 6 to 21. The sum of criteria for classifying an area as promising is determined to be 15 points, since this number of criteria corresponds to the only A deposit explored within the area, assumed in this case as a reference object.

In modern geological practice, assessing the prospects of fields is an important stage in making decisions on further investments in exploration and mining of mineral resources. The proposed assessment method provides a visual expert assessment of the criteria distribution nature in areas, which makes it possible to identify promising zones for subsequent detailed study.

The approach proposed in this paper makes it possible to efficiently allocate the most promising areas for further detailed exploration. In the future, additional geological studies and more accurate analysis methods can be used to clarify the prospects of these areas and make informed decisions on further exploration and mining of the deposits. Thus, visual expert assessment will be an important tool in future geological survey and exploration, providing a basis for informed decision-making in the mining industry.

Based on the geological prediction, decisions are made on the feasibility of conducting further more detailed geological-surveying, prospecting, assessment, and exploration work in identified promising areas, taking into account the geological-economic assessment of expected mineral resources. Here, the method of visual expert assessment of the criteria distribution nature in areas to determine their prospects has a number of practical applications, especially in geological exploration and prospecting for mineral deposits.

One of the key advantages of this method is its relative ease of learning and use. It does not require sophisticated equipment or specialized skills and can be applied by geologists with different levels of experience. Visual expert assessment allows for rapid assessment of multiple areas and identification of the most promising zones for more detailed study, which is especially important at the initial stage of exploration, when decisions on further steps need to be made quickly. In addition, this method takes into account various criteria, including geological, geophysical, geochemical and other ones. This provides a comprehensive picture of the prospects of the areas. Subsequently, an assessment of the prospects of the areas, based on a visual expert assessment, can serve as a basis for making informed decisions on further investments in exploration and mining of the fields.

Conclusions. The relevance of this research lies in the need to increase copper-porphyry reserves in zones whose mineral potential has long been proven. This can be based on a scientific and methodological framework, consisting of a set of relevant mineragenetic and prospecting signs that would facilitate solving the problem of identifying resources, on the one hand. On the other hand, the required criteria and prospecting signs should be consistent with the conditions and capabilities of information technology. The paper shows the technology for collecting information for successful formation of criteria for the purpose of prospecting and exploration of copper-porphyry deposits.

The information provided will assist in further preparations for field work, requiring additional collection and examination of available stock data on promising areas selected according to the criteria presented. During the presented technology implementation, geological-geophysical and geochemical data packages can be generated in any modeling software and, as a result, a 3D geological model of the study area is updated, characterized by high reliability and accuracy. All of these activities will help to increase the success of further exploration studies.

References.

1. Akylbekov, S.A., & Uzhkenov, B.S. (2022). Prospects for the development of mineral resources of the largest mining enterprises in the short and long term periods of their activity. Part I. Copper, iron. *Engineering Journal of Satbayev University*, *144*(5), 26-35. https://doi.org/10.51301/ejsu.2022.i5.04.

2. Issatayeva, F.M., Aubakirova, G.M., Maussymbayeva, A.D., Togaibayeva, L.I., Biryukov, V.V., & Vechkinzova, E. (2023). Fuel and Energy Complex of Kazakhstan: Geological and Economic Assessment of Enterprises in the Context of Digital Transformation. *Energies*, *16*(16), 6002. https://doi.org/10.3390/en16166002.

3. Aubakirova, G., Rudko, G., & Isataeva, F. (2021). Assessment of metallurgical enterprises' activities in Kazakhstan in the context of international trends. *Economic Annals-XXI*, *187*(1-2), 121-130. https://doi.org/10.21003/EA.V187-12.

4. Begalinov, A., Peregudov, V., Tretyakov, A., Shautenov, M., Almenov, T., Bektur, B., & Sakhipova, K. (2023). Polygenic gold mineralization in quartz-pebble formations on the Takyr-Kaljir site of the Southern Altai, East Kazakhstan Region. *Mining of Mineral Deposits*, *17*(3), 32-41. https://doi.org/10.33271/mining17.03.032.

5. D'yachkov, B.A., Mizernaya, M.A., Khromykh, S.V., Bissatova, A.Y., Oitseva, T.A., Miroshnikova, A.P., & Yeskaliyev, Y.T. (2022). Geological history of the Great Altai: Implications for Mineral Exploration. *Minerals*, *12*(6), 744. https://doi.org/10.3390/min12060744.

6. Rudko, G.I., Myatchenko, A.V., Isataeva, F.M., & Portnov, V.S. (2018). Geological-economic estimation of Kazakhstan deposits. *Sustainable Development of Mountain Territories*, *10*(4), 471-480. https://doi.org/10.21177/1998-4502-2018-10-4-471-480.

7. Rakishev, B.M. (2022). About the metallogeny of Kazakhstan and its significance for the forecast of mineral deposits. *Engineering Journal of Satbayev University*, *144*(4), 25-33. https://doi.org/10.51301/ejsu.2022.i4.04.

8. Kalybekov, T., Rysbekov, K., Nauryzbayeva, D., Toktarov, A., & Zhakypbek, Y. (2020). Substantiation of averaging the content of mined ores with account of their readiness for mining. *E3S Web of Conferences*, (201), 01039. https://doi.org/10.1051/e3sconf/202020101039.

9. Tolovkhan, B., Smagulova, A., Khuangan, N., Asainov, S., Issagulov, S., Kaumetova, D., Khussan, B., & Sandibekov, M. (2023). Studying rock mass jointing to provide bench stability while Northern Katpar deposit developing in Kazakhstan. *Mining of Mineral Deposits*, *17*(2), 99-111. https://doi.org/10.33271/mining17.02.099.

10. Ablessenova, Z., Issayeva, L., Togizov, K., Assubayeva, S., & Kurmangazhina, M. (2023). Geophysical indicators of rare-metal ore content of Akmai-Katpar ore zone (Central Kazakhstan). *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 34-40. https://doi.org/10.33271/nvngu/2023-5/034.

11. Uteshov, Y., Galiyev, D., Galiyev, S., Rysbekov, K., & Nauryzbayeva, D. (2021). Potential for increasing the efficiency of design processes for mining the solid mineral deposits based on digitalization and advanced analytics. *Mining of Mineral Deposits*, *15*(2), 102-110. https://doi.org/10.33271/mining15.02.102.

12. Umarbekova, Z. (2017). The gold ore deposit Bakyrchik and views on the formation of the mineral deposits in Black Shale Strata. *SGEM International Multidisciplinary Scientific GeoConference*, *17*(1.1), 1111-1118. https://doi.org/10.5593/sgem2017/11/s04.142.

13. Omirserikov, M.S., Duczmal-Czernikiewicz, A., Isaeva, L.D., Asubaeva, S.K., & Togizov, K.S. (2017). Forecasting resources of rare metal deposits based on the analysis of ore-controlling factors. *News of the National Academy of Sciences of the Republic of Kazakhstan*, *3*(423), 35-43.

14. Malanchuk, Z.R., Moshynskyi, V.S., Korniienko, V.Y., Malanchuk, Y.Z., & Lozynskyi, V.H. (2019). Substantiating parameters of zeolite-smectite puff-stone washout and migration within an extraction chamber. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 11-18. https://doi.org/10.29202/nvngu/2019-6/2.

15. Nazirova, A., Abdoldina, F., Dubovenko, Y., & Umirova, G. (2019). Development of GIS subsystems for gravity monitoring data analysis of the subsoil conditions for oil and gas fields. *International Conference on Geoinformatics – Theoretical and Applied Aspects*, 1-5. https://doi.org/10.3997/2214-4609.201902099.

16. Akpanbayeva, A., & Issabek, T. (2023). Assessing a natural field of rock mass stress by means of in-situ measurements within Vostochnaya Sary-Oba deposit in Kazakhstan. *Mining of Mineral Deposits*, *17*(3), 56-66. https://doi.org/10.33271/mining17.03.056.

17. Aidarbekov, Z.K., & Istekova, S.A. (2022). Classification of Geophysical Fields in the study of geological and structural features of the Zhezkazgan Ore District. *News of the National Academy of Sciences of the Republic of Kazakhstan*, *2*(452), 33-48. https://doi.org/10.32014/2022.2518-170x.158.

18. Shogelova, N., & Sartin, S. (2023). Earth remote sensing application for forest fire size, burn state and fire recovery. Engineering *Journal of Satbayev University*, *145*(3), 31-39. https://doi.org/10.51301/ejsu.2023.i3.05.

19. Ratov, B. (2017). About a half-wave length of the bottom-hole core drill composed of structural elements of different stiffness. *SGEM International Multidisciplinary Scientific GeoConference*. https://doi.org/10.5593/sgem2017/12/s02.005.

20. Ratov, B.T., Mechnik, V.A., Bondarenko, M.O., & Kolodnitskyi, V.M. (2022). Physical and mechanical properties of WC–Co–CRB2 matrices of composite diamond-containing materials sintered by vacuum hot pressing for drilling tool applications. *Journal of Superhard Materials*, *44*(4), 240-251. https://doi.org/10.3103/s1063457622040086.

21. Baibatsha, A., Dussembayeva, K., & Shakirova, G. (2018). Geological and mineralogical features of the Sayak ore district (Kazakhstan). *International Multidisciplinary Scientific GeoConference: SGEM*, *18*(1.1), 159-166. https://doi.org/10.5593/sgem2018/1.1/s01.021.

22. Baibatsha, A.B. (2014). Paleovalleys mapping using remote sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, (40), 83-86. https://doi.org/10.5194/isprsarchives-xl-5-83-2014.

23. Issayeva, L., Togizov, K., Duczmal-Czernikiewicz, A., Kurmangazhina, M., & Muratkhanov, D. (2022). Ore-controlling factors as the basis for singling out the prospective areas within the Syrymbet rare-metal deposit, northern Kazakhstan. *Mining of Mineral Deposits*, *16*(2), 14-21. https://doi.org/10.33271/mining16.02.014.

24. Abdoldina, F.N., Nazirova, A.N., Dubovenko, Y.I., & Umirova, G.K. (2020). On the solution of the gravity direct problem for a prism with a simulated annealing approach. *Geomodel*, (1), 1-5. https://doi.org/10.3997/2214-4609.202050014.

25. Baibatsha, A., Omarova, G., & Shakirova, G. (2019). Innovative technologies of mineral resources predictioin on covered territories. *International Multidisciplinary Scientific GeoConference: SGEM*, *19*(1.1), 271-278. https://doi.org/10.5593/sgem2019/1.1/s01.033.

26. Baltiyeva, A., Orynbassarova, E., Zharaspaev, M., & Akhmetov, R. (2023). Studying sinkholes of the earth's surface involving radar satellite interferometry in terms of Zhezkazgan field, Kazakhstan. *Mining of Mineral Deposits*, *17*(4), 61-74. https://doi.org/10.33271/mining17.04.061.

27. Umarbekova, Z.T., Dyusembayeva, K.Sh., Ozdoev, S.M., & Gadeev, R.R. (2021). The Bakyrshik deposit's gold mineralisation prospecting model. *Series of Geology and Technical Sciences*, *4*(448), 99-107. https://doi.org/10.32014/2021.2518-170x.87.

28. Amralinova, B., Agaliyeva, B., Lozynskyi, V., Frolova, O., Rysbekov, K., Mataibaeva, I., & Mizernaya, M. (2023). Rare-Metal Mineralization in Salt Lakes and the Linkage with Composition of Granites: Evidence from Burabay Rock Mass (Eastern Kazakhstan). *Water*, *15*(7), 1386. https://doi.org/10.3390/w15071386.

Формування пошукових критеріїв родовищ мідно-порфірового типу на основі побудування еталонних моделей

С. Болатбекули[1], *Г. Умірова*[1], *М. Закарія*[1], *Р. Теміргханова*[1], *К. Тогізов*[*2]

1 – НАТ «Казахський національний дослідницький технічний університет імені К.І.Сатпаєва», м. Алмати, Республіка Казахстан

2 – Інститут геологічних наук імені К.І.Сатпаєва, м. Алмати, Республіка Казахстан

[*] Автор-кореспондент e-mail: k.togizov@satbayev.university

Мета. Дати оцінку сучасної методики формування списку мінерагенічних факторів і пошукових ознак рудних полів і родовищ мідно-порфірового типу на основі еталонних об'єктів і моделей побудов на прикладі родовищ Жунгаро-Балхаської складчастої області.

Методика. Методика виявлення шуканих факторів і критеріїв ґрунтується на зборі та аналізі опублікованих та історичних даних, формуванні цифрових баз даних з використанням растрових і векторних геологічних карт. Також включає використання сучасних, передових спеціалізованих технологій і програмних комплексів для геофізичних досліджень і даних дистанційного зондування. У відповідності до прийнятої технології використовуються результати аерокосмічних методів, що включають аерофотозйомку, космічну радіолокаційну, інфрачервону, спектробагатозональну та ін. У дослідженнях виконувалася інтерпретація супутникових знімків WorldView-3.

Результати. Сформовано список металогенічних ознак, що описують потенційну мідно-порфірову мінералізацію в межах району досліджень. Із застосуванням інфрачервоного спектрометра Spectral Evolution PSM-3500 виділені та оконтурені характерні області вторинних змін мідно-порфірових систем. Дані спектрального супутникового радіометра ASTER дозволили ідентифікувати спектри мінералів, гідроксиди заліза, пропілові асоціації, області окварцювання й силіфікації. За інтерпретацією супутникових знімків WorldView-3 отримані цифрові файли з виявленням залізорудних мінералів (гематит, гетит), вторинних кварцитів (просунуті аргілізити), різновиди серициту та інші глинисті мінерали, кремній, карбонати та пропіліти (хлор). На основі дешифрування в межах гранітних тіл виявлена «паркетна» тріщинуватість, а в межах галузі розвитку вулканогенних та осадових товщ – структурні лінії, що показують простягання шарів і пачок порід.

Наукова новизна. На прикладі однієї з пошукових ділянок на основі аналізу апріорних і сучасних відомостей визначено характер комплексу відповідних критеріїв та ознак для прогнозування й пошуку, спрямованого на підвищення достовірності та точності формування геолого-геофізичних моделей.

Практична значимість. Зібрані й систематизовані геофізичні дані можуть послужити основою при розробці планів подальших геологорозвідувальних робіт, виявленні перспективних ділянок, визначенні необхідних обсягів і методів геофізичних досліджень, а також сприяти збільшенню показників запасів та обсягів видобутку на гірничодобувних об'єктах. Підготовлені моделі призначені для попередньої оцінки відомих і щойно виявлених рудних покладів різних типів, а також для визначення напрямів геологорозвідувальних робіт у рамках пошукових ділянок у Північному Прибалхашші.

Ключові слова: *Північне Прибалхашшя, родовища мідно-порфірові, Жунгаро-Балхаська складчаста область, геофізичні критерії, пошукові ознаки*

The manuscript was submitted 10.12.23.