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PREDICTED RESOURCE ASSESSMENT OF CENTRAL KAZAKHSTA ORE DISTRICTS BASED ON AIRBORNE GEOPHYSICAL METHODS

Purpose. The research is aimed at creating a high-quality geophysical basis for the additional geological study of Central Kazakhstan in determining the geological structure of the study area, identifying promising areas for further geological exploration, as well as analyzing the anomalous distribution of various minerals.

Methodology. The research uses the methods of aeromagnetic, airborne gamma-ray spectrometry and gravimetric (ground) surveys. The obtained new airborne geophysical data are used for additional study of the geological structure of the district and the creation of a model of the geological structure of the study area. Gamma-ray spectrometry data analysis is conducted for detailed mapping of intrusive complexes and study of their lithological heterogeneity.

Findings. The processing and interpretation of the materials of the conducted field studies in combination with the results of the geological-geophysical data analysis made it possible to refine the geological structure and to present a model of ore-prospecting complexes in the study area. Areas with an anomalous distribution of potassium, uranium, and thorium have been identified, which make it possible to assess the structural heterogeneity of hidden magmatic massifs and to reveal a connection with gold, copper-polymetallic and rare-metal mineralization. Recommendations for further detailed geological exploration, including prospecting-exploration drilling, are given.

Originality. Research has shown the high efficiency of airborne geophysical methods, such as aeromagnetic and airborne gamma-ray spectrometry surveys to study the geological structure of ore areas, and in combination with detailed gravimetric exploration to identify lithological heterogeneity of igneous and sedimentary rocks in the study area. New scientific-methodological techniques and the geological structure model based on them gave an opportunity to assess the prospect of the study area for ore mineralization.

Practical value. The identified promising areas for mining of minerals are of interest for further research and exploration. The integrated use of geological-geophysical data will make it possible to determine more precisely the nature of radioactive anomalies and to reveal their relationship with ore-prospecting horizons. In general, the research results contribute to increasing the efficiency and reducing the geological survey costs.

Keywords: *airborne gamma-ray spectrometry survey, interpretation, mineral resources, geophysical surveys, zoning*

Introduction. The task of replenishing mineral resources is becoming more and more urgent for Kazakhstan every year. Its solution can be achieved only on the basis of further systematic study of the Republic's subsoil at the regional, zonal and local levels. The concept for the development of the Kazakh geological industry until 2030 provides for a systematic study of the most promising areas in order to make a reasonable selection of local sites for detailed prospecting and exploration. The program of this concept is aimed at creating a modern cartographic geological basis, assessing predicted mineral resources, identifying areas that are promising for discovering new mineral deposits, followed by compiling a condition-based State geological map of the Republic of Kazakhstan at a scale of 1:200 000. Long-term and successful practice of geological exploration in Kazakhstan, Russia and other countries has convincingly proved the high efficiency and expediency of geophysical studies ahead of additional geological study, including airborne geophysical magnetic-, gamma-ray spectrometry studies and ground gravimetric exploration.

Modern Airborne Gamma-ray Spectrometry Survey (AGSS) is one of the fastest and most economical methods of geophysics, which is traditionally used in combination with magnetic and electrical prospecting to study the geological structure and assess prospects in the search for radioactive ores and non-ferrous metal deposits [1]. By measuring the area-averaged values of the natural content of potassium (K), uranium (eU) and thorium (eTh) in the near-surface layer of rocks and weathered materials, as well as by detecting gamma radiation, the anomalous zones are identified [2]. Using paragenetic relationships between geochemical, ore and radioactive elements for various rocks and genetic classes of minerals, in addition to other prospecting methods, detailed geological mapping and assessment of the study area prospects for gold, copper-polymetallic and rare-metal mineralization is conducted based on the identified anomalies [3, 4].

Today, airborne gamma-ray spectrometry is a mandatory method for conducting advanced airborne geophysical surveys for additional geological study of the study district, which makes it possible to re-assess the predicted resources of previously surveyed areas and rationalize subsequent prospecting and prospecting-appraisal work at the modern level [5, 6]. According to the Guidelines for organizing and conducting additional geological survey at a scale of 1:200 000 in the Republic of Kazakhstan, "... a necessary condition for setting up planned geological work is the provision of the area with high-quality materials for geophysical, geochemical, aerial and space surveys and topographic base, as well as a serial legend approved by the Scientific-Editorial Council..." [7]. Planned geological work is not allowed in the absence of condition materials for advanced geophysical-geochemical work [8].

The study area is characterized by a complex internal structure and a long, difficult stage of development. Sarysu Teniz uplift occupies most of the study area [9]. A characteristic peculiarity of this area is its blocky composition, caused by a system of subparallel faults of northwestern and sublatitudinal strike, separating a series of linearly lowered and uplifted blocks, forming a series of graben-synclines [10]. The most developed orogenic complex is represented by terrestrial volcanogenic and terrigenous Devonian molasses and a quasi-platform folded complex, composed of a marine transgressive series of the Upper Devonian and Carboniferous deposits [11]. Three structural levels are clearly distinguished in the district structure, corresponding to three major stages in its development: Late Caledonian (geosynclinal), orogenic (postgeosynclinal) and a folded complex of superimposed depressions [12].

In metallogenic terms, the site of work is part of the Balkhash uranium-manganese metallogenic zone [13]. The confinement of the territory to the junction zone of the largest Central Kazakhstan structures, the tense tectonic situation, the wide distribution of polyfacial igneous formations (both outcropping on the surface and traced by geophysical methods at depth) determine a rather high metallogenic area load, especially in its southern and eastern parts [14, 15]. The following metallogenic zones have been identified in the study area: Teniz, Sarysu Teniz, Vostochny-Sarysu Teniz (Kondrashenkov I. I., 1986), within the boundaries of which 30 ore occurrences and one medium-sized mineral deposit have been identified, a significant part of which (10 out of 30) has a pronounced polymetallic specialization (Fig. 1).

In addition to uranium and manganese, the district has gold, tin, copper, asbestos and other minerals forming non-industrial resources [16]. Gold ore occurrences belong to the quartz-vein genetic type and are associated with small intrusions of average composition [17]. Tin mineralization is represented by bedrock and placer cassiterite. Tin-bearing placers tend to be alaskite granites of the Dalnensky massif. In the northwestern part of the area, halos of molybdenum dissemination with a concentration of up to 0.001 % have been revealed. Molybdenum halos are associated with lead (0.01 %), zinc (0.01 %) and silver (0.00001 %). This entire group of halos is associated with biotite-corniferous granites of the Upper Ordovician age, among which aplite dikes, granite porphyries and diorites are widely distributed [18]. As a result of the work on deep lithogeochemistry, primary halos of copper, lead, and zinc have been identified, which are confined mainly to the contact of intrusive rocks with host rocks [19].

The analysis of materials on the geological-geophysical knowledge of the study area shows that geological and detailed prospecting work has been conducted here for quite a long time, different-scale geological, structural-tectonic, metallogenic maps and schemes have been constructed [20, 21]. However, in the light of modern stratigraphic, geodynamic and metallogenic studies, many geological data and concepts are outdated (rock age, configuration and petrographic composition of intrusions, tectonics, and minerals) [22, 23]. In order to summarize and link all existing accumulated and modern geological-geophysical data, to clarify controversial and obtain new ones, additional geological-geophysical studies are performed and, first of all, modern research methods are used for advanced regional geophysical works at a scale of 1:50 000 [24, 25].

In order to create a high-quality geophysical basis for additional geological study of the study area within Central Kazakhstan, which covers the eastern part of Sarysu Teniz uplift,

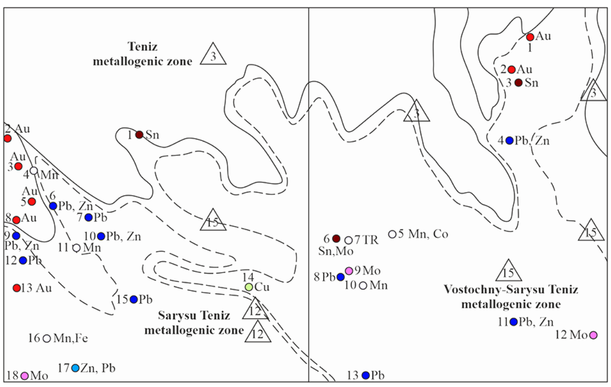


Fig. 1. Scheme of location of ore minerals in the study area (Kondrashenkov I. I., 1986)

the southern part of the Teniz Depression and the Sarysu Teniz segment of the Devonian volcano-plutonic belt have been studied using the methods of aeromagnetic, airborne gamma-ray spectrometry and gravimetric (ground) surveys. Most of the study area is characterized by low outcropping, which gives special advantages to geophysical methods [26].

By conducting airborne geophysical measurements and analyzing gamma-ray spectrometry data, the authors of this research aim at obtaining a more accurate understanding of the study area geological structure. This will make it possible to identify sites with an anomalous distribution of potassium, uranium, and thorium, which can be considered promising for discovery of gold, copper-polymetallic and rare-metal deposits.

Research methods. The complex of geophysical works in the study area is represented by aeromagnetic, airborne gamma-ray spectrometry and gravimetric (ground) surveys. The research uses the latest achievements in the field of airborne geophysical work, including advanced specialized technologies and software systems for processing and interpreting data obtained through gravimetry, magnetometry and gamma-ray spectrometry [27]. In terms of quality, the survey complies with all modern instructive requirements and solves the set tasks of additional geological study of areas. The actual accuracy of geophysical measurements exceeds design accuracy [28].

Field studies. Airborne gamma-ray spectrometry is performed by a regular network of 500 × 5000 m, with an average survey flight altitude of 75 m. The survey is conducted with a general flow around the relief. The flight altitude is controlled according to the radio altimeter readings and is measured from the earth's surface. When conducting airborne gamma-ray spectrometry survey, a digital 1024-channel spectrometer RSX-500 with two units of NaJ (Tl) RSX-4 and RSX-5 polyscine detectors with a total capacity of 32 l is used. The detection unit RSX-5, unlike RSX-4, comprises an additional detector with a capacity of 4 liters, shielded from the lower half-space radiation and designed to assess the atmospheric radon concentration.

To calculate the natural radionuclide content and total gamma radiation dose rate, the following energy windows are used: integrity channel: 0.4–2.81; Potassium: 1.37–1.57; Thorium: 2.41–2.81; Uranium: 1.66–1.86 MeV.

The calibration operations prior to the start of the survey are as follows: determination of the contribution rates of space radiation and the background board constant; determination of the contribution rates of the background radon component to the standard spectrometer windows; determination of effective absorption coefficients of gamma radiation by air; determination of sensitivities (scale factors) for standard spectrometer windows.

The contributions of space radiation and background board constant in the standard spectrometer windows are determined empirically from measurements of the spectrum over the water body [29]. Measurements are made in the altitude range from 1500 to 3000 m with an interval of 300 m and duration of about 4 minutes at each altitude. The contribution rates are determined both for the main block of detectors and for the upper half-space detector.

Determination of the contribution rates of the background radon component to the standard spectrometer windows. The radon background is calculated using a single upper half-space detector. The coefficients of the ratio of the counts in the uranium window (recorded by the upper half-space detector) to the count channels of potassium, uranium, thorium and the total counts of the lower half-space detectors are determined using water-surface profiles [30].

The effective absorption coefficients of gamma radiation by air are determined empirically for each window by spectrum measurements. The flights are performed at altitudes from 50 to 230 m from the ground with a step of 30 m.

The concentration sensitivities (scale factors) for standard spectrometer windows K, U, and Th are determined according to the data of measurements made on the calibration profile of the Aidarly test site. Test measurements are made along the test site axial line in straight and reverse directions (north-south and south-north). The flights are performed with a general flow around the relief at altitudes from 50 to 230 m from the earth's surface with a step of 30 m. The flight altitude is controlled according to the radio altimeter readings and is measured from the earth's surface.

The aeromagnetic data collection is performed using the second generation DAARC-500 aerogeophysical complex with adaptive aeromagnetic compensation in real time. The modulus of the magnetic field induction vector is measured with a highly sensitive quantum aeromagnetometer with a cesium vapor sensor CS-3 manufactured by Scintrex Company (Canada). Magnetic field recording frequency is 10 measurements/s. The magnetometer sensitivity is 0.001 nTl. To take into account daily changes in the geomagnetic field, the entire period of the aeromagnetic survey is accompanied by the recording of geomagnetic variations by a ground base station, set at a distance of 8 km from the airborne geophysical survey area. A Geometrics G-882 quantum magnetometer is used as a magnetic variation station.

To provide differential mode of geodetic referencing of airborne geophysical measurements, a dual-frequency L1/L2 TrimbleR7 GNSS GPS receiver is used as a ground base station. The equipment uses an advanced GPS chip of Trimble Maxwell™ Custom Survey GNSS.

Gamma-ray spectrometry processing is performed in two stages: both by the traditional method, based on the use of count rate data in differential windows, and by the NASVD analysis method.

Geosoft Oasis Montaj software package is used for initial processing and current quality control of the work. After entering the gamma-ray spectrometry data from the onboard computer into the computer memory of the field processing complex and entering them into the program databases, the standard technology operations for processing data from multichannel airborne gamma-ray spectrometers are performed, namely: energy scale calibration; consideration of the "dead" spectrometer time; consideration of the space component and the constant component of the residual background; elimination of the variable (atmospheric) component of the residual background – correction "for radon". In addition to the traditional method based on the use of count rate data in differential windows, the processing of airborne gamma-ray spectrometry data is performed by the NASVD analysis method (space background removal, consideration of the Compton scattered radiation, calculation of the covariance matrix) in the OasisMontaj program Praga 4 modulus.

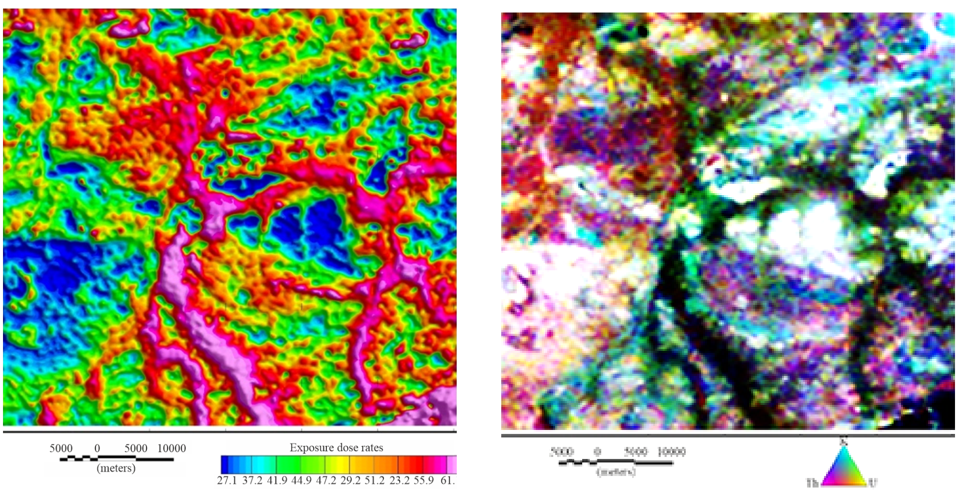
At this stage, during processing, the sums of the number of pulses within energy intervals are extracted from the spectrum, which reflect the contribution of potassium, uranium, thorium, cosmic radiation, respectively, as well as dose rate to the total spectrum. When the Compton scattering contribution is taken into account, the contribution rates of natural radionuclides to the windows *K*, *eTh*, and *eU* are used. Further, the pulse count rates in the standard spectrometer windows are recalculated into the concentrations of uranium, thorium, potassium (weight percent), and the exposure dose rate (EDR) of gamma radiation (nGy/hr) is calculated (Fig. 2, *a*). As a result, a color synthesis map of the contents of potassium, uranium, thorium and a scheme for zoning the territory according to the values of the contents of potassium, uranium, and thorium are presented (Fig. 2, *b*).

From the spectral ratios of 214Bi and 214Pb, the local gas Rn component is calculated and a correction for "free" radon is introduced into the uranium and total count channels. The correction value "for radon" characterizes free radon concentration in the ground-level atmosphere at the survey time and can be used to construct the corresponding map.

Given the highly-dynamic nature of this value variability, it makes sense to analyze the spatial changes only in the radon concentration local component. The maximum change in the ratio is achieved between the energy windows of 0.609 and 2.204 MeV, which is the most indicative and sustainable when assessing the presence of radon in the atmosphere.

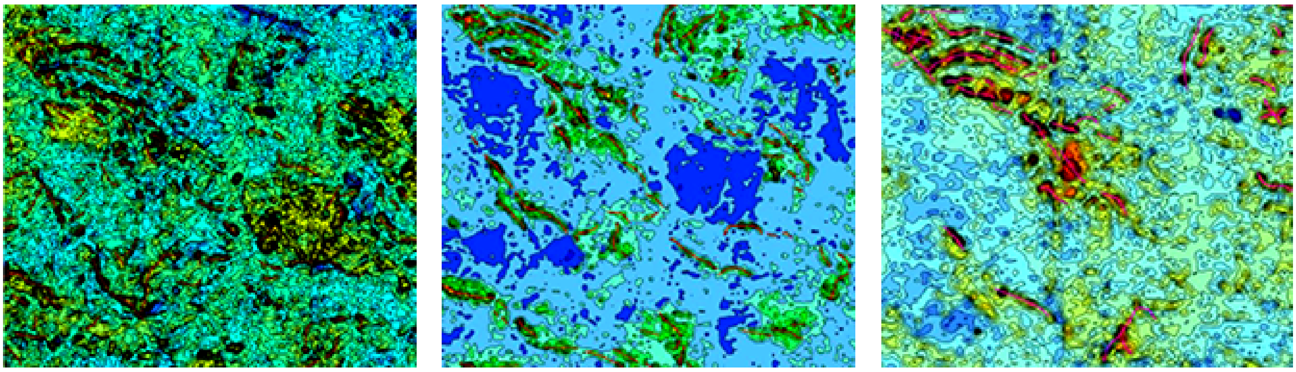
The procedure for analyzing airborne geophysical materials consists of a qualitative analysis and quantitative interpretation of the initial data and begins with the study of the survey results at the stage of field processing of the primary data. At the stage of qualitative interpretation, zoning of geophysical fields is performed with subsequent clarification of their relationship with geological structures, as well as the identification of areas with a high content of radioactive elements (*K*, *U*, *Th*). In the process of qualitative interpretation, objects for quantitative interpretation are identified and their parameters are assessed. In the process of analyzing airborne gamma-ray spectrometry data, a set of maps is used that characterizes the radio- geochemical fields of the study area based on the distribution of gamma-activity of rocks and the content of radioactive elements in them, such as potassium (*K*), uranium (*U*) and thorium (*Th*). In addition to maps of the main four channels (*EDR*, *K*, *U* and *Th*), maps of radioactive element parameters are used for interpretation: ratios of U/K, Th/U and Th/U, multiplicative parameter $(U \times K)/Th$ normalized to standard (Fig. 3).

Quantitative interpretation of the airborne gamma-ray spectrometry survey data is based on the rock difference effect in terms of radioactive element content [31]. In this case, the value of radioactive element concentration is directly correlated with the amount of radioactive minerals in the rock, which is associated with structural peculiarities and specific conditions



a *b*

Fig. 2. Airborne gamma-ray spectrometry processing results:
a – exposure dose rate map; b – color synthesis map of potassium, uranium, thorium contents



a *b* *c*

Fig. 3. Maps of radioactive element interpretation parameters:
a – uranium isoconcentrations; b – U/K ratio; c – U × K/Th ratio

for the formation of rocks that determine their formation affiliation and age [32]. All this predetermines the mapping value of the AGSS – data, taking into account the landscape and geomorphological conditions of the district. The radio-geochemical thorium and potassium fields have the greatest mapping information. Uranium often forms supergene clusters that are not directly related to the surrounding rocks [33].

The presence of correlations between the contents of uranium and thorium, uranium and potassium, thorium and potassium is a characteristic sign of an undisturbed, primary constitutional distribution of elements. The stability of thorium-uranium, thorium-potassium, and uranium-potassium ratios in radio-geochemistry is a criterion for assessing the degree of rock variability and identifying zones of epigenetic redistribution of radioactive elements.

Radio-geochemical halos associated with minerals differ from rocks with increased radioactivity not by the intensity of anomalies, but by their "spectral" composition – the ratio of radioactive elements. The general pattern is the confinement of the radio geochemical field of "ore" anomalies to areas of extreme predominance of one or two radioactive elements, while typical "rock" anomalies have a three-element composition with an approximately equal ratio of uranium, thorium and potassium.

Research findings. In the geological interpretation of the performed AGS survey, the radiometric and spectrometric characteristics of rocks are used, obtained from the data of field studies conducted on adjacent areas. Based on it, more reliable information has been obtained for similar rock complexes, since the conditions for AGSS measurements are much more favorable due to better outcropping.

Terrigenous-sedimentary and effusive formations of medium-basic composition, in general, are characterized by low clarke contents of radioactive elements and are practically not differentiated from each other (EDR = 2.0–3.0 mcR/h; $U = 1.5 \cdot 10^{-4}$ %; $Th = 4–8 \cdot 10^{-4}$ %; K = 1.5–2.5 %). The separate sections of these rocks, including lavas of andesitic-basaltic composition, lava-breccia, ignimbrites, tuffs, confined to different Lower and Middle Devonian suites are characterized by slightly increased gamma-activity and radioactive element content (EDR = 2.5–3.5 mcR/h; $U = 1.5 \cdot 10^{-4}$ %; $Th = 6–10 \times 10^{-4}$ %; K = 2.0–2.5 %).

Intrusive formations are noted most contrasting in radiometric properties (EDR = 3.0–4.5 mcR/h; $U = 1.5–4.5 \cdot 10^{-4}$ %; $Th = 8–10 \cdot 10^{-4}$ %; K = 2.0–3.0 %). In the zones of some tectonic disturbances, in the exo- and endo- intrusion contacts, where there are metasomatic and near-ore alterations in the rocks occur, the radioactive element distribution ratios are disturbed. This radio-geochemical peculiarity of potentially ore-bearing zones predetermines the search orientation and the AGSS method effectiveness for the detection and prediction of mineralization.

Identification of intrusive bodies and complexes of various compositions according to AGSS-data is most effective in conditions of good outcropping and significant areas of their development. At the same time, the differentiation of radio-geochemical fields is directly proportional to the increase in the intrusion phases, reaching 2–3 times the values of the AGSS parameters. Igneous rocks are characterized by an increase in radioactive element content from coarse-crystalline to fine-crystalline varieties, that is, late phases and their derivatives are more radioactive than the initial ones. On the maps of element contents, the latter are detected by annular anomalies of uranium-thorium and potassium-thorium nature, which determines the zonal character in terms of the location of radio-geochemical fields. Heavily eroded intrusive massifs have more radioactive peripheral zones, and vice versa – weakly eroded massifs are marked by radioactive element anomalies tending to the central part of the massifs. The exocontact zones are characterized by increases in uranium-potassium due to hornfelsing of rocks. Acidic dikes are detected by gamma-ray anomalies of all three elements. According to AGSS-data, zones of hydrothermalites are identified based on the discrepancy between the measured radioactive element concentrations and their clarkes (especially thorium-potassium), that is, the greater this discrepancy, the higher the degree of hydrothermal alteration in this rock.

The average background value of the exposure dose rate (Fig. 4, *a*) on the study area is 69 nGy/hr (8 mcR/h). The average background potassium content is 1.29 %, the minimum is 0.05 %, the maximum is 3.63 %, and the dispersion is ±0.33 %. The entire central strip of the study area is characterized by increased values (Fig. 4, *b*). The average background uranium content is $4.95 \cdot 10^{-4}$ %, the minimum is $0.88 \cdot 10^{-4}$ %, the maximum is $15.74 \cdot 10^{-4}$ %, and the dispersion is $\pm 0.93 \cdot 10^{-4}$ % (Fig. 4, *c*). The average background thorium content is 6.30×10^{-4} %, the minimum content is $0.10 \cdot 10^{-4}$ %, the maximum is $28.60 \cdot 10^{-4}$ %, and the dispersion is $\pm 1.54 \cdot 10^{-4}$ % (Fig. 4, *d*).

The minimum values of gamma-activity have been obtained above the water surface of the lakes Karatomar, Izendi, Tuzkol, Akdalasor and others, which are of different sizes and salinity in the area. The gabbro-diorites of the Upper Ordovician age (Tasshokinsk intrusive massif) and outcrops of carbon deposits are noted by reduced values of the gamma radiation dose rate up to 40 nGy/hr, potassium content 0.8 % and thorium $(3–4) \cdot 10^{-4}$ %. According to the minimum uranium content $(3–4) \cdot 10^{-4}$ %, sections of the territory are distinguished, the surface of which is represented by Quaternary deposits.

The map of potassium content in the area shows that the outcrops of coal-bearing deposits are characterized by values below the background ones. Areas with a high K content are noted above the Devonian sediment outcrops (of different divisions and suites) and along fault lines that bound them. A series of anomalies is confined to intrusive massifs of granitoid composition – the Amantau massif (up to 2 %), the Beladyr massif (up to 2.4 %), the Kyzymshek massif (up to 2.2 %), and the Akrysh massif granites (up to 2.8 %). Granitoid massifs are

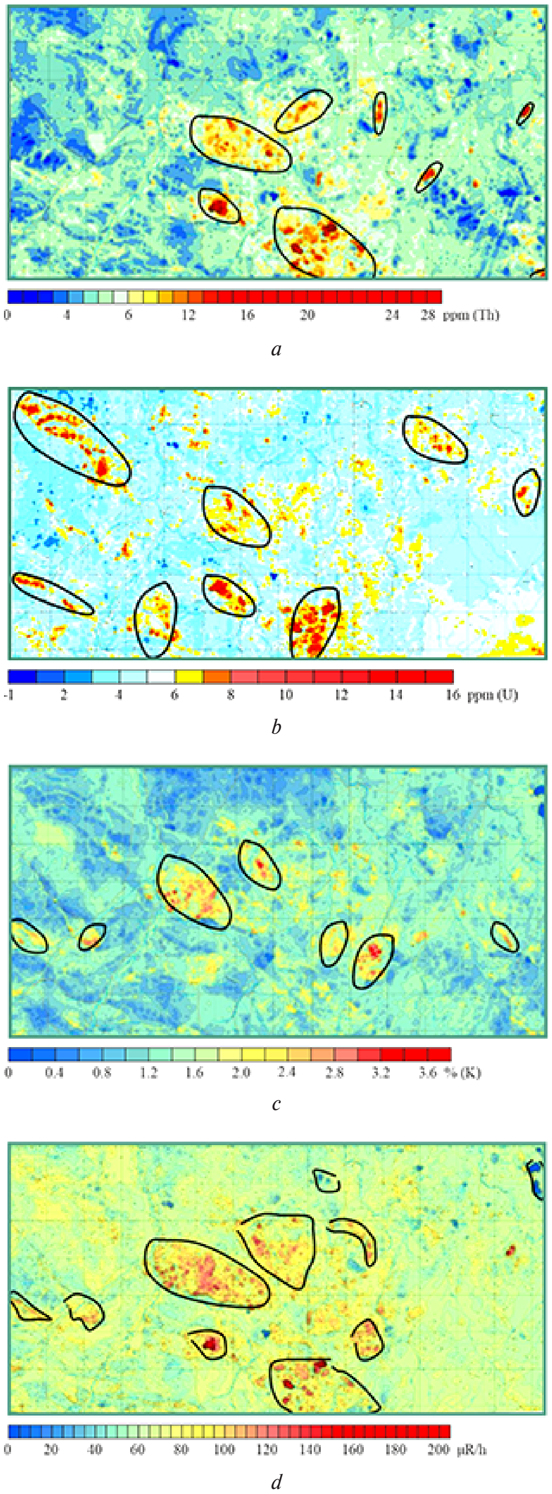


Fig. 4. Identification of anomalous zones by AGSS-data:

a – by the exposure dose rate map; b – by potassium content; c – by uranium content; d – by thorium content

characterized by a two-phase intrusion and potassium content of the last phase. Subvolcanic bodies also of Devonian age are characterized by increased potassium content (rhyolites, trachyandesites – K content up to 3.2 %, slightly lower – basalts up to 2 %). Thus, all anomalies in the content of potassium tend to be Devonian age formations.

The maximum gamma radiation dose rates up to 188 nGy/hr, potassium content 3.63 %, uranium $16 \cdot 10^{-4}$ % and thorium $29 \cdot 10^{-4}$ % are fixed in the central, southern and eastern parts of the area, for all elements above the intrusive massifs composed of granites.

Increased potassium content (in the central and south-central parts of the area) is associated with outcropping Devonian deposits, often effusive and subvolcanic bodies. Outcrops of coal-bearing deposits (northwest, northeast and center of the area), as well as granite massifs in the southern, eastern and southeastern parts of the area are characterized by increased uranium content. The maximum thorium content, as well as uranium, is identified above intrusive formations composed of granites. By its spectral composition, the anomaly is complex, of thorium-uranium-potassium nature, and it is likely to be genetically related to the processes of greisenization of granitoids and may be a search sign of rare-metal mineralization. However, the real ore content of radio-geochemical anomalies should be assessed based on the results of targeted ground verification.

Each element maps a specific group of geological bodies or objects. The radioactive element content changes dramatically from point to point (not like in magnetic and gravitational fields). Therefore, in order to remove excessive "diversity" and obtain more statistical content values, the filtering method is used [34].

The identification of the low-frequency component by a two-dimensional filtering method makes it possible to remove "artifacts" from large geological objects and to distinguish local anomalies in the content of *K*, *U* and *Th* of small and medium sizes (Fig. 5).

An analysis of the anomalies in the *U* content shows that the general uranium content background is about $5 \cdot 10^{-4}$ %, and this background for the study area has a certain tendency in the direction from the northwest to the southeast, that is from the more submerged part of the Teniz Depression onboard zone. Some of the detected anomalies have a linear shape, expressed in chains of local anomalies in a certain direction. Reference of these chains to the geological map shows that the outcrops of coal-bearing deposits, in particular the Rusakovsk suite, correspond to the zones of anomalously high uranium content (Fig. 6).

The distribution of uranium is strongly correlated with the structural peculiarities of the distribution of carbon deposits in the northwestern corner of the area, in its western and central parts. Naturally, the increased uranium content acts as a reference point in carbon deposits. In addition, isometric areas are distinguished in the southern and southeastern parts of the area associated with Devonian granosyenites and leucogranites (Karamenda intrusive complex, Amantau massif).

An analysis of the low-frequency component through the thorium channel shows that its high content is concentrated in the central and southern parts of the area and is confined to Ordovician and Devonian diorites. According to thorium, anomalies create volcanic bodies, outcropping intrusions, mainly of acidic composition. On all four channels (EDR, K, U, Th), structurally, the radioactive element contents in graben-synclinal zones are background. The statistical description of the identified areas is presented in the Table.

In general, based on the airborne gamma-ray spectrometry data, 20 zones of high radioactive element contents have been identified. These zones comprise both anomalous groups and individual local anomalies. The anomaly identification is based on the excess of the average level concentrations, taking into account the dispersion. The following levels are accepted as the lower threshold for detecting anomalies: for exposure dose rate – 80 nGy/hr; for potassium – 1.8 %; for uranium – $7 \cdot 10^{-4}$ %; for thorium – $9 \cdot 10^{-4}$ %.

As a result of airborne gamma-ray spectrometry surveys, 12 districts (or classes) have been identified in the area, characterized by different parameters of potassium, uranium and thorium content. The nature of the gamma-radioactivity field distribution, including its spectral composition, is clearly illustrated by the color synthesis image map of potassium, uranium and thorium contents (Fig. 7).

Dark colors to black correspond to areas of high radioactivity with anomalously high levels of all three naturally occurring radioactive elements of potassium, uranium, and thori-

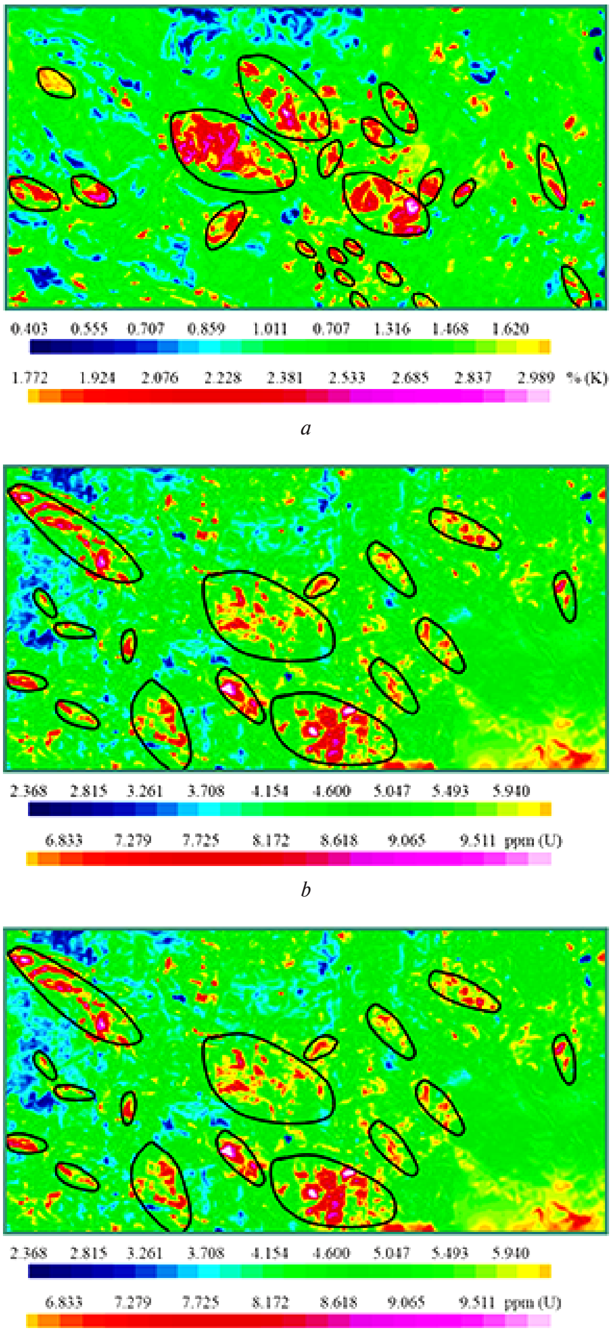


Fig. 5. Identification of the low-frequency component of local anomalies by a two-dimensional filtering method:

a – by potassium content; b – by uranium content; c – by thorium content

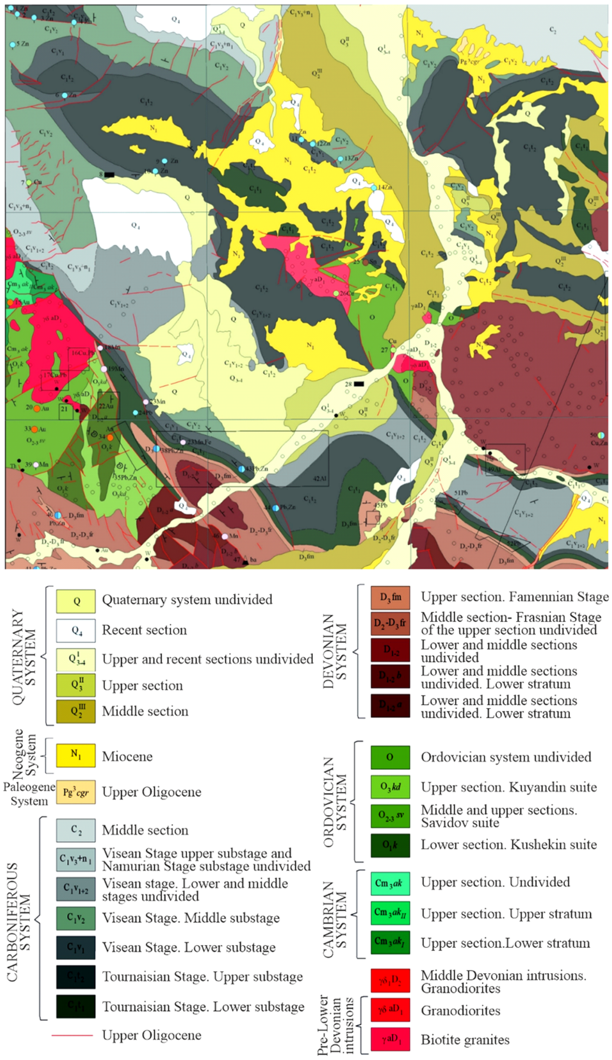


Fig. 6. Geological interpretation of the airborne gamma-ray spectrometry results (fragment of geological map according to content analysis of U, K and the ratio of $U \times K/Th$

um. Areas of minimum gamma radioactivity on the map are colored white. Areas rich in thorium are colored red, uranium – yellow and potassium – blue.

According to the three-color mixing diagram, anomalous areas of synchronous increase in uranium and potassium contents on the map are marked green with the transition to blue with an increase in the proportion of potassium, or with the transition to yellow if uranium predominates. The coloring of thorium-uranium anomalies correspondingly changes from red through pink to yellow when the radio-geochemical type of the anomaly changes from predominantly thorium to uranium.

As a result, based on the analysis of airborne gamma-ray spectrometry data, additional information has been obtained on the study area geological structure. This information forms the basis for further research to confirm and detail the results of geophysical measurements and includes detailed geological survey, well drilling, laboratory sample analysis and detailed geophysical methods (electromagnetic survey, etc.)

Numerical modeling of gamma-ray spectrometry data can serve as a basis for the development of new geological models and hypotheses on the origin and structure of hidden geological complexes of the study area, as well as for a deeper understanding of geological processes and related mineralization [35]. The research results can be used to expand the boundaries of the study area in adjacent districts. This will provide a more complete picture of the geological structure and resource potential of the entire area.

An important step in further research will be an integrated geological-geophysical interpretation with extensive use of geological maps, geochemical analyses of rock samples and other information. Modeling of physical fields in the environment of modern geographic information systems will help to obtain a more complete and accurate picture of the geological structure and resource potential of the study area.

The research results can be used in practical activities related to geological exploration and mining of minerals in other districts. For example, they can be used in planning of deposit mining, well-drilling site selection and the identification of promising sites for mining investment.

Conclusions. The analysis of gamma-ray spectrometry data conducted in this research confirms that this method is effective for mapping the composition of intrusive and strati-

Table

Classification by signs of zoning of the territory according to the content of potassium, uranium, thorium

Class	Distribution area, %	Class color designations	Potassium content, %			Uranium content, $\times 10^{-4}$ %			Thorium content, $\times 10^{-4}$ %		
			average	dispersion	standard	average	dispersion	standard	average	dispersion	standard
1	8.06		0.84	0.13	0.156	5.59	0.49	0.088	5.54	1.05	0.189
2	1.38		0.87	0.16	0.180	7.40	0.66	0.089	5.91	0.81	0.137
3	2.51		0.95	0.17	0.176	3.64	0.65	0.178	3.55	0.60	0.169
4	36.55		1.26	0.12	0.098	4.33	0.40	0.092	5.95	0.87	0.146
5	5.38		0.85	0.15	0.171	4.26	0.48	0.113	5.13	0.96	0.187
6	23.87		1.26	0.13	0.103	5.38	0.39	0.072	6.27	0.74	0.118
7	5.35		1.62	0.12	0.073	4.43	0.35	0.078	6.24	0.77	0.124
8	3.43		1.26	0.17	0.136	6.03	0.82	0.136	8.78	0.92	0.104
9	5.60		1.62	0.12	0.075	5.42	0.44	0.081	6.81	0.59	0.086
10	3.05		2.25	0.25	0.110	5.34	0.67	0.126	7.93	1.20	0.152
11	4.44		1.70	0.16	0.094	5.96	0.64	0.107	9.15	1.11	0.122
12	0.38		1.89	0.23	0.120	8.81	1.59	0.180	15.19	3.39	0.223

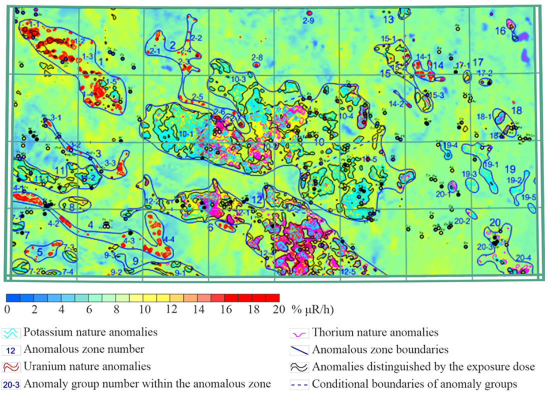


Fig. 7. Identification of anomalies by the content of radioactive elements

fied units, as well as separating intrusive complexes in certain areas of Central Kazakhstan by phase and sub-phase composition. Using the obtained airborne geophysical data, the study area geological structure has been detailed, and a model of the study area geological structure has been developed, in which areas with an anomalous distribution of potassium, uranium, and thorium are identified, representing perspective for the detection of gold, copper-polymetallic and rare-metal mines. Further geological exploration of these sites is recommended.

Further integrated use of all available geological-geophysical data in the geological interpretation of local gravitational anomalies, an anomalous magnetic field, modern seismic studies, taking into account radioactive element concentrations, will more confidently and unambiguously determine the nature of most newly identified radioactive anomalies. The performed research contributes to improving the efficiency of geological exploration in general, thereby reducing the time and costs associated with conducting geological research.

References.

1. Jurza, P., Campbell, I., Robinson, P., Wackerle, R., Cunneen, P., & Pavlík, B. (2005). Use of 214Pb Photopeaks for Radon Removal: Utilising Current Airborne Gamma-Ray Spectrometer Technology and Data Processing. *Exploration Geophysics*, *36*(3), 322-328. https://doi.org/10.1071/eg05322.

2. Qin, G., Xu, Y., Li, F., Zhou, W., Li, W., & Zhao, G. (2022). Calibration of an airborne γ-ray spectrometer based on an unmanned aerial vehicle using a point source. *Annals of Nuclear Energy*, (178), 109349. https://doi.org/10.1016/j.anucene.2022.109349.

3. El-Sadek, M. A. (2022). Using of airborne gamma-ray spectrometric data to the exposure of potassic alteration-recognition of alteration relates to gold mineralization. *Applied Radiation and Isotopes*, (190), 110511. https://doi.org/10.1016/j.apradiso.2022.110511.

4. 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.

5. Mitran, T., Sreenivas, K., Janakirama Suresh, K. G., Sujatha, G., & Ravisankar, T. (2021). Spatial prediction of calcium carbonate and clay content in soils using airborne hyperspectral data. *Journal of the Indian Society of Remote Sensing*, (49), 2611-2622. https://doi.org/10.1007/s12524-021-01415-5.

6. Salikhov, T. K., Tulegenova, D. K., Berdenov, Zh. G., Sarsengaliyev, R. S., & Salikhova, T. S. (2022). Study of the soil cover of ecosystems of the Chingirlaus district of the Western Kazakhstan region on the basis of the application of GIS technologies. *Series of geology and technical sciences*, *3*(453), 226-242. https://doi.org/10.32014/2022.2518-170x.192.

7. Yermolov, P., Khasen, B., Antonyuk, R., & Makat, D. (2019). Geodynamics and metallogeny of Tekturmas ophiolite belt (According to the records of the grant of the Science Fund of the Republic of Kazakhstan 2018–2020 "Depth prognosis, surveys, exploration of mineralization areas in Tekturmas ophiolite belt). *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *6*(438), 235-245. https://doi.org/10.32014/2019.2518-170X.175.

8. Baibatsha, A.B., & Muszynski, A. (2020). Geological-geophysical prospecting indicators of the arganaty district predictive blocks (Eastern Balkhash). *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *2*(440), 31-39. https://doi.org/10.32014/2020.2518-170X.28.

9. Moldabayeva, G. Z., Suleimenova, R. T., Akhmetov, S. M., Shayakhmetova, Z. B., & Suyungariyev, G. E. (2021). The process of monitoring the current condition of oil recovery at the production fields in Western Kazakhstan. *Journal of Applied Engineering Science*, *19*(4), 1099-1107. https://doi.org/10.5937/jaes0-30840.

10. Togizov, K., Muratkhanov, D., & Aksholakov, Y. (2020). Rare-earth element concentration conditions in the rare-metal deposits of the Karakamys ore district. *Science and Technologies in Geology, Exploration and Mining*, 271-278. https://doi.org/10.5593/sgem2020/1.1/s01.034.

11. Rakishev, B., Kenzhetaev, Z., Mataev, M., & Togizov, K. (2022). Improving the Efficiency of Downhole Uranium Production Using Oxygen as an Oxidizer. *Minerals*, *12*(8), 1005. https://doi.org/10.3390/min12081005.

12. Stepanets, V. G., Levin, V. L., Savelyev, N. A., Khakimzhanov, M., & Makat, D. K. (2017). Evolution of picrite magmatism and ore formation in the Ulytau region of central Kazakhstan. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *1*(421), 18-36.

13. Baibatsha, A., Arshamov, Y., Bekbotayeva, A., & Baratov, R. (2017). Geology of the main industrial types of copper ore deposits in Kazakhstan. *International Multidisciplinary Scientific Geoconference SGEM*, (11), 231-238. https://doi.org/10.5593/sgem2017/11/s01.029.

14. 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.

15. Baibatsha, A. B., Bekbotayeva, A. A., & Bekbotayev, A. T. (2015). Ore minerals of Carboniferous copper sediment-hosted Zhezkazgan

deposit (Central Kazakhstan). *Surveying Geology and Mining Ecology Management*, (1), 329-335.
16. 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.
17. Gornostayev, S.S., Crocket, J.H., Mochalov, A.G., & Laajoki, K.V.O. (2009). The platinum-group minerals of the Baimka placer deposits, Aluchin horst. *Canadian Mineralogist*, *37*(5), 1117-1129.
18. Begalinov, A., Shautenov, M., Almenov, T., & Bektur, B. (2022). Leaching process intensification of gold-bearing raw materials. *Mining of Mineral Deposits*, *16*(2), 42-48. https://doi.org/10.33271/mining16.02.042.
19. D'yachkov, B.A., Bissatova, A.Y., Mizernaya, M.A., Khromykh, S.V., Oitseva, T.A., Kuzmina, O.N., Zimanovskaya, N.A., & Aitbayeva, S.S. (2021). Mineralogical tracers of gold and rare-metal mineralization in Eastern Kazakhstan. *Minerals*, *11*(3), 1-23. https://doi.org/10.3390/min11030253.
20. Togizov, K., & Antonenko, A. (2020), The structural tectonic position and predictive search criteria for the lead-zinc karst mineralisation (South Kazakhstan). *International Multidisciplinary Scientific Geoconference SGEM*, (20), 335-340. https://doi.org/10.5593/sgem2020/1.1/s01.042.
21. Shoimuratov, T.H., Hajitov, N.Sh., & Kurbanyazov, S.K. (2022). The role of hydrodynamic and structural-tectonic factors in the formation of hydrocarbon deposits in the Jurassic sediments of the Bukharo-Khiva region. *Engineering Journal of Satbayev University*, *144*(4), 41-45. https://doi.org/10.51301/ejsu.2022.i4.06.
22. Antonenko, A., & Khodzhimuratova, A. (2020). Local criteria in search for karst mineralization in the Achisai ore district (South Kazakhstan). *International Multidisciplinary Scientific Geoconference SGEM*, (20), 147-153. https://doi.org/10.5593/sgem2020/1.1/s01.019.
23. Wang, J., Apel, D.B., Dyczko, A., Walentek, A., Prusek, S., Xu, H., & Wei, C. (2022). Analysis of the damage mechanism of strainbursts by a global-local modeling approach. *Journal of Rock Mechanics and Geotechnical Engineering*, *14*(6), 1671-1696. https://doi.org/10.1016/j.jrmge.2022.01.009.
24. Mukhanova, A.A., Yessengaziyev, A.M., Barmenshinova, M.B., Samenova, N.O., Toilanbay, G.A., & Toktagulova, K.N. (2022). Improvement of the technology related gold-containing raw materials with the use of ultramicroheterogeneous flotoreagent. *Metalurgija*, *61*(3-4), 777-780.
25. Yessengaziyev, A., Mukhanova, A., Tussupbayev, N., & Barmenshinova, M. (2022). The usage of basic and ultramicroheterogenic flotation reagents in the processing of technogenic copper-containing raw materials. *Journal of Chemical Technology and Metallurgy*, *57*(6), 1235-1242.
26. Kassymkanova, K.K., Istekova, S., Rysbekov, K., Amralinova, B., Kyrgizbayeva, G., Soltabayeva, S., & Dossetova, G. (2023). Improving a geophysical method to determine the boundaries of ore-bearing rocks considering certain tectonic disturbances. *Mining of Mineral Deposits*, *17*(1), 17-27. https://doi.org/10.33271/mining17.01.017.
27. Lewinska, P., Dyczko, A., & Matula, R. (2017). Integration of Thermal Digital 3D Model and a MASW (Multichannel Analysis of Surface Wave) as a Means of Improving Monitoring of Spoil Tip Stability. *Baltic Geodetic Congress,* 232-236, 8071478. https://doi.org/10.1109/BGC.Geomatics.2017.29.
28. Stepanenko, N.I., Dyusembaeva, K.Sh., & Isaeva, L.D. (2017). Ore-bearing weathering mantle of Kundybay rare earth deposit (North Kazakhstan). *Gornyi Zhurnal*, (2), 33-38. https://doi.org/10.17580/gzh.2017.02.06.
29. Mukhamedzhanov, M.A., Makyzhanova, A.T., & Kulagin, V.V. (2017). The rationale and definition of prospects by the use of groundwater for irrigation, forage production and pastures irrigation of Kazakhstan. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*, *3*(423), 72-83.
30. Jurza, P., Campbell, I., Robinson Wackerle, R., Cunneen, P., & Pavlik, B. (2005). Use of 214Pb phtopeaks for Radon removal: utilizing current airborne gamma-ray spectrometer technology and data processing. *Exploration Geophysics*, (36), 322-327. https://doi.org/10.1071/EG05322.
31. Ratov, B.T., Bondarenko, M.O., Mechnik, V.A., Strelchuk, V.V., Prikhna, T.A., Kolodnitskyi, V.M., Nikolenko, A.S., ..., & Borash, A.R. (2021). Structure and Properties of WC–Co Composites with Different CrB2 Concentrations, Sintered by Vacuum Hot Pressing, for Drill Bits. *Journal of Superhard Materials*, *43*(5), 344-354. https://doi.org/10.3103/s1063457621050051.
32. 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.
33. Issayeva, L., Assubayeva, S., Kembayev, M., & Togizov, K. (2019). The formation of a geoinformation system and creation of a digital model of Syrymbet rare-metal deposit (North Kazakhstan). *International Multidisciplinary Scientific Geoconference SGEM*, *19*(1), 609-616. https://doi.org/10.5593/sgem2019/1.1/s01.075.
34. Amralinova, B.B., Frolova, O.V., Mataibaeva, I.E., Agaliyeva, B.B., & Khromykh, S.V. (2021). Mineralization of rare metals in the lakes of East Kazakhstan. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 16-21. https://doi.org/10.33271/nvngu/2021-5/016.
35. Kenzhetaev, Zh., Togizov, K., Abdraimova, M., & Nurbekova, M. (2022). Selecting the rational parameters for restoring filtration characteristics of ores during borehole mining of uranium deposits. *Mining of Mineral Deposits*, *16*(3), 1-10. https://doi.org/10.33271/mining16.03.001.

Оцінка прогнозних ресурсів рудних районів Центрального Казахстану на основі аерогеофізичних методів

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Мета. Створення якісної геофізичної основи для геологічного довивчення Центрального Казахстану, щодо геологічного будови площі досліджень, виділення перспективних ділянок для подальших геологорозвідувальних робіт і аналізу аномального розподілу різних корисних копалин.

Методика. Дослідження проводилися із застосуванням методів аеромагнітної, аерогама-спектрометричної та гравіметричної (наземної) зйомки. Отримані нові аерогеофізичні дані використовувалися для довивчення геологічної будови району та створення моделі геологічної будови площі досліджень. Аналіз даних гамма-спектрометрії був проведений для детального картування інтрузивних комплексів і вивчення їхньої літологічної неоднорідності.

Результати. Обробка та інтерпретація матеріалів проведених польових досліджень у комплексі з результатами аналізу геолого-геофізичних даних дозволила уточнити геологічну будову та представити модель рудоперспективних комплексів площі досліджень. Виділені ділянки з аномальним розподілом калію, урану, торію, що дозволяє дати оцінку неоднорідності будови прихованих магматичних масивів і встановити зв›язок із золотим, мідно-поліметалевим і рідкометалевим орудненням. Наведені рекомендації для подальших детальних геологорозвідувальних робіт, включаючи пошуково-розвідувальне буріння.

Наукова новизна. Дослідження показали високу ефективність аерогеофізичних методів, таких як аеромагнітна та аерогама-спектрометрична зйомки для вивчення геологічної будови рудних районів, а в комплексі з детальною гравірозвідкою для виявлення літологічної неоднорідності магматичних і осадових гірських порід району досліджень. Нові науково-методичні прийоми й побудована на їх основі модель геологічної будови дали можливість оцінити перспективність площі досліджень на рудне орудненння

Практична значимість. Виділені перспективні ділянки виявлення корисних копалин становлять інтерес для подальших досліджень і розвідки. Комплексне використання геолого-геофізичних даних дозволить точніше визначити природу радіоактивних аномалій і встановити їх зв›язок із рудоперспективними горизонтами. Загалом, результати досліджень сприяють підвищенню ефективності та скороченню витрат на геологічні дослідження.

Ключові слова: *аерогама-спектрометрична зйомка, інтерпретація, корисні копалини, геофізичні дослідження, районування*

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