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CHARACTERISTICS OF GEOPHYSICAL FIELDS AND GEOPHYSICAL SIGNS OF MINERALIZATION IN THE BUKANTAU MOUNTAINS IN THE SOUTHERN TIEN-SHAN

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Summary. The Bukantau Mountains are located in the northwestern part of the Southern Tien Shan folded gold ore belt. In geodynamic zoning, the Bukantau Mountains are divided into the North Bukantau and the South Bukantau structural-formational zones (SFZ). They are complexly curved uplifts complicated by smaller folds. The ores of the North Bukantau SFZ form copper-zinc-pyrite with gold (Karamurun), gold-sulfide-quartz (Irlir, Dzhetymtau) and secondary copper-molybdenum-skarn (Orazaly I, II) and chromite formations. The main ore deposits of the South Bukantau SFZ are rare metal-gold ore (Altyntau deposit), gold-arsenic (Kokpatas deposit), gold-polymetallic (Turbay deposit), gold-silver (Okzhetpes deposit) mineralization, tungsten-bearing skarns and skarnoids (Sautbay deposit).

The paper contains an analysis of long-term data from complex geophysical studies of the Bukantau Mountains. The characteristics of changes in the values of the physical field of 63 objects in the Bukantau Mountains were analyzed and complexes of geophysical features and relationships with the localization of mineralization were created.

The search criteria were formulated based on a study of the features of physical fields characteristic of known ore occurrences and deposits, from the point of view of the degree of unambiguity of their reflection in electric, gravitational and magnetic fields. Comparison of remote sensing data, geophysical and geochemical data using static and metallogenic analyses made it possible to determine predictive and promising positions, confirmed by field interpretation and driving of mine workings, recommended for further geological exploration work.

1. INTRODUCTION

Currently, scientific studies are being conducted worldwide to identify the physical properties of rocks and their analysis. In particular, special attention is given to conducting extensive complex geological and geophysical studies in the USA, Russia, China, India and the states of Central Asia to meet the demand for minerals. Such a scientific approach improves the methodology to solve quantitative interpretation problems of geophysical mineralization signs in the exploration and search for mineral deposits.

Determining the main factors of gold ore localization and other manifestations of minerals is necessary to improve the efficiency of forecasting and prospecting.

To date, identifying localization factors of gold deposits is based primarily on empirical data and on the search for deposit placement patterns relative to geological structural elements of the regions. Therefore, one of the main conditions for the successful identification of localization factors of deposits is studying the geological structure and history of the geological development of territories and determining the place and time of concentration formation.

Endogenous ore deposits represent abnormal concentrations of useful elements in a relatively small volume of the Earth's crust that arose due to the confluence of favourable circumstances under the influence of various factors during the development of the Earth. Their detection is the main goal of geological research, in which there are stages of forecasting and researching. These stages are based on identifying objective patterns of the formation and placement of specific ores in the upper horizons of the Earth's crust. To accomplish this, various geological, geophysical, geochemical, surficial, and hydrogeological methods are used, and the prerequisites for the occurrence of the desired ores in certain formations or structures and the empirical patterns of the placement of known mineralization relative to specific lithological, tectonic and magmatic factors are taken into account. A positive result is achieved only while considering the totality of all data reflecting the peculiarities of the formation of a specific mineralization type.

The purpose of this paper is a static analysis of the anomalies in the geophysical fields of the Bukantau Mountains (the western end of the southern Tien Shan (Fig. 1)) for further metallogenic prediction (Борисов и Глух, 1982; Рогачев, 1977; Сердюков, 1978; Глух и др., 2002; Goipov, et al., 2020a; 2020b; Гоипов, 2021).

The gold deposits and manifestations of the Bukantau are part of four formations: gold-sulfide veined-interspersed ores, gold-sulfide-quartz, gold-silver and gold-scarn. The deposits of the gold (sulfide)-quartz formation can be divided into two subformations: a) low-sulfide veined zones and stockwork and b) low-sulfide veins, linear vein zones and breccias.

The established main factors of the localization of ore fields are common to the entire folded system.

In addition, the roles of some of these factors may be different in each tectonic segment. For each type of gold deposit, the selected factors have slightly different meanings.

All deposits and manifestations of the Bukantau gold are located within extended intrablock crushing zones and are usually subconsistent with the host strata. Therefore, these zones play the role of ore-controlling structures and are comparable to ore-bearing faults (Гоипов, 2021). In addition to crushing, the zones are characterized by small rods and dikes of small bodies with variegated composition that often form belts and bundles, and sometimes there is an increased number of veins, including quartz veins.

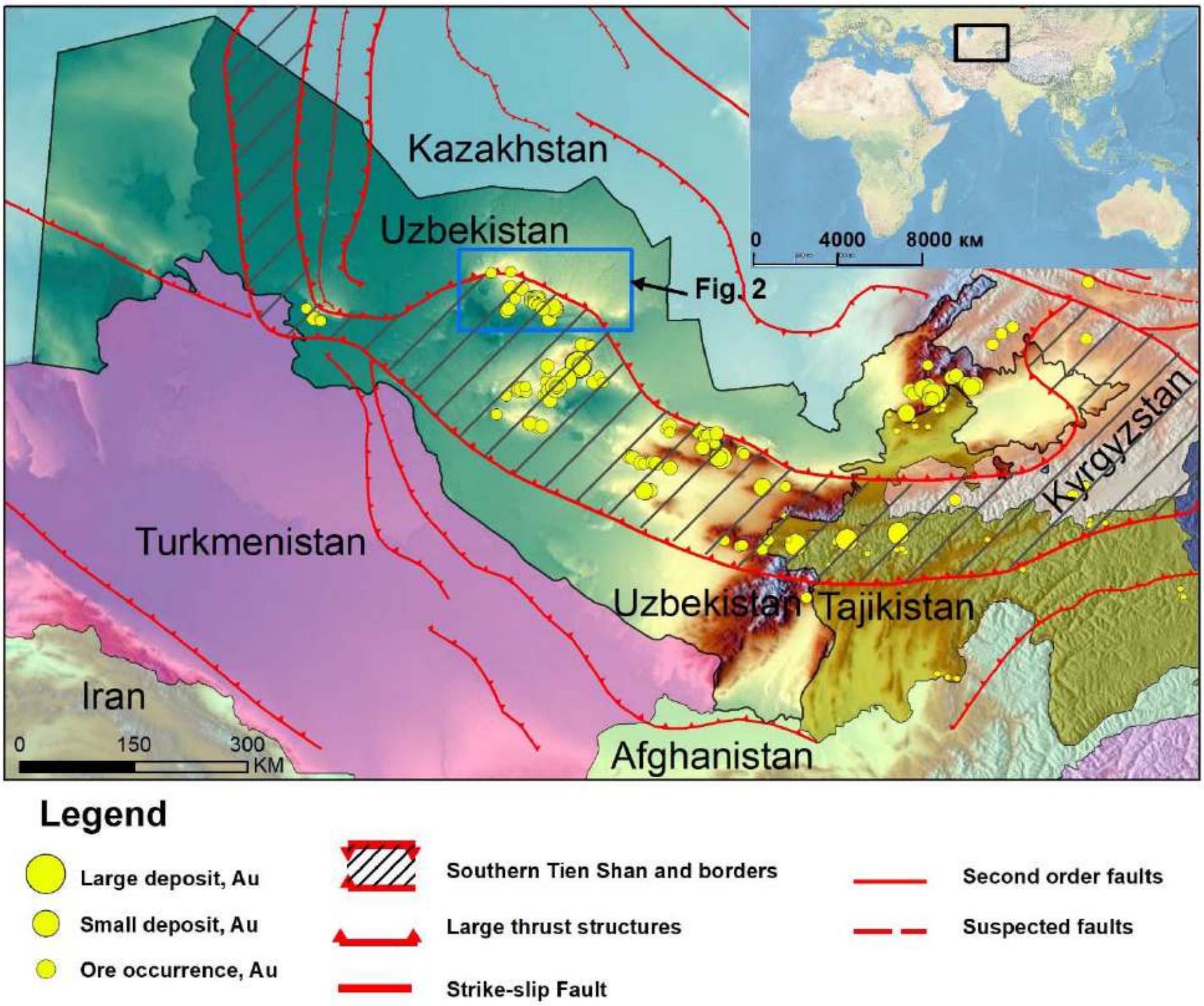


Fig. 1. Schematic zoning of the western part of the South Tien Shan orogenic system in the territory of Central Asia (Mukhin et all., 2023) with gold ore deposits and deep faults (Кремнев, 1981) based on a global digital relief model (compiled by A.B.Goipov)

The role of ore-controlling structures is played by transverse and diagonal ruptures and zones of ruptures of different orders: from small ruptures affecting the localization of ore bodies and pillars in deposits to regional transblock ruptures, near and at the intersection of which ore fields are localized with longitudinal zones.

An important role in the localization of ores, especially gold-sulfide-sulfide veined-interspersed, is played by ore-shielding surfaces, which are usually the soles and roofs of dolomite-siliceous carbonate strata, as well as thrust planes. In some cases, this is especially typical for the Bukantau, the role of ore-controlling structures in relation to ore fields is played by the folds (Исаходжаев и др., 2015).

The geophysical field characterization was carried out by qualitatively analysing the structure, intensity and geological structure of the area and determining the possible nature of the selected structural elements based on a comprehensive analysis of all available data in the Arc GIS (geospatial analysis) environment, including the results of processed remote sensing materials.

2. RESEARCH METHODS

Geophysical signs of mineralization in the territory of the Bukantau Mountains are given using the above mentioned results, especially in terms of the geological interpretation of the selected geophysical field elements. The main tasks involved in integrating the cosmogeological (remote sensing) results with geological and geophysical materials require a correlation analysis of changes in the geophysical field values.

This work was carried out according to the application of the ArcGIS program with the digitization of stock materials, and remote sensing Earth materials and maps of geochemical halos were integrated.

For gravimetric research, the morphological feature map of local gravimetric field components based on the results of zoning was digitized in the form of gravitational field intensity lines for a static analysis of the automated allocation of promising areas by known reference objects.

The geological formations composing the Bukantau Mountain structure are part of two structural and formation zones: the North Bukantau and the South Bukantau. The boundary of the structural formation zones is the North Bukantau interzonal fault, in which the formations of the North Bukantau structural formation zone (SFZ) are uplifted (thrown up) over the deposits of the South Bukantau SFZ. In the gravitational field, the North Bukantau fault is indicated by a linear zone of horizontal gradients.

The local components of the gravity field of the North Bukantau interzonal fault are accompanied by linear zones of high-frequency minima, which show the fragmentated and dissociated zones accompanying the main fault plane.

The geological structural features of the structural formation zones are well displayed both by the regional component of the gravity field and on the map of anomalies in the reduced field (Кремнев, 1981).

The North-Bukantau SFZ, which is composed of dense volcanogenic and volcanogenic-sedimentary rocks and overlying upper Paleozoic molasses, is characterized mainly by positive field values ranging from 10 to 39 mGal. The intensity of the anomalies gradually decreases from West to East. This is because dense volcanogenic rocks that were developed in the West are overlapped in the eastern direction by a less dense molasse formation and then by loose Mesozoic formations.

The South-Bukantau SFZ, which is composed of terrigenous formations of the Cambro-Silurian and acidic intrusions that break through them, is characterized by low negative gravitational field values ranging from -39 to -5 mGal. The intensity of the field naturally increases from the South, where large granitoid massifs are developed to the North, and where the terrigenous section increases via carbonate formations of the Irlir Ridge.

Thus, the main geological structural elements of the Bukantau Mountains coincide with the characteristic features of the regional gravitational field component.

In the North-Bukantau SFZ, against the background of the generally higher gravity field, two gravitational maxima are distinguished: in the west, Karamurunsky, and in the east, South-Tokhtatau.

The maximum intensity of the Karamurun, which reaches 39 mGal, is caused by green shales of the Kumbulak Formation and basaltoids of the Tubabergen Formation and reaches the level of the eroded section. The boundaries of the maximum practically coincide with the geological boundaries.

The South-Tokhtatau maximum is located in the eastern part of the square. The site is covered with loose sediments up to 200 m thick. The intensity of the gravity field here reaches 11.5 mGal (Кремнев, 1992).

Wells drilled within the limits of the gravitational maximum revealed the Kumbulak and Tubabergen Formations, i.e., the geological natures of the described gravity field maxima are similar.

The maximum intensities of the gravity field of the East of the Karamurun are 6-9 mGal (Кремнев, 2005). The rocks of the Argali, Tokhtatau and Ashibulak Formations (molasse formation) are exposed here. They are underlain by basaltoids of the Tubabergen Formation and broken by numerous dikes of the main composition.

In the cores of small anticlinal folds, the Tubabergan Formation approaches the daytime surface, which is recorded by local anomalies of the linear field with an intensity reaching 11.5 mGal.

In the south-east direction, the molasse formation sinks under the loose formations of the foothill plain, the thickness of which reaches 200-250 m. Accordingly, the depths of the Tubaberg and Kumbulak Formations increase. This causes a decrease in the intensity of the field to -4 mGal.

In the northern part of the Bukantau Mountains, a section of a reduced field value is allocated inside the positive gravity field northeast of the Karamurun maximum. The intensity of the field here varies from 5 to -3 mGal. The direction of the iso-anomaly is the northeast. This area of the reduced field value corresponds to the Bokalinsky intrusive, composed of tonalites and trondhjemites, which density is 2.68 g/cm^3. Intrusions break through the rocks of the Argali Formation. Contacts with the host rocks are steep at angles of 70-75°.

An isometric negative anomaly of the gravity field with an intensity reaching -12 mGal is distinguished in the northern part of the intrusive zone. Perhaps this anomaly corresponds to an incoming magmatic channel (the "leg" of the intrusion).

Magnetometric research indicates that for the zoning of the magnetic field, a map of the anomalous magnetic field on a scale of 1:100,000 was used. The map of the regional component of the magnetic field with an average radius of 10 km and the map of the local component were auxiliary.

The magnetic field in the area of the Bukantau Mountains is quite complex and differentiated. Its intensities vary from -100 to +300 nanotesla (nT).

By the nature of the field, the area of the Bukantau Mountains is divided into two parts, namely, the northern and the southern (this is most clearly visible on the map showing the regional component of the field). The boundary of the section approximately coincides with the North-Bukantau interzonal fault.

The North-Bukantau and South-Bukantau structural formation zones are well expressed in the observed magnetic field.

In the North-Bukantau SFZ in the northern part of the area, two areal positive magnetic field anomalies with an intensity reaching 400 nT are distinguished. The western anomaly corresponds to the Bokalin intrusive tonalite-trondhjemite composition (the magnetic susceptibility of tonalites and trondhjemites reaches 1350×10^{-6} CGS (Кремнев, 2005; Крикунова и др., 2012).

The anomaly coincides with the shape and size of the intrusion mapped during the geological survey. The second anomaly is located somewhat in the northeast of the Bokalinsky intrusive. In its form, it also resembles an intrusive array. The anomaly is located above the foothill plain, i.e., the magnetically disturbing object is blocked by loose formations of considerable power. According to the shape of the anomaly and its intensity, it presumably maps an intrusion with the same composition as the Bokalin intrusion. To the southeast of this anomaly, there is another, smaller anomaly with an intensity of more than 300 nT. The depths to the upper edge of the disturbing objects according to the quantitative interpretation of these anomalies are 1000-1300 m, the effective magnetization values range from 1000 to 2400 × 10^{-6} CGS units (the eastern object has effective magnetization values that are slightly lower than 900-1000 units), and I.G. Kremnev links these anomalies with volcanogenic formations of the main composition (gabbro and gabbro porphyrites).

The East of the meridian of the Kokpatas gold deposit, the magnetic field of the North Bukantau SFZ is calm and positive with intensities of 40-50 nT. The stretch of the isodynam smoothly varies from the northwest to the northeast and back. Against the background of a calm field, anomalies of an isometric form with an intensity reaching +100 nT are observed. Their diameters are 4-5 km. Isometric anomalies are located along the North Bukantau interzonal fault (Fig. 2). Their possible geological nature is the vent facies of the Tubabergan subvolcanic complex.

In the eastern part of the area overlain by loose sediments, two rather large positive anomalies with intensities of 100-300 nT are distinguished and are obviously caused by volcanogenic formations of increased basicity.

The nature of the magnetic field over the South-Bukantau structural and formation zones is much more complicated. The magnetic field here is predominantly negative, its intensity varies from -10 nT to -100 nT, and the nature of the field is mosaic. Areal and isometric negative magnetic field anomalies map granitoid massifs and rods, and linear anomalies correspond to the terrigenous rocks containing them (Кузнецов, Муравьев, 1986; Максудов и др., 2010; 2015; 2016).

Against the background of the general negative magnetic field, linear, annular and arc-shaped positive anomalies with intensities of 50-150 nT are distinguished, giving the magnetic field a very complex differentiated character.

3. DISCUSSION OF THE RESULTS

In the southwestern part of the area, large granitoid intrusions, namely, the Altyntau and Kokpatas intrusions, are mapped by two areal negative magnetic field anomalies with an intensity of up to -100 nT. Areal negative magnetic field anomalies along the perimeter are framed by small positive intensity anomalies of up to +150 nT. Their geological nature has been clearly established during prospecting operations at the deposits and ore occurrences of gold in Cholchoratau, Altyntau, etc. Positive magnetic field anomalies correspond to the keratinized and scarred rocks of the Kokpatas Formation in the intrusive exocontacts. Discontinuous disturbances of latitudinal, meridional, north-eastern and, less often, north-western directions are confidently distinguished in the magnetic field (Fig. 2).

In the central part of the square, in the Turbay Mountains, negative magnetic field anomalies with an intensity of up to -100-150 nT are distinguished. Their shape is isometric or elongated in the northwest direction. They are framed on the periphery by annular, linear and isometric positive magnetic field anomalies with an intensity of up to +100 nT.

The described negative magnetic field anomalies correspond to the Turbai, Sautbay and Sarytau granitoid intrusions, which in turn represent rod-shaped and ridge-shaped protrusions of the roof of a large granitoid massif – Sautbay-Sarytau – that does not reach the level of the eroded section. The Sautbay-Sarytau granitoid intrusion is uniquely installed in the gravity field. It is also possible that the Turgai and Sautbay intrusions are rods that break through the intrusion and that do not reach the level of the eroded section.

Positive magnetic field anomalies map the zones of keratinized and scarred rocks of the Kokpatass Formation, to which the gold and tungsten mineralization of the Bulutkan deposits and the Sarytau group ore occurrences are confined (Fig. 3).

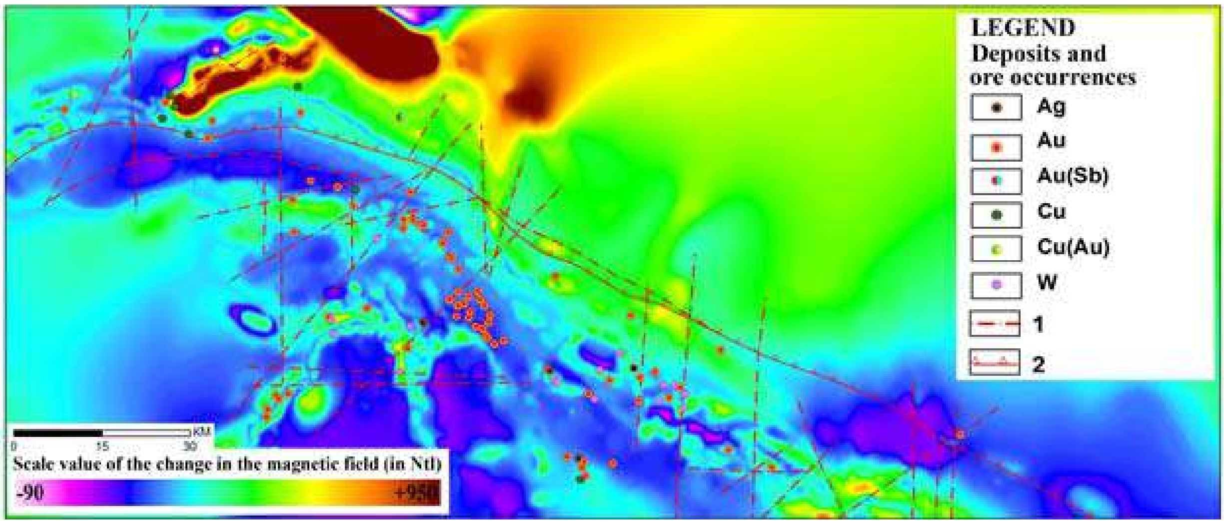


Fig. 2. Map of morphological features of the ΔTa aeromagnetic field. 1 – boundaries between structural and formation zones; 2 – faults identified by geophysical data (using materials by Дементеенко, Киндерова, 2007)

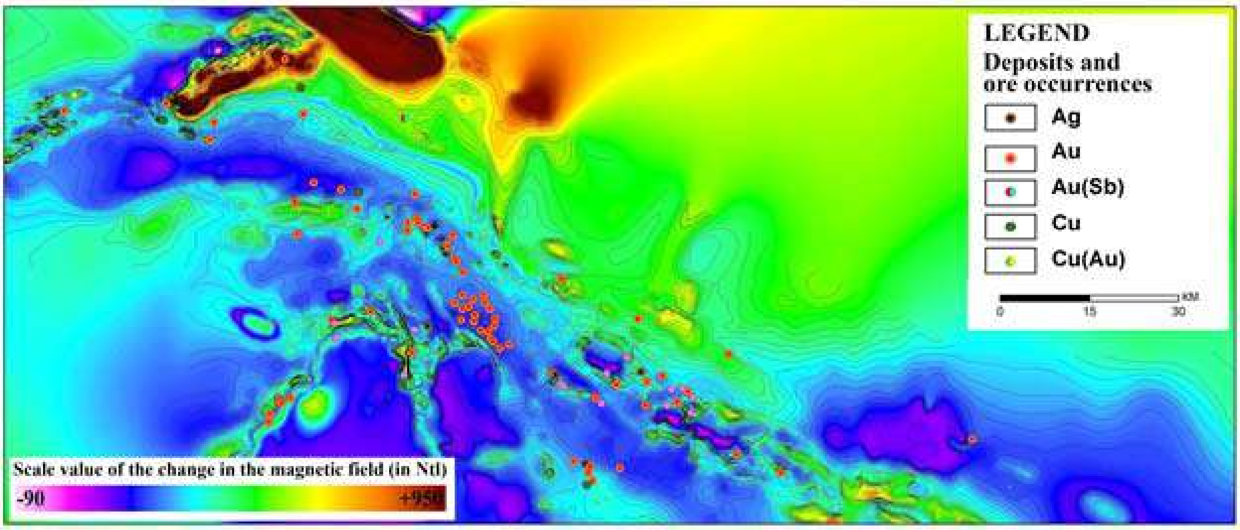


Fig. 3. Magnetic field with overlapping deposits and ore occurrences (using materials by Дементеенко, Киндерова, 2007)

In the south-eastern part of the square, a mosaic magnetic field that is sharply differentiated in intensity indicates the South-Dzhetymtau (Mullalinsky) intrusion that does not reach the level of the pre-Mesozoic foundation, as well as keratinized and scarred rocks in the exocontacts of its roof.

Small arc-shaped positive magnetic field anomalies with intensities of +20 - +30 nTl in the Boztau area are of particular interest. They are confined to the north-western periclinal immersion of the Kokpatas-Boztau anti-form and probably map serpentinites (or serpentinite melange) lying at the base of the tectonic plates. Low-lying serpentinite bodies of small capacity (10-20 m) were opened by drilling wells during prospecting operations in the Boztau area. The presence of magnetite was established while studying serpentinites.

Linear positive magnetic intensity anomalies are distinguished between the Turbay Mountains and the North Bukantau interzonal fault; the values range from +50 - +100 nT. The bedrock within these anomalies has a low magnetic susceptibility. The magnetically disturbed objects that caused a significant increase in the magnetic field are located below the level of the eroded section and are apparently caused by pyrite-pyrrhotite mineralization (Кремнев, 1981, 1992, 2005; Крикунова и др., 2012).

The exploration and informative value of the natural electric field anomalies in the Bukantau Mountains are not clear, although this method has studied almost the entire uplift area, where pre-Mesozoic deposits are exposed at the surface and are present at a depth of up to the first tens of metres. Extensive (up to 10-15 km) negative EP field potential anomalies with intensities in the first hundreds of millivolts are identified here and are usually explained by graphitized (carbonaceous) and permeable rocks.

The natural electric field in the study area is characterized by a complex structure and values of the potential intensity ΔUEP from +500 mV to -450 mV (Fig. 4). Positive EP anomalies, as a rule, correspond to intrusive formations and carbonate and monolithic rocks that have not undergone any changes (hydrothermal changes, crushing, or fracturing).

The Karamurun negative EP field is confined to the western part of the Bukantau fault. The Karamurun deposit (copper-pyrite with gold) is located in the area of weakly positive EP field values.

The Aitym negative EP field is confined to the deposits of the Koksai Formation (O_2-S_1ks), represented by an interlayer of carbonaceous siliceous-micaceous shales, with interlayers of flints of the first subformation and siltstones, sandstones, mudstone shales, and siltstone mica-quartz of the second and third subformations. The internal structure of the Aitym negative EP field is determined by negative anomalies of the second order, which fix the zones of the tectonic disturbances of the northeastern and near-latitude strike. The gold deposits of Aytym, Ayakashchi-2, as well as a number of gold ore manifestations are located in the region of negative field values or gravitate to areas of its greatest gradient.

Positive EP anomalies in the area of the Kokpatas ore field are mapped by the Karashakh volcanogenic-sedimentary complex (C_2kg) and limestones of the West Okzhetpes Formation (C_1zk).

The Okzhetpes negative EP field is confined to the deposits of the Bostau Formation (C_2bs), which is represented by siltstones, mudstones, gravelites, sandstones, conglomerates, and limestone lenses. The internal structure of the negative EP field is determined by negative anomalies of the second order, mainly of the northwestern strike, thereby fixing zones of tectonic disturbances.

In the area of the Bulutkan ore occurrence, in general, an increase in the EP potential values in the southern direction is clearly recorded, reaching a relative excess of up to 250 MV over the northern part. This pattern is explained by the spread of intrusive formations in the southern part of the site.

For the electrical exploration of the VP, in the Bukantau Mountains, various surveys using the VP method were studied, mainly individual ore fields, deposits, ore occurrences and their flanks, where pre-Mesozoic deposits are exposed on the surface or lie at a depth of up to the first metres. In this connection, a single, integral map of the anomalous VP (polarization induced) field for the entire elevation area was not compiled. The scheme of the anomalous VP field of the Bukantau Mountains has been compiled, including separate areas (sections) of work by the VP method.

4. RESULTS

In the study area, regional anomalies of the first order were identified and were associated with scattered inclusions of sulfides and an increased concentration of carbonaceous material in rocks (hc = 5-10%); regional anomalies of the second order correspond to a higher concentration of sulfides and carbonaceous material in rocks (hc =7.5-15%). The internal structure of the regional anomalies of the first and second orders of the VP is determined by local VP anomalies corresponding to local zones that are most enriched in sulfides (hc an.=20% or more).

All numerical values that were digitized and analysed are given in Table 1.

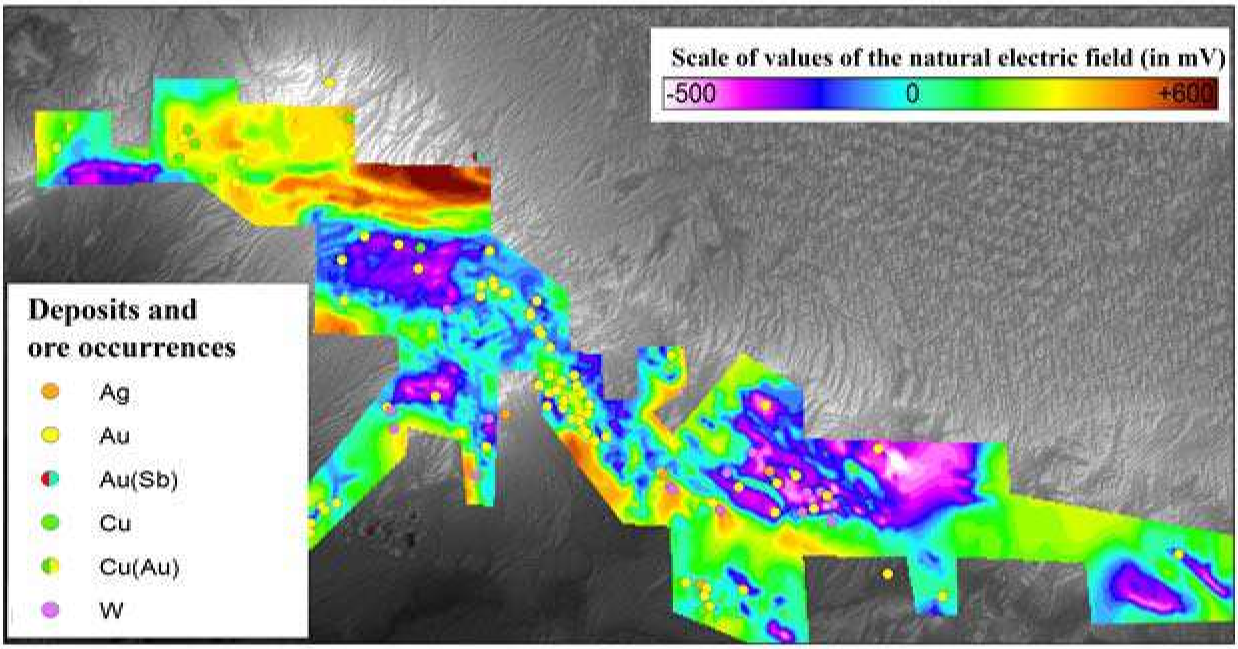


Fig. 4. Morphological map of the features of the natural field (EP) based on the results of zoning (using materials by Дементеенко, Киндерова, 2007).

Table 1

The complex geophysical features and the relationship with the localization of the mineralization of the Bukantau Mountains (compiled by A.B. Goipov)

№	Deposits and ore occurrences	Element		ΔGa in mgl	ΔTa in nTl	ΔU in mV
1	Aytym-II	●	Au	0-(-0,5)	-40-50	-50
2	Altyntau-VII, VIII	●	Au	1,5-2,0	10-20	-100
3	Argali	●	Cu	-1,5-2,0	260-270	300
4	Ayakashyi	●	Au	0 -(+0,5)	-20-30	-250
5	Barkhany	●	Au	0,5-1,0	-60-70	-200
6	Shoe covers	●	W	0,5-1,0	-110-120	0
7	Shoe covers	●	Cu	0, 5-1,0	-130-140	0
8	Middle-I, II	●	Au	0 -(+0,5)	-80-90	0
9	Budukan	●	Au	0 -(+0,5)	-30-40	350
10	Burgut	●	W	-0,5-1,0	30-40	300
11	Eastern-I, II	●	Au	0-(-0,5)	-50-60	50
12	Mountain	●	Au	0-(-0,5)	-40-50	-50
13	Farther	●	Au	0-(+0,5)	-30-40	-200
14	Flannelette	●	Au	0,5-1,0	10-20	-50
15	Dautbay	●	Au	0-(+0,5)	60-70	50
16	Jazzik	●	Au	0-(+0,5)	-70-80	-100
17	Derbez-I	●	Ag	0 -(+0,5)	50-60	200
18	Jelsay-II	●	Au	0-(+0,5)	-10-20	0
19	Jetymtav II	●	Ag, Au	0-0,5	-60-70	-50
20	Jelandi	●	W	1,0-1,5	80-90	350
21	Jirakuduk	●	Au	0-0,5	10-20	200
22	Jirakuduk	●	Cu, Au	0 -(+0,5)	40-50	250
23	Dolomit	●	Au	0-0,5	-40-50	-100
24	Irlir	●	Cu, Au	0,5-1,0	0-10	250
25	Irintav	●	W	-0,5-1,0	-80-90	200

26	Kantokken		Au	0,5-1,0	10-20	-10
27	Kantokken		Au, W	1,0-1,5	40-50	-20
28	Karamurun		Au, Cu	2,0-2,5	20-30	200
29	Karashokho-I, II		Au	0 -(+0,5)	-50-60	50
30	Kansay		Au	+0,5-1,0	-50-60	-250
31	Okzhetpes		Ag	0-(+0,5)	-40-50	-150
32	Orazali		Cu	0-(-1,5)	10-20	300
33	Pridorozhny		Au	0 -(+0,5)	-100-110	150
34	Prirazlomny		Au	0 -(+0,5)	-60-70	-70
35	Prikontaktov		Au	0 -(+0,5)	-90-100	0
36	Foothill		Au	0-(-0,5)	-60-70	0
37	Plain		Au	0 -(+0,5)	-60-70	0
38	Sarapan		W	1,0-1,5	20-30	-100
39	Sarapan		Au	1,0-1,5	0-10	-100
40	Sarkekazgan		Au	0-(-0,5)	-70-80	-250
41	Sarytau		W	-1,0-1,5	0-10	-100
42	Sautbau		W	0-(-0,5)	-20-30	300
43	North Altyntau		Au	1,5-2,0	70-80	50
44	North Aytym		Au	0,5-1,0	-40-50	-50
45	North Jilindin		Au	1,5-2,0	-70-80	0
46	North Karabulak		Au	0,5-1,0	-10-20	100
47	Northern I, II		Au	0-(-0,5)	-40-50	50
48	Northeast		Au	0-(-0,5)	-40-50	100
49	North-West I, II		Au	0-(+0,5)	-40-50	-200
50	Silver		Ag, Au	0-(+0,5)	-60-70	0
51	Sulfide		Au	0-(-0,5)	-40-50	200
52	Taraubay		Au	0-(-0,5)	10-20	-350
53	Turbay		Au	0-(-0,5)	-10-20	-200
54	Turbay		Ag	0-(-0,5)	0-10	-100
55	Turbay (west)		Au, Ag	0-(+0,5)	-20-30	300
56	Terensay		Au	0,5-1,0	-50-60	150
57	Ulkentau		Au, Ag, Cu, W	-0,5-1,0	-20-30 -30-40 -20-30 -20-30	-100
58	Haydarkul		Au	0-(-0,5)	60-70	0
59	Central		Au	0,5-1,0	-50-60	50
60	Cholcharatau-I		Au	0-(+0,5)	0-10	-150
61	Latitudinal		Au	0,5-1,0	-60-70	200
62	Southern Bektash		W	1,0-1,5	10-20	-50
63	Southern-I, II, III		Au	0-0,5	-60-70	200

Legend for table number 1

$_{\Delta}$Ga in mgl	The value of the gravity of deposits and ore occurrence in the gravitational field (gravity is measured in milligals (1 mGal = $10^{-5} m/s^2$)
$_{\Delta}$Ta in nTl	The value of the magnetic field of deposits and ore occurrence in nanotesla (1 nT = 1 nanotesla = 10^{-9}Tesla = 10^{-9}Tl)
ΔU EП in mV	The value of the natural electric field of deposits and ore occurrence in millivolts (1 millivolt [mV] = 0.001 volt [V]) ΔU
	Gold deposits and ore occurrences
	Silver deposits and ore occurrence
	Gold-silver deposits and ore occurrence
	Silver-gold-deposits and ore occurrence
	Tungsten deposits and ore occurrence
	Copper occurrence

The features of the change in the values of physical fields of 63 objects (deposits and ore occurrences) were analyzed throughout the territory of the Bukantau Mountains. Then these objects for each type of mineralization (gold, silver, tungsten) were compared and the relationships were determined for the quantitative distribution of ore objects by complex geophysical features (Table 2).

Positive magnetic field anomalies map the zones of keratinized and scarred rocks of the Kokpatas Formation, to which the gold and tungsten mineralization of the Turbai, Sautbay, Bulutkan deposits and the ore occurrences of the Sarytau Group are confined.

Seven negative anomalous EP fields of the first order can be distinguished in the square (from west to east): I – Karamurun, II – Aitym, III – Cholcharatau, IV – Kokpatas, V – Okzhetpes, VI – Turbay, and VII – Jetym.

The Karamurun negative EP field is confined to the zone of the Bukantau fault (in its western part). The Karamurun deposit (copper-pyrite with gold) is located in the area of weakly positive EP field values.

Positive EP field anomalies correspond to the limestones of the Okzhetpes Formation ($D_{2\text{-}3}$ok). At the Okzhetpes site (Ващенко и др., 1980), all manifestations of gold are located either in the gradient region of the EP field or (less often) in the negative EP field but in areas with relatively elevated potential values. Considering the position of the Bulutkan and Barkhan ore occurrences, one can ensure that they are also located in the marginal parts of large negative natural electric field anomalies.

In the area of the Bulutkan ore occurrence, in general, an increase in the EP potential values in the southern direction is clearly recorded, reaching a relative excess of up to 250 MV over the northern part. This pattern is explained by the spread of intrusive formations in the southern part of the site.

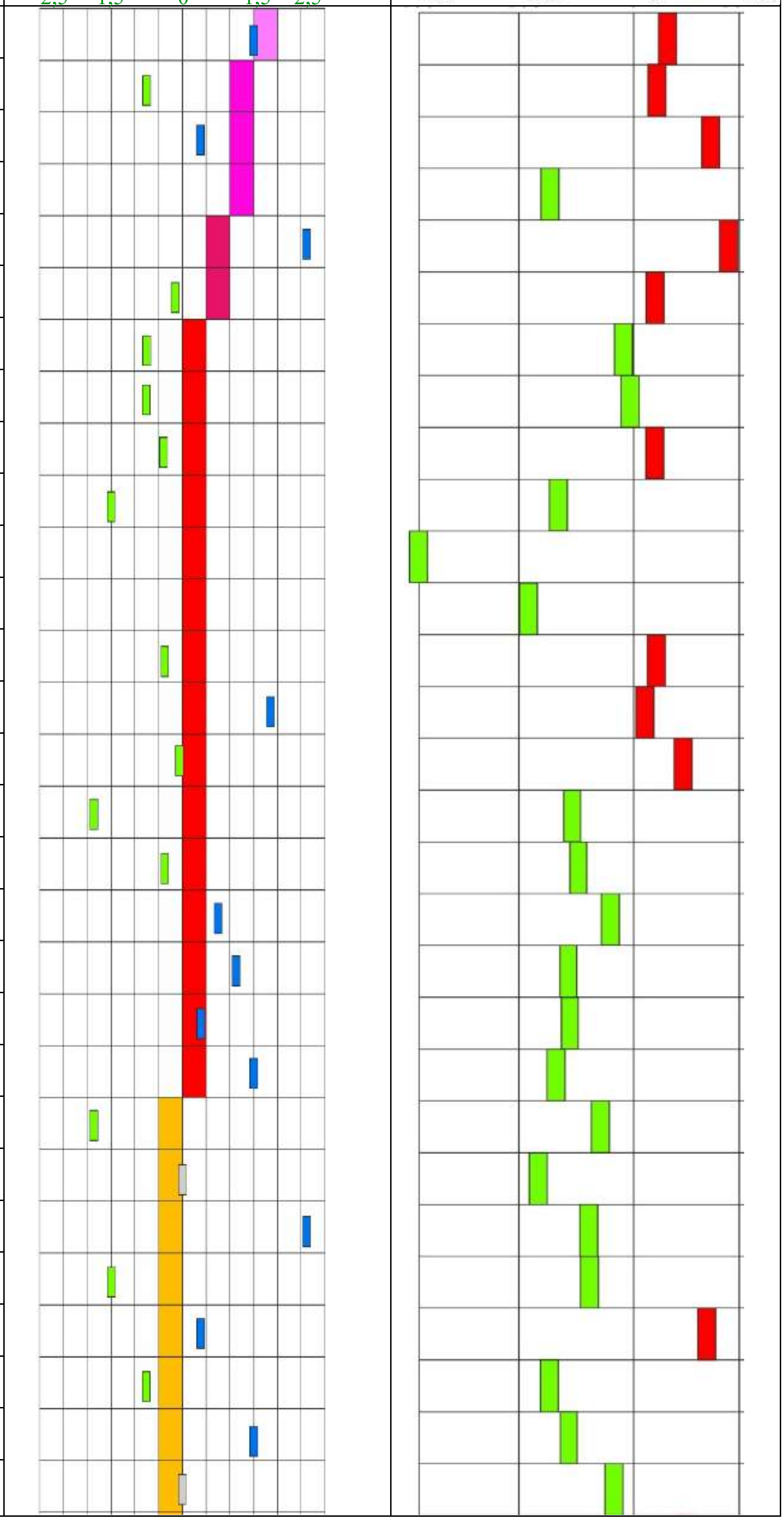
The increased polarizability of ores was established and used in studies via the method of induced polarization at a number of sites in Dzhetymtau (Ващенко и др., 1980) in the Turbay Mountains and Okzhetpes site (Усманов и др., 1984). Gold sulfide ores, as a rule, are distinguished by an increase in apparent polarizability (hc); however, the allocation of anomalies in many cases is difficult due to the influence of graphitization and uneven sulfidization of the host rocks. Their separation is a simultaneously important and very difficult task, the solution of which probably lies in the way of studying the transient characteristics of the decline in the VP and nonlinear processes.

The South Bukantau regional EP anomaly is confined to the southern branch of the Bukantau fault, which is represented by crushed, fractured rocks with scattered inclusions of sulfides and is located within the limits of the Karamurun negative EP anomaly.

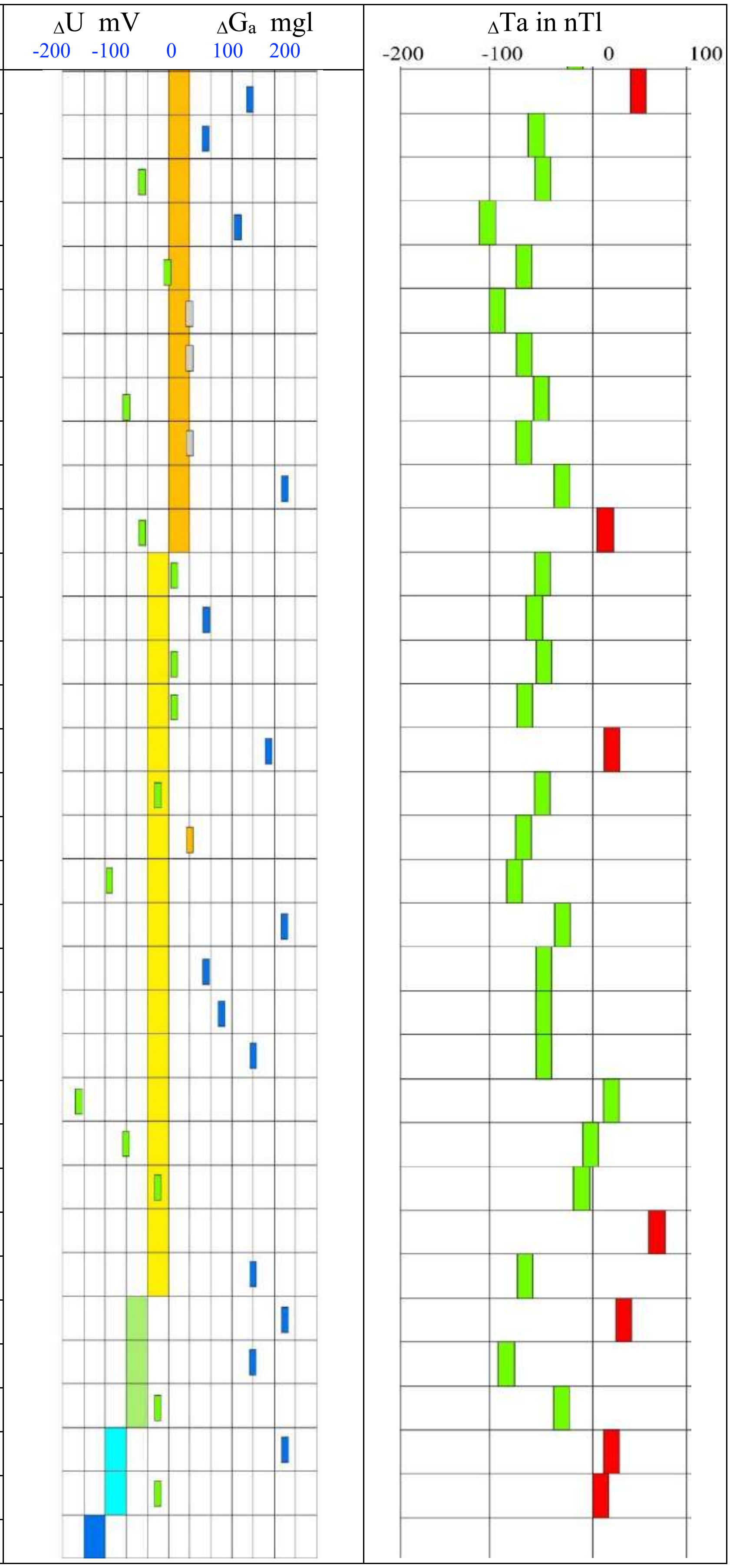
Table 2

Quantitative distribution and interrelations of ore objects of Bukantau mountains according to complex geophysical features (compiled by A.B. Goipov)

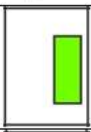
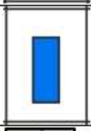
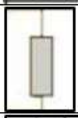
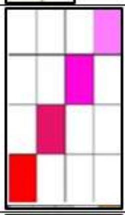
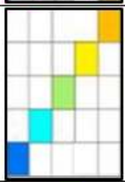
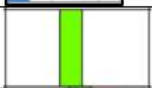
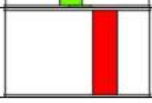
№	Deposits and ore occurrences	$_{\Delta}U$ mV (-200, -100, 0, 100, 200); $_{\Delta}G_a$ mgl (-2,5, -1,5, 0, 1,5, 2,5)	$_{\Delta}Ta$ in nTl (-200, -100, 0, 100)
1	Karamurun		
2	Altyntau VII, VIII		
3	North Altyntau		
4	North Jilindinskoe		
5	Jelands		
6	Cantroken		
7	Sarapan (Au)		
8	Sarapan (W)		
9	Yu. Bektash		
10	Barkhany		
11	Shoe covers (W)		
12	Shoe covers (Au)		
13	Flannelette		
14	Irlir		
15	Cantroken		
16	Kansai		
17	Sev. Aitym		
18	Sev. Karabulak		
19	Terensai		
20	Central		
21	Latitudinal		
22	Ayakashi II		
23	Middle I, II		
24	Budukan		
25	Far		
26	Dautby		
27	Jazz		
28	Derbez I		
29	Jelsai II		



№	Deposits and ore occurrences	ΔU mV ΔGa mgl	ΔTa in nTl
30	Jirakuduk		
31	Karashoho I, II		
32	Okzhetpes I		
33	Pridorozhny		
34	Prirazlomny		
35	Prikontaktovy		
36	Ravninny		
37	Severo-zapadnoye I, II		
38	Serebryany		
39	Turbay (Zapad.)		
40	Cholcharatau I		
41	Aitym II		
42	Vostochny I, II		
43	Gorny		
44	Jetymtau II		
45	Jirakuduk		
46	Dolomite		
47	Predgorny		
48	Sarcecasgan		
49	Southbay		
50	Severnoye I, II		
51	Severo-vostochnoye		
52	Sulfide		
53	Tarabay		
54	Turbay (Au)		
55	Turbay (Ag)		
56	Haidarkul		
57	Yuzhny I, II III		
58	Burgut		
59	Irintau		
60	Ulkentau		
61	Orazaliyev		
62	Sarytau		
63	Arhar		



Legend for table number 2

Sign	**Values**	**Materials used**
	Negative values of the natural electric field	The value of the natural electric field is given in millivolts (mV) according to the map of the natural field at a scale of 1:200,000 [Дементеенко и Киндерова, 2007].
	Positive values of the natural electric field	
	Zero values of the natural electric field	
	Positive values of the gravitational field	ΔGa is given mGl according to the local component of the gravitational field on a scale of 1:200,000 [Дементеенко и Киндерова, 2007].
	Zero values of the gravitational field	
	Negative values of the abnormal magnetic field	ΔTa is given in nTl according to the map of the anomalous magnetic field on a scale of 1:200,000 [Дементеенко и Киндерова, 2007].
	Positive values of the abnormal magnetic field	

5. CONCLUSION

Within the Central and Northern Altyntau areas, the zone of local gravimetric anomalies is associated with geochemical halos of gold and tungsten and characteristic minerals of quartz, gold, scheelite, pyrite, and arsenopyrite. According to structural tectonic factors, mineralization is controlled by faults in the northeastern and northwestern directions, which consist of a zone of fractured and crushed rocks and feathered structures. The magmatic factor of mineralization is represented by granite-granodiorite intrusions and an exocontact zone of magmatic formations complicated by large faults. The ore formation according to the reference sites is rare gold and quartz.

Local negative gravimetric anomalies and positive anomalies of induced polarizations associated with the sulfide mineralization zone were detected within the Karashakh, near-contact, dike, and latitudinal sections. According to geochemical data, halos of gold and arsenic are present. The types of mineralization are gold, pyrite, and arsenopyrite. Structurally, it is represented by the arched zone of the anticline fold, faults, and thrusts. The ore formation is gold-sulfide.

In some areas of the Dzhelsai, Barkhannoy and Okzhetpes ore fields, VP anomalies and zones of negative magnetic anomalies are associated with geochemical halos of gold. The type of mineralization is gold quartz and sulfide. The structural factors of mineralization are the northeastern, northwestern and submeridional faults, the brachianticline, and the feathering structures of the Kokpatas deep fault. The type of ore formation according to the reference sites is gold-quartz.

In the Sautbay, Sarytau, and Cholcharatau areas, negative magnetic field anomalies correlate with geochemical halos of tungsten, molybdenum, and copper. Characteristic minerals are scheelite, fluorite, molybdenum, pyrrhotite, chalcopyrite and antimony. Magmatic mineralization includes rod-shaped granodiorite intrusions and scarn zones at the contacts of intrusions. The type of ore formation is gold-rare-metal quartz. On a detailed scale, the magnetic field value for each object changes, but the nature of the negative or positive anomaly remains.

Changes in the values of the physical field are associated with the geological and tectonic structure of the region and the occurrence of the foundation, as well as the composition of rocks.

All available values are used for static analysis and are converted to a raster format for the automated allocation of promising areas by known reference objects.

Thus, the prospecting signs and ore-controlling factors of mineralization and their interrelations with the values of the anomalous geophysical and geochemical fields were analysed in the territory of the Bukantau Mountains.

As a result of the integration of remote sensing, geophysical, and geochemical data using static and metallogenic analyses, predictive and promising positions have been identified and certified by field decryption (Goipov et al., 2020) and the sinking of mine workings, which are recommended for subsequent geological prospecting.

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ХАРАКТЕРИСТИКА ГЕОФИЗИЧЕСКИХ ПОЛЕЙ И ГЕОФИЗИЧЕСКИХ ПРИЗНАКОВ ОРУДЕНЕНИЯ ГОР БУКАНТАУ ЮЖНОГО ТЯНЬ-ШАНЯ

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Резюме. В северо-западной части Южного Тянь-Шаньского складчатого золоторудного пояса расположены горы Букантау. В геодинамическом районировании горы Букантау разделены на Северобукантаускую и Южнобукантаускую структурно-формационные зоны (СФЗ). Они представляют собой сложно изогнутые поднятия, осложнённые более мелкими складками.

Руды Северобукантауской СФЗ образуют медно-цинково-колчеданную с золотом (Карамурун), золото-сульфидно-кварцевую (Ирлир, Джетымтау) и второстепенные медно-молибденово-скарновую (Оразалы I, II) и хромитовую формации. Проявления золота относятся к золото-сульфидно-кварцевому геолого-промышленному типу. Основные рудные объекты Южнобукантауской СФЗ образуют редкометально-золоторудную (месторождение Алтынтау), золотомышьяковую (месторождение Кокпатас), золотополиметаллическую (месторождение Турбай), золотосеребряную (месторождение Окжетпес) минерализации, вольфрамоносные скарны и скарноиды (месторождение Саутбай).

Геофизическими признаками могут служить различные элементы геофизических полей – интенсивность поля, оси положительных и отрицательных аномалий, градиенты поля и др. Районирование физических полей горы Букантау на структурно-формационной основе позволило типизировать и разделить гравитационные и магнитные аномалии на однородные группы.

Статья содержит анализ многолетних данных комплексных геофизических исследований гор Букантау. Были проанализированы характеристики изменения значений физического поля 63 объектов на территории гор Букантау и созданы комплексы геофизических признаков и взаимосвязей с локализацией оруденения.

Поисковые критерии формулировались на основе изучения особенностей физических полей, характерных для известных рудопроявлений и месторождений, с точки зрения степени однозначности их отражения в электрическом, гравитационном и магнитном полях. Сопоставление данных Дистанционного зондирования Земли, геофизических и геохимических данных с использованием статического и металлогенического анализов позволило определить прогнозно-перспективные позиции, подтверждённые полевым дешифрированием и проходкой горных выработок, рекомендованные для дальнейших геолого-поисковых работ.

Ключевые слова: *Месторождения, эндогенные процессы, золото, структура, формирование, геофизические поля, интрузивные породы.*

CƏNUBİ TYAN-ŞANIN BUKANTAU DAĞLARININ GEOFİZİKİ SAHƏLƏRİNİN VƏ ƏLAMƏTLƏRİNİN SƏCİYYƏSİ

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Xülasə. Cənubi Tyan-Şanın şimal-qərb hissəsində yerləşən Bukantau dağları qızıl filizli qurşağında yerləşir. Geodinamik rayonlaşdırmada Bukantau dağları Şimal Bukantau və Cənub Bukantau struktur-formasiya zonalarına (SFZ) bölünür. Onlar mürəkkəb əyilmiş qalxımlar olub, daha kiçik qırışıqlarla mürəkkəbləşmişdir. Şimal Bukantau SFZ filizləri mis-çink-pirit (Karamurun), qızıl-sulfid-kvars (İrlir, Cetimtau) və az miqdarda mis-molibden-skarnoid (Orazalı I, II) və xromit formasiyalarına bölünürlər. Qızıl təzahürləri qızıl-sulfid-kvars geoloji-sənaye tipinə aid edilir. Cənub Bukantau SFZ-də əsas filiz obyektləri nadir metal-qızıl filiz (Altyntau yatağı), qızıl-arsen (Kokpatas yatağı), qızıl-polimetal (Turbay yatağı), qızıl-gümüş (Okjetpes yatağı) mineralizasiyası, volfram skarn və skarnoidləri (Sautbay yatağı) olaraq göstərilir. Geofiziki təsirlər - geofiziki sahələrin özünəməxsus elementləri - əsas sahələr, müsbət və mənfi anomaliyalar, sahələrin gradientləri və s. kimi qəbul edilə bilər. Bukantau dağlarının struktur-formasiya əsasında fiziki sahələrinin rayonlaşdırılması, qravitasiya və maqnit anomaliyalarını homogen qruplara və tiplərə ayırmağa imkan verir.

Məqalədə Bukantau dağlarının çoxillik kompleks geofiziki tədqiqatları məlumatlarının təhlili aparılmışdır. Bukantau dağları ərazisində 63 obyektin fiziki sahə göstəricilərinin dəyişmə xüsusiyyətləri təhlil edilmiş və filizləşmənin lokallaşması ilə əlaqəli geofiziki əlamətlərin və qarşılıqlı əlaqələrin kompleksləri yaradılmışdır.

Axtarış meyarları, mövcud filiz təzahürləri və yataqlarına xas olan fiziki sahələrin xüsusiyyətlərinin, onların elektrik, qravitasiya və maqnit sahələrində nə dərəcədə dəqiq əks olunduğu baxımından öyrənilməsi əsasında formalaşdırılmışdır. Yerin məsafədən zondlanması məlumatları, geofiziki və geokimyəvi məlumatların statistik və metallogenik təhlillərlə müqayisəsi nəticəsində, sahə dekodlaşdırılması və dağ qazma işlərilə təsdiqlənmiş, gələcək geoloji-axtarış işləri üçün tövsiyə olunan perspektivli mövqelər müəyyən edilmişdir.

Açar sözlər: *Yataqlar, endogen proseslər, qızıl, struktur, formalaşma, geofiziki sahələr, intruziv süxurlar*