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Research Article

INTEGRATED INTERPRETATION OF GEOPHYSICAL DATA OF THE KULZHUKTAU MOUNTAINS

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ABSTRACT
An integrated interpretation of geophysical data from the Kulzhuktau Mountains was conducted to refine the geological model and identify prospective zones for mineralization. Geological–geophysical analysis, supported by seismic and drilling data, enabled mapping of the Paleozoic basement structure, intrusive complexes, and overlying Meso-Cenozoic cover. Distinct geophysical signatures allowed delineation of granitoid and gabbro-ultramafic bodies and their structural relationships. Identified fault systems and zones of hydrothermal alteration, fracturing, and sulfide mineralization are spatially associated with geophysical anomalies and known gold occurrences, indicating high exploration potential. The results provide a geophysical basis for further exploration and targeting of gold mineralization in the region.

Keywords: *Geophysics, Magnetic Survey, Mineralization, Resistivity, Velocity*

INTRODUCTION

The geological constructions are based on a detailed, comprehensive analysis of the nature of geophysical fields, spatial distribution, and the nature of anomalies, which allows for a schematic representation of the reflection of the main geological complexes in geophysical fields. The comprehensive interpretation was performed taking into account data from geological surveys, seismic exploration, and boreholes that penetrated the basement (fig.1) (*Khamrabaev, 1975*).

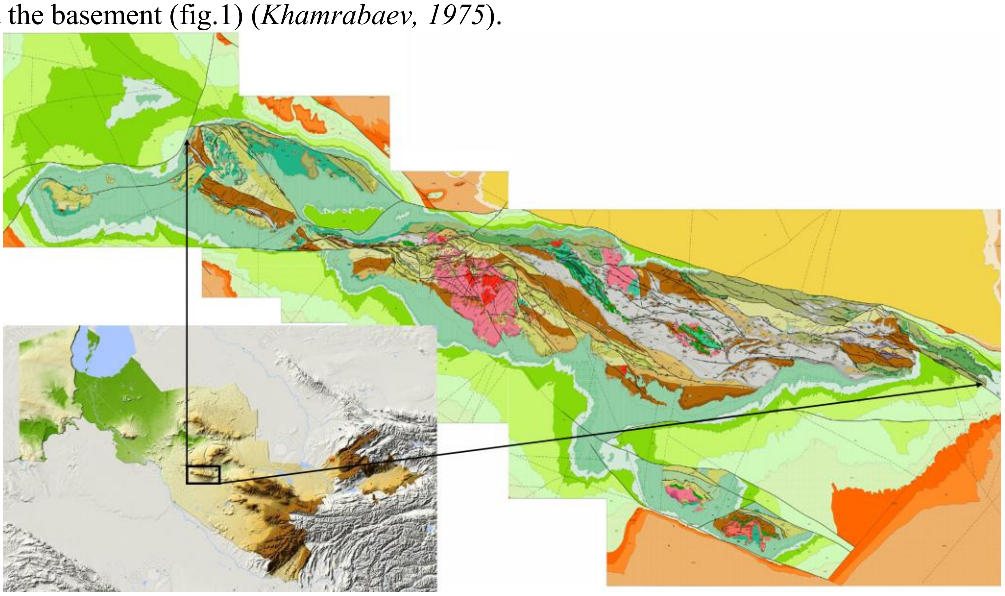

Figure 1. Location and schematic geological map of the Kulzhuktau mountains
(*modified from Aysanov, 1984*).

The geological structure of the region comprises compositionally diverse, highly dislocated Paleozoic formations and less dislocated Mesozoic and Cenozoic deposits. The region is characterized by a variety of folded and faulted structures, significantly complicated by intrusive activity and fault deformations. The Paleozoic basement is composed of Ordovician volcanogenic-terrigenous, partially carbonate formations; thick carbonate formations of the Silurian, Devonian, and Lower Carboniferous; and volcanogenic-terrigenous and molasse strata of the Middle and Upper Carboniferous, intruded by granitoid and gabbro-ultramafic intrusions. Much of the area is overlain by loose Mesozoic-Cenozoic formations 50-800 m thick (*Eisfeld et all, 2010*).

MATERIALS AND METHODS

Terrigenous formations (shales, sandstones, siltstones, and gravelites) of the Ordovician Kazakasu and Shuruk Formations and the Middle Carboniferous Taushan Formation have relatively low densities, averaging 2.67-2.69 g/cm³, and are virtually nonmagnetic. Molasseoid formations of the Upper Carboniferous Kamystin Formation are characterized by similar parameters. Within the exposed part of the basement, terrigenous rocks are often distinguished by elevated polarizability values ranging from 4-8% to 12-17%, depending on the degree of graphitization and sulfidization of the rocks. They exhibit reduced electrical resistivity fields, ranging from a few tens to 50-100 ohms, and are often accompanied by negative EP fields. They are not distinguished in gravimetric fields and are considered to be a host background medium. An exception are metamorphic rocks of the biotite-chlorite subfacies of the greenschist facies of regional progressive (thermal) metamorphism, which contain syngeneic disseminated pyrite-pyrrhotite and pyrrhotite mineralization. In the buried basement, terrigenous deposits are distinguished by boundary velocities with values of 4.6-5.7 km/sec, taking into account data from drillholes. Moreover, according to the available body of information, siltstone-shale formations are mostly marked by relatively higher values of boundary velocities (V=5.0-5.5 km/sec), while sandstone-shale formations are marked by lower values (V=4.6-5.0 km/sec). Higher velocity values correspond to the appearance of carbonaceous and quartz-sericite shales in most of the section. The age correlation of terrigenous complexes distinguished in the buried basement is made according to Ya.B. Aisanov. In the north, west, and south of the region, terrigenous formations are assigned to the Kazakasuyskaya Formation, in the east – to the Taushanskaya Formation.
Carbonate rocks, predominantly limestones, have an average density of 2.67 g/cm³ and, accordingly, are not distinguished by the gravitational field. With an increasing role of dolomites in the composition of carbonate rocks, their density increases to 2.75-2.78 g/cm³. The rocks are practically non-magnetic. They are characterized by high electrical resistivity values from 200-500 to 5,000-10,000 ohms or more, and usually low polarizability of 1-2%. In the presence of carbonaceous limestones and dolomites, horizons of terrigenous rocks, alteration zones, and sulfide mineralization, polarizability increases to 4-6% or more. Carbonate formations, represented by limestones and dolomites, are accompanied by elevated gravitational fields, and in cases where they are represented by dolomites or dolomitized limestones, localized gravity maxima. The magnetic field above them is calm, reduced to negative. In the buried basement, the areas of development of carbonate rocks were traced by high boundary velocities of 5.8-7.0 km/s, local gravity maxima, by direct tracing along the gravitational field from their outlets in the Kuldzhuktau, Beltau, Tuzkuy, Kyngyrtau mountains using data from drill holes (*Kerimov et all, 2010*).

RESULTS

Meso-Cenozoic deposits are characterized by low and decreased values of apparent electrical resistivity (ρ_k from a few om*m to 30-50 ohm*m), the lowest polarizability values (η_k from 0.5% to 1-1.5%), and the lowest density (1.68-2.52 g/cm^3, averaging 2.08 g/cm^3). The rocks are virtually non-magnetic. In geophysical fields, Meso-Cenozoic sediments are distinguished by an anomalous region of low resistivity, anomalously low polarizability, and a negative gravity field. They are not reflected in a magnetic field, since the rocks are non-magnetic; only a decrease in the intensity of magnetic anomalies is observed with increasing sedimentary cover thickness.

The igneous formations of the region are represented overwhelmingly by granitoid complexes and rocks of basic-ultramafic composition.

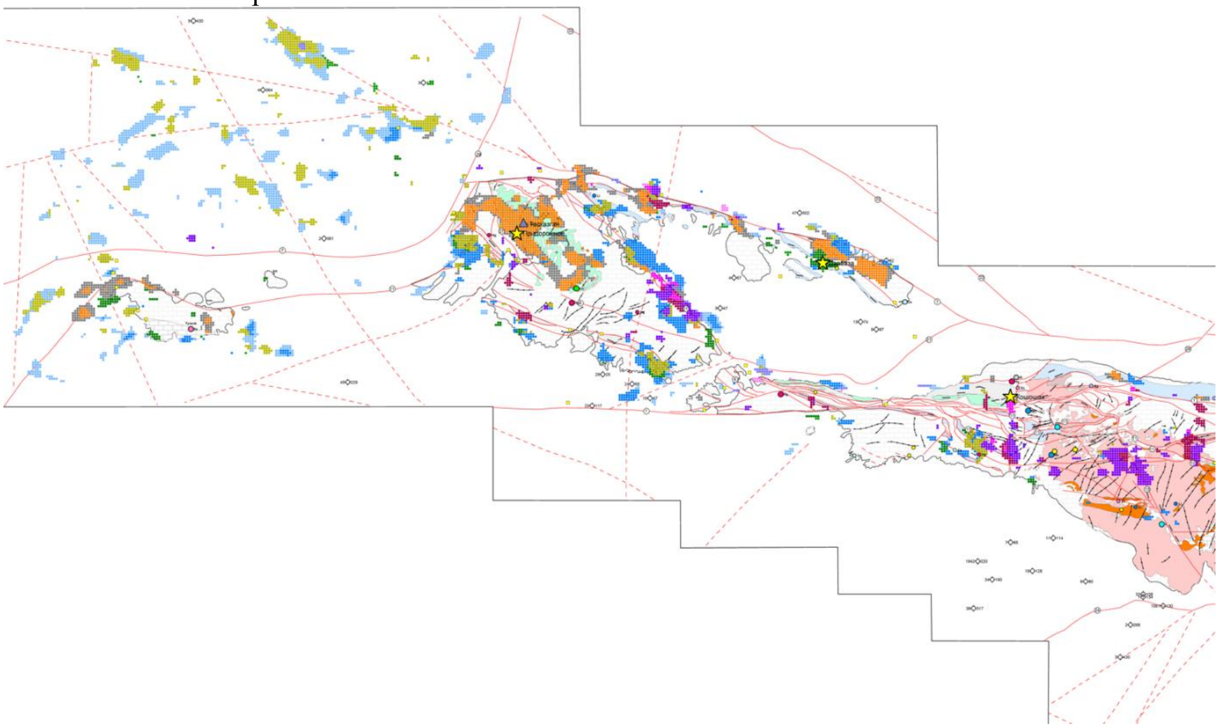

Figure 2. Forecasting map of Western part of Kulzhuktau mountain with an integrated interpretation of geophysical data. For the legend see figure 4.

Granites have a low density of 2.52-2.63 g/cm^{3,} averaging 2.60 g/cm^3. They are non-magnetic and characterized by low polarizability of 1-2%, high apparent resistivity values of 500-1000 to 3000 Ohm and high boundary velocities of 5.3-5.8 km/s, tending toward the lower limit. Gabbros have higher density values from 2.69-2.94 to 3.06 g/cm^3 on average, depending on the composition and dissemination of sulfides. The rocks are non-magnetic, with the exception of varieties containing sulfides (pyrrhotite). Ultramafic rocks are mainly magnetic and have a high density of 2.85-3.16 to 3 or more g/ cm^3. Granodiorites and syenite-diorites occupy an intermediate position and are characterized by similar density properties of 2.66-2.71 g/ cm^3 .

Igneous rocks of basic and ultrabasic composition are mapped by local positive magnetic and gravity anomalies that coincide in plan, high values of boundary velocities and apparent resistivities.

Felsic intrusive rocks are characterized by coincident negative magnetic and gravity anomalies, moderate boundary velocities, and relatively high resistivities. Intrusions are characterized by the development of a series of small, usually low-intensity magnetic peaks along the periphery. Boundary velocities range from 5.3 to 5.8 km/s, tending toward the lower limit. The coincidence of positive magnetic anomalies with negative gravity anomalies is characteristic of felsic granitoids that do not outcrop on the basement surface and therefore retain ferromagnetic features in their contact areas, including the apical parts (*Eisfeld et all, 2010*).

The Beltau Intrusive is located in the Beltau Mountains at the northwestern end of the Kulzhuktau Mountains among Silurian limestones and dolomites. It is a complex, stock-like body. It consists of hornblende and augite gabbros with small bodies of ultramafic rocks (lherzonites, pyroxenites, peridotites, and hornblendites).

In a magnetic field The Beltau gabbro is marked by a positive magnetic anomaly of average intensity, 55-60 nT. In a gravity field, it exhibits an intense (5 mH) gravity maximum, with the anomaly's contour virtually coinciding with the geological boundaries of the intrusion, indicating a nearly vertical dip at its contacts. In electric fields, the gabbro is characterized by very low resistivity (less than 25 ohms), localized polarizability anomalies of varying order caused by graphitization and sulfidization, and is framed at the contacts by a negative EP anomaly, marking an area of increased rock fracturing. Ultramafic rock stocks have been mapped within the intrusion using localized, intense, small positive magnetic anomalies.

The Shaidaraz intrusion is a narrow (1 to 1.5 km wide) dike-shaped body 12 km long, gradually tapering to the northwest and southeast. It lies primarily among sandstones, shales, and cherts of the Taushan Formation (C_2tš). It is composed of gabbro and gabbro-norite at the center and quartz gabbro and diorite at the margins.

The intrusion is unremarkable in electric fields and is characterized by the same electrical parameters as the host terrigenous formations of the Taushan and Kazakasuy suites. The northern half of the intrusion is characterized by elevated resistivity (100-150 Ohm) and a positive EP anomaly, while the southeastern half is characterized by very low resistivity (less than 25 Ohm) and a negative EP anomaly. In the apparent polarizability electric field, the gabbro is characterized by a generally elevated background, indicating its graphitization.

In the gravity field, the Shaidaraz intrusion is mapped by a positive gravity anomaly with an intensity of 2-3 mGal, almost completely coinciding with the geological boundaries of the gabbro, indicating its steep contacts. In the magnetic field, the intrusion is marked by a low-intensity positive magnetic anomaly (5-15 nT). In the southeast direction, the gravity and magnetic anomalies are traced as a continuous band of elevated fields to the Taushan intrusion, mapping the overlying portions of the gabbro. Local, intense, small-scale positive magnetic anomalies within it have been mapped to indicate stocks of ultramafic rocks, both known and suspected (*Zinovkin et all, 2011*).

Taushansky intrusion The Taushan intrusion is a southeastern continuation of the Shaidaraz massif. Geophysically, the Taushan intrusion is mapped by an isometric positive gravity anomaly, slightly elongated in a northwesterly direction, with an intensity of up to 4 mGal, an isometric positive magnetic anomaly of low intensity (10-20 to 30 nT), an elevated resistivity of 100-400 Ohm, and a positive EP anomaly. Like the Shaidaraz intrusion, it is accompanied by high polarizability values of over 5%, caused by its graphitization and sulfidization. The epicenters of the gravity and magnetic anomalies are confined to a gabbroic outcrop, and the contours of the anomalies themselves significantly exceed the geological boundaries of the intrusion in the south, indicating southward expansion of the gabbroic rock with depth. In general, the Shaidaraz and Taushan intrusions are connected to each other in gravitational and magnetic fields and quite likely represent different parts of a single intrusive body, exposed by erosion, stretching from the northwest to the southeast.

The Tozbulak intrusive is composed primarily of biotite and two-mica granites. It is characterized by relatively complex gravimetric fields, reflecting its multiphase, heterogeneous structure. In electric fields, the intrusive does not stand out among the host carbonate rocks and is characterized by the same electrical parameters as the host formations. The resistivity of the rocks is high, exceeding 1000 ohms; polarizability is low, 1-2%, rarely 3% in altered rocks; the field is positive.

Overall, it can be noted that a reduced gravity field is observed above the intrusion. However, the northern, larger half, exhibits minimal gravity. A more elevated gravity field is characteristic of the southern part of the intrusion. A similar division of the granitoid into two parts, northern and southern, is also observed in the magnetic field. Based on the distribution of the gravity and magnetic fields, it can be assumed that granites predominate among the phase I granites in the northern part of the intrusion, while granodiorites predominate in the southern part. The continuation of the intrusion beneath the sedimentary cover is not visible in the gravity field. Ya.B. Aisanov (1984) believes that the intrusion is lacollithic in shape with a vertical thickness of up to 3 km and can be traced southward beneath Mesozoic formations. In this case, the northern gravity minimum maps the main body of the granitoid, extending to great depths, while the relatively elevated gravity field in the south maps its tongue portions, limited in depth.

In the Tozbulak massif and its exocontacts, positive magnetic anomalies have identified suspected skarnification zones, zones of hydrothermally altered rocks with sulfide mineralization, and a gabbro stock, based on a combined magnetic anomaly and gravity maximum. Local magnetic field minima within the intrusion have identified suspected zones of increased fracturing and crushing, possibly with hydrothermal reworking, with a sublatitudinal and northeasterly strike.

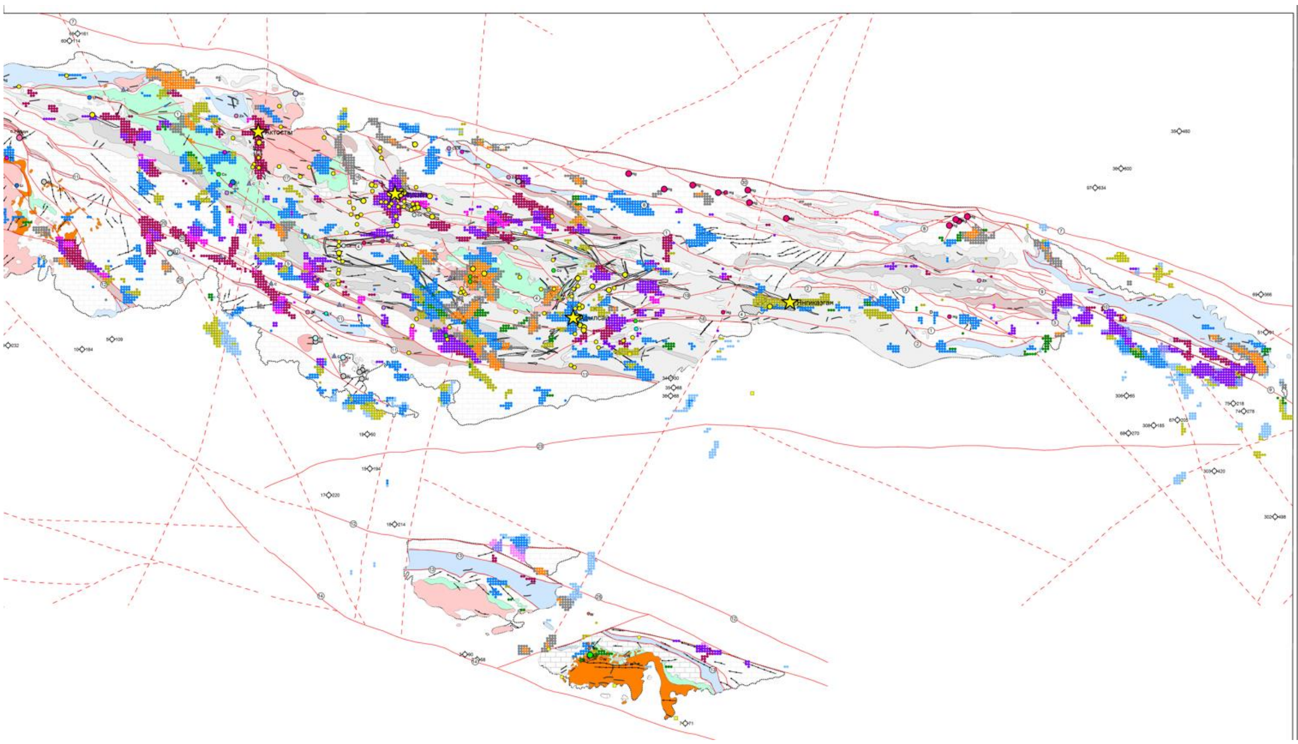

Figure 3. Forecasting map of Eastern part of Kulzhuktau mountain with an integrated interpretation of geophysical data. For the legend see figure 4.

The Aktostinsky intrusive is composed of biotite granites. A gabbro stock is located at the eastern end of the massif. In the gravity field, the intrusion is mapped by a gravity minimum and is not detected in the magnetic field. In electric fields, it is characterized by an elevated resistivity of 500 ohms, reduced polarizability (1-2%), and a positive EP anomaly. The gabbro stock is marked by small localized increases in gravity and magnetic fields, as well as polarizability (up to 3%), likely due to minor graphitization and sulfidization. The western and southern contacts with terrigenous rocks are clearly visible in the electric fields, while the eastern contact with limestones is less pronounced.

The Ayaguzhumdinsky two-mica granite stocks are mapped by local gravity minima and positive magnetic anomalies of isometric shape. According to geophysical data, these stocks are parts of a single intrusive body. Polarizability and resistivity data for the northern stock are unknown, while those for the southern stock are 1-2% and 150 ohms.

To the east and west of the Ayaguzhumdinsky stocks, three more felsic intrusive bodies have been identified beneath sediments based on similar local gravity minima. All of them fit into a west-northwest-trending linear structure, likely a weakened zone of increased permeability through which the intrusions were intruded.

South of the Shaidaraz intrusion, a hidden stock of non-magnetic gabbroic rocks has been identified along an isometric gravity maximum spatially confined to the Central Kuldzhuktau Fault zone. Local gravity maximums and magnetic anomalies have identified hidden bodies of sulfidized gabbroids in the Central Kuldzhuktau Fault zone and in the northwestern exocontact of the Tozbulak granitoid.

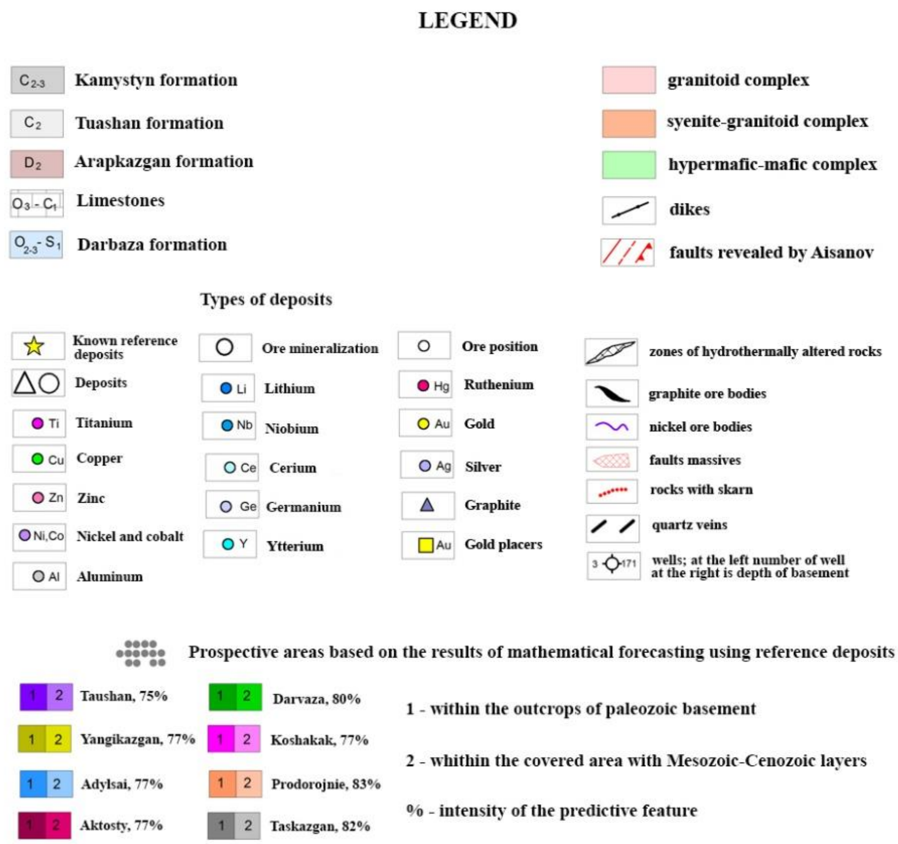

Figure 4. Legend for forecasting maps (figures 2 and 3).

West Kyngyrtau (Shuruk) intrusion the intrusion is composed primarily of biotite granites and lies among Wenlockian dolomites. It is characterized by high electrical resistivity (up to 500 ohms), low polarizability (1-2%), and positive EP values. It is not distinguished from the surrounding carbonate rocks, which have similar electrical parameters. The outcrop of the intrusion, including gabbroic bodies, and its buried portion are clearly marked by a local oval-shaped gravity minimum and an associated local negative magnetic anomaly, possibly with reverse magnetization. Gabbroid bodies are also marked by local magnetic minima. In the exocontacts of the intrusion, presumed overlying skarn zones have been identified by narrow chains of magnetic maxima.

The East Kyngyrtau intrusion is composed of porphyritic quartz syenite-diorite and lies among Lower Devonian limestones. Only the northern part of the intrusion is exposed at the surface; to the south, it is overlain by Lower Cretaceous deposits. It is characterized by high electrical resistivity (up to 500 ohms), low polarizability (1%), and positive EP values. It does not stand out from the surrounding carbonate rocks, which have virtually identical electrical parameters. The intrusion also does not stand out in the gravity field, as the syenite-diorite and the host limestones have similar densities ($\sigma = 2.71$ g/cm^3). Instead, it is marked by a common positive anomaly mapping the Kyngyrtau horst-anticline. In the magnetic field, the massif is distinguished by a rather contrasting mosaic magnetic field, which delineates it beneath

Cretaceous sediments. The gabbroic bodies that make up the marginal parts of the intrusion are not revealed by magnetic fields, indicating that they are composed of non-magnetic varieties (without sulfides), a finding confirmed by the VP electrical prospecting. On the eastern flank of the intrusion, a body of $\varphi\iota C_3$ hornblendites, which makes up the marginal eastern part of the intrusion, was traced beneath sediments along an intense positive magnetic anomaly of submeridional strike and the associated VP and EP anomalies (*Yin et all, 2025*).

In the magnetic field, the Kyngyrtau intrusions and the well-known South Tozbulak granitoid massif, exposed by a series of boreholes beneath the Mesozoic-Cenozoic cover, are located within a regional negative magnetic anomaly striking northwest. Judging by the nature of the magnetic field, the South Tozbulak granitoid is a western continuation of the Kyngyrtau intrusions. The formations composing them are magnetized opposite to the modern magnetic field.

Within the buried basement, well-known large granitoid massifs-the Mingchukur, Makbulay, South Kazakasu, and South Tozbulak massifs-were mapped using extensive, deep gravity minima, while relatively small intrusions were identified using local gravity minima. Gabbroid intrusions were identified using local gravity maxima.

In the southeast, south of the Kyngyrtau Mountains, an intrusive massif of gabbro-ultramafic formation is identified under a thick sedimentary cover based on an intense positive magnetic anomaly. Gabbro-ultramafic intrusions have also been identified based on intense magnetic anomalies within Paleozoic basement outcrops and in a confined area, while moderate-intensity anomalies indicate suspected sulfidized gabbroic bodies.

Almost all of them are located at the margins of felsic intrusions. This once again confirms the constant, and therefore clearly non-random, relationship between gabbroids and granitoids within the Kuldzhuktau aureole. As it is noted, a close association of gabbroids and granitoids is generally possible only in the case of igneous injections occurring close together in time, when the structural plan does not have time to change significantly.

CONCLUSION

Discontinuous faults. Based on geophysical data, faults of sublatitudinal, submeridional, northwesterly, and northeasterly strikes have been identified in the area. The overwhelming majority of northwesterly and sublatitudinal faults coincide with known faults. Diagonal faults of submeridional, north-northwesterly, and northeasterly strikes have been identified for the first time, and only a small number of them coincide with previously known faults identified from aerial photographs.

Zones of decompression, shearing, crushing, intense silicification, and hydrothermal reworking. Based on local linear minima of the gravitational, magnetic, and natural electric fields (EF), zones of rock decompression (crushing, shearing, silicification, and hydrothermal reworking) have been identified within the area, potentially holding potential for gold mineralization. The decompression zones trend sublatitudinal and northwesterly. Their length ranges from 1.5-2 km to 5-8 km; their width ranges from 250-500 m. Nearly all known manifestations of gold mineralization, including the Taushan deposit, are located within these zones or are confined to them, allowing them to be considered ore-localizing and ore-conveying structures.

Graphitization and sulfide mineralization zones. Within the terrigenous rocks of the Taushan, Kazakasu, and Shuruk formations, areas of altered carbonated, sulfidized rocks have been identified based on first - order polarizability anomalies. Second- order polarizability anomalies have identified graphitization and sulfide mineralization zones, promising for gold mineralization, extending onto the erosional basement surface and overlain by thin carbonate rocks (sub-screen position).

Pyrrhotite mineralization zones. Based on local magnetic field maxima, pyrrhotite mineralization zones have been identified that are potentially promising for gold mineralization. The Taushan deposit is located within one of these zones. The pyrrhotite mineralization zones range in length from 1-1.7 km to 3-3.5 km, and their width ranges from 200-500 m. They trend sublatitudinal, east-northeastward, and submeridional.

In the northwest and northeast of the area, magnetic exploration revealed areal linear-elongated positive magnetic anomalies, which may be caused by gabbroic intrusions of the Shaidaraz and Taushanskaya types, but may also reflect manifestations of regional thermal metamorphism along the deep fault zone, and in this case their nature may be due to pyrite-pyrrhotite mineralization, favorable for the localization of gold mineralization.

The constructions we've performed are probabilistic in nature due to the lack of verification and parametric drilling, particularly with regard to deciphering the geological nature of magnetic anomalies. However, they will in any case serve as a geophysical basis for subsequent geophysical surveys and geomagnetic surveys.

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