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ORE POTENTIAL OF EARLY DEVONIAN INTRUSIONS IN THE SARYSU-TENIZ UPLIFT

Abstract. The article assesses the ore potential of the Terekty and Kokkuduktobe Early Devonian intrusive complexes in the southeastern part of the Sarysu-Teniz uplift, Central Kazakhstan. The study is based on geological, structural and geophysical data, as well as comparison with a known copper-gold deposit associated with the Karamendy intrusive complex. The focus is on studying the contacts between intrusive and effusive rocks, as well as zones of deep faults and intense crushing, which likely served as pathways for the migration of hydrothermal fluids and the localization of mineralization. The data obtained allows us to identify several promising areas of copper-gold mineralization, confined to zones of interaction between intrusions and Upper Ordovician effusive rocks. The identified geological and geophysical features confirm the prospectivity of the studied complexes and define priority targets for further exploration.

Key words: *intrusive magmatism, Early Devonian intrusions, ore potential, geophysical methods, deep faults, Sarysu-Teniz uplift, Central Kazakhstan.*

Сарысу-Теңіз көтерілімі ерте девон интрузивті кешендерінің кендік әлеуеті

Андатпа. Мақалада Орталық Қазақстандағы Сарысу-Теңіз көтерілімінің оңтүстік-шығыс бөлігінде орналасқан Теректі және Көкқұдықтөбе ертедевон интрузивтік кешендерінің кендік әлеуеті бағаланады. Зерттеу геологиялық, құрылымдық және геофизикалық деректерге, сондай-ақ Қарамеңді интрузивтік кешенімен байланысты белгілі мыс-алтын кен орнына салыстырмалы талдауға негізделген. Негізгі назар интрузивті және эффузивті жыныстардың жанасу аймақтарына, терең жарылымдар мен қарқынды ұсақталу зоналарына аударылған. Бұл аймақтар гидротермалдық флюидтердің көшу жолдары және минералданудың шоғырлану орындары болуы мүмкін. Алынған нәтижелер перспективалы мыс-алтын минералдану учаскелерін анықтауға мүмкіндік береді.

Түйінді сөздер: *интрузивтік магматизм, ерте девон интрузиялары, рудалық әлеует, геофизикалық әдістер, терең жарылымдар, Сарысу-Теңіз көтерілімі, Орталық Қазақстан.*

Рудоносный потенциал раннедевонских интрузивных комплексов Сарысу-Тенизского поднятия

Аннотация. В статье оценивается рудный потенциал раннедевонских Теректинского и Коккудуктюбинского интрузивных комплексов, расположенных в юго-восточной части Сарысу-Тенизского поднятия Центрального Казахстана. Исследование основано на геологических, структурных и геофизических данных, а также на сопоставлении с известным медно-золотым месторождением, связанным с Карамендинским интрузивным комплексом. Основное внимание уделено контактам интрузивных и эффузивных пород, зонам глубинных разломов и интенсивного дробления, которые могли служить путями миграции гидротермальных флюидов и локализации минерализации. Полученные результаты позволяют выделить перспективные участки медно-золотой минерализации и определить приоритетные направления дальнейших поисковых работ.

Ключевые слова: *интрузивный магматизм, раннедевонские интрузии, рудоносный потенциал, геофизические методы, глубинные разломы, Сарысу-Тенизское поднятие, Центральный Казахстан.*

Introduction

The Sarysu-Teniz segment of the Devonian volcanic-plutonic belt is one of the key geological structures of Central Kazakhstan. Its tectonic-magmatic evolution was accompanied by the formation of granitoid intrusive complexes and volcanogenic-sedimentary strata, which created favorable conditions for the development of ore-bearing systems [1, 2].

The aim of this study is to assess the prospects for hydrothermal-plutogenic copper-gold mineralization within the Terekty and Kokkuduktobe Early Devonian intrusive complexes in the southeastern part of the Sarysu-Teniz uplift. The assessment is based on a comparative analysis of geological, geophysical and geochronological data with the Karamendy intrusive complex, where the Zhaltyrbulak gold-copper ore occurrence has been identified [3, 4].

The Karamendy, Terekty and Kokkuduktobe intrusive complexes are considered as elements of a single Early Devonian magmatic system. The Zhaltyrbulak mineralization associated with the Karamendy complex is used as an analog model. Its main ore-controlling features include intrusive-effusive contacts, exo- and endocontact alteration zones, crushing and fracturing zones, deep faults, quartz-sulfide mineralization and local geophysical anomalies. These criteria were applied to evaluate the ore potential of the Terekty and Kokkuduktobe complexes.

Geophysical and geological evidence indicates similar mineralogical composition and close age values of the studied intrusive complexes within the analytical error [5]. Therefore, the Terekty and Kokkuduktobe complexes are considered promising objects for comparative geological and geophysical assessment using the analogy method and expert ranking of diagnostic ore-controlling features.

Analysis of the results of previous studies

Geological and geophysical data on the exploration of the Sarysu-Teniz segment of the Devonian volcano plutonic belt were collected primarily during regional and detailed exploration work conducted in the second half of the 20th century. The bulk of the research was concentrated within the Karamendy intrusive complex, where, from 1967 to 1972, K. I. Marichev, V. T. Kazimir, and V. A. Bogach conducted a series of geological, geophysical, and mining surveys that identified the Zhaltyrbulak gold deposit and several associated ore occurrences within the Zhaltyrbulak ore field.

The manifestations of gold-sulfide mineralization at the Zhaltyrbulak site are confined to the endocontact zone of granites and granodiorites of the Karamendy intrusive complex with Ordovician ***(O₃)*** effusive formations. This contact area is the main mining control zone, which is confirmed by the totality of geological observations and the results of geophysical work carried out in 1967–1968 (Figure 1) [6, 7].

Mineralization at the Zhaltyrbulak site is confined to the endocontact zone of granites and granodiorites with Upper Ordovician effusive rocks. Ore-bearing structures are mainly represented by northwest-trending crushed and fractured zones associated with quartz-sulfide veins. The mineralization includes pyrite, chalcopyrite, molybdenite and hematite, while the oxidation zone contains iron hydroxides and copper oxides. Magnetometry data show that ore-bearing and hydrothermally altered zones are marked by local magnetic field minima of up to 200–300 γ and bends in the ΔZa isolines, indicating

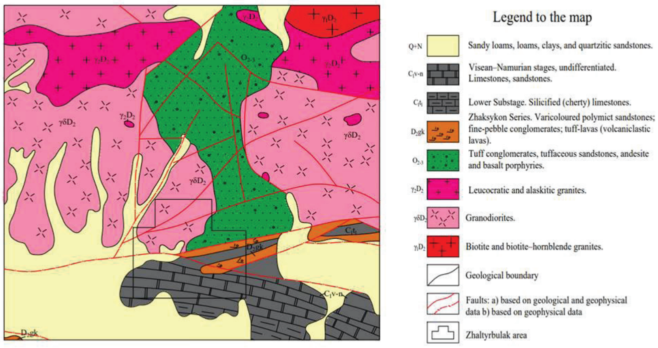


Figure 1. Geological map of the Zhaltyrbulak site (sheet M-42- XXXIII).
Сурет 1. Жалтырбұлақ учаскесінің геологиялық картасы (М-42- XXXIII парағы).
Рис. 1. Геологическая карта участка Жалтырбулак (лист М-42-XXXIII).

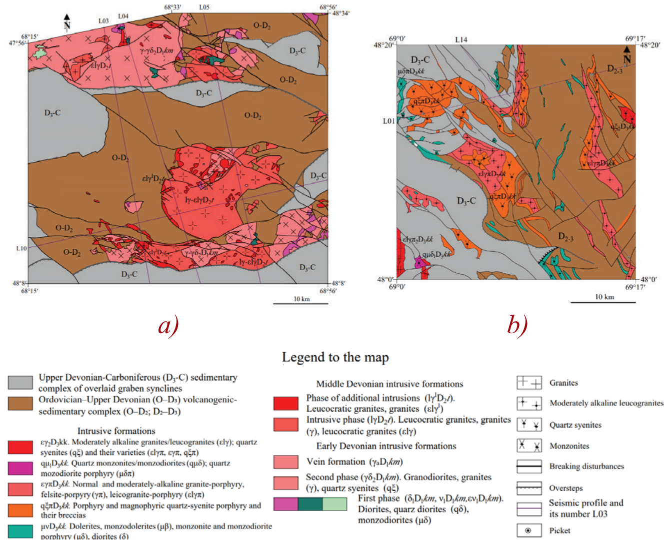


Figure 2. Geological maps*: a) Karamendy and Terekty intrusive complexes, profiles L03, L04, L05, L10 (sheet M-42-XXXIII); b) Kokkuduktobe intrusive complex, profiles L01, L14 (sheet M-42-XXXIV).*
Сурет 2. Геологиялық карталар: *a) Қарамендi және Теректi интрузивтi кешендер, L03, L04, L05, L10 профильдерi (М-42-XXXIII парағы); b) Көкқұдықтөбе интрузивтi кешенi, L01, L14 профильдерi (М-42-XXXIV парағы).*
Рис. 2. Геологические карты: *а) Карамендинский и Теректинский интрузивные комплексы, профили L03, L04, L05, L10 (лист М-42-XXXIII); б) Коккудуктюбинский интрузивный комплекс, профили L01, L14 (лист М-42-XXXIV).*

tectonic disturbances and reduced magnetic susceptibility of altered rocks. These geological, mineralogical and geophysical features confirm the high prospectivity of the Zhaltyrbulak site and can be used as criteria for further exploration and evaluation work [8, 9].

Materials and Methods

Exploratory work was conducted within each intrusive complex to identify promising areas for expanding the mineral resource base of the region. The studies included geological, geophysical, geochemical and geochronological investigations, absolute age determination, drilling, well logging and integrated data interpretation. Geophysical surveys were carried out along extended submeridional and sublatitudinal profiles crossing intrusive bodies, contact zones, regional and local faults, and structural-formation boundaries. The profile layout was aimed at revealing the deep structure of intrusive bodies and potential ore-controlling zones (Figure 2).

The geophysical complex included magnetic, gravity, electrical, seismic and gamma-ray surveys. Magnetic measurements were performed using a GSM-19W proton magnetometer, gravity data were obtained with a Scintrex CG-5 Autograv gravimeter, and VES-IP data were interpreted in ZondRes2D. Seismic profiling was carried out by the 2D common depth point method. Integrated interpretation made it possible to identify intrusive contacts, fault zones and areas favorable for hydrothermal mineralization.

Results and Discussion

As a result of the interpretation of new geological and geophysical data obtained from a system of extended profiles intersecting the Terekty and Kokkuduktobe intrusive complexes, stable patterns of spatial distribution of magnetic, gravitational and electrical anomalies have been established. The revealed anomalous fields reflect the structural features of intrusive bodies, their contact zones and associated fault structures, which are interpreted as deep structural elements potentially controlling ore mineralization.

The Terekty intrusive complex, previously treated as Middle Devonian, is considered in this work as Early Devonian and is represented by leucogranites of normal and moderate alkalinity embedded in Devonian volcanogenic-sedimentary strata [5]. According to the geological survey and geophysical surveys of 2020–2022, intrusive bodies can be traced within the profiles L03, L04, L05, L10 and L13, where pronounced contact and exocontact zones are formed (Figure 2*a*).

The exocontact zones of the Terekty intrusive complex have a thickness of 10–50 m, which is confirmed by geological observations and geophysical interpretation of the profiles. Hydrothermally altered rocks are developed within these zones, confined to the contacts of intrusive bodies with the host Devonian strata. According to geological features, exocontacts are estimated as zones of high probability of mineralization, while the central parts of the intrusive without pronounced structural disturbances correspond to a medium-high probability (Figure 3).

Structurally, the Terekty intrusive complex is confined to discontinuous disturbances. The marginal parts of the massif are complicated by zones of crushing and increased fracturing with a width of 10–40 m, which coincide with the exocontacts of intrusive bodies and are considered as the main channels of migration of ore-bearing hydrothermal fluids. The intersection points of faults and contacts, most clearly expressed on profiles L05 and L10, are the main ore-controlling structures and are estimated as zones of high probability of mineralization.

The mineralogical features of the Terekty complex correspond to the intrusive hydrothermal type of mineralization. Pyrite and chalcopyrite were found in the exocontact zones, which indicates the presence of primary sulfide mineralization. Secondary copper minerals malachite and azurite, which are associated with cracks and decompression zones, are widely developed in the oxidation zone. The association of ***Cu*** with ***Ag*** and ***Mo*** has a local character and is considered as a supporting sign of medium to high significance.

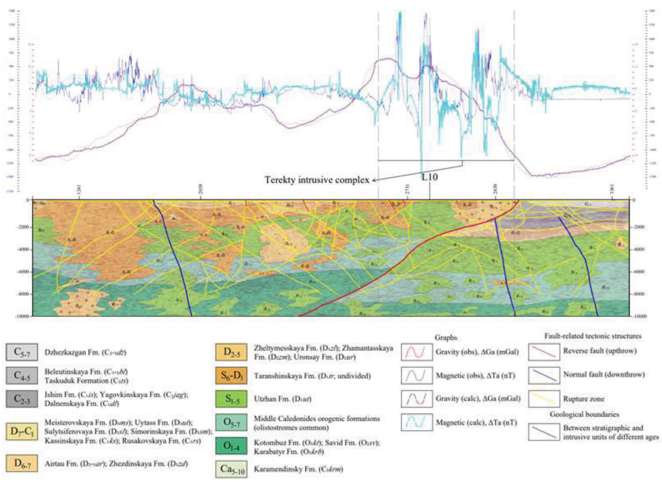


Figure 3. Geological and geophysical section along the L03 profile.
Сурет 3. L03 профилі бойынша геологиялық және геофизикалық қима.
Рис. 3. Геолого-геофизический разрез профиля L03.

The geophysical data provide a quantitative justification for the ore prospects of the Terekty complex. According to magnetometry data, stable local minima of the anomalous magnetic field ΔZ with an amplitude of 100–200 NT are recorded on profiles L03, L04, L05, and L10, confined to exocontacts and crushing zones; these anomalies are interpreted as the result of rock demagnetization due to hydrothermal processing (Figure 4) [10, 11].

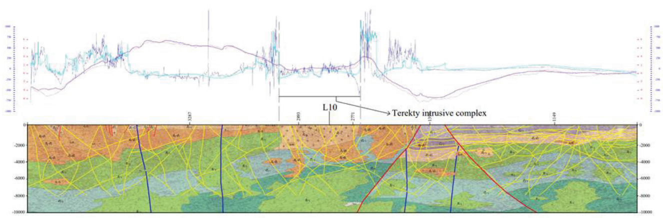


Figure 4. Geological and geophysical section along the L04 profile.
Сурет 4. L04 профилі бойынша геологиялық және геофизикалық қима.
Рис. 4. Геолого-геофизический разрез профиля L04.

According to the data of gravity exploration, local decreases in the gravitational field have been revealed in the same intervals, coinciding with magnetic minima; when they coincide with ΔZ = 100–200 NT, their prognostic significance increases (Figure 5) [12].

Electrical exploration revealed anomalies in the exocontact zones of apparent resistance R_k = 300–600 Ohms · m, corresponding to quarried and fractured rocks. At the same time, anomalies of induced polarization n = 4–6% exceeding the background values are recorded here. The combination of resistances of 300–600 Ohms·m and a polarizability of 4–6% is a reliable indicator of latent sulfide mineralization.

The gamma-ray survey data shows the variability of the radiation background associated with the lithological composition of granites and host rocks. Numerical values of gamma activity do not correlate with the ΔZ = 100–200 NT and n = 4–6% zones, which is why the gamma radiometric feature is assessed as low in prognostic significance.

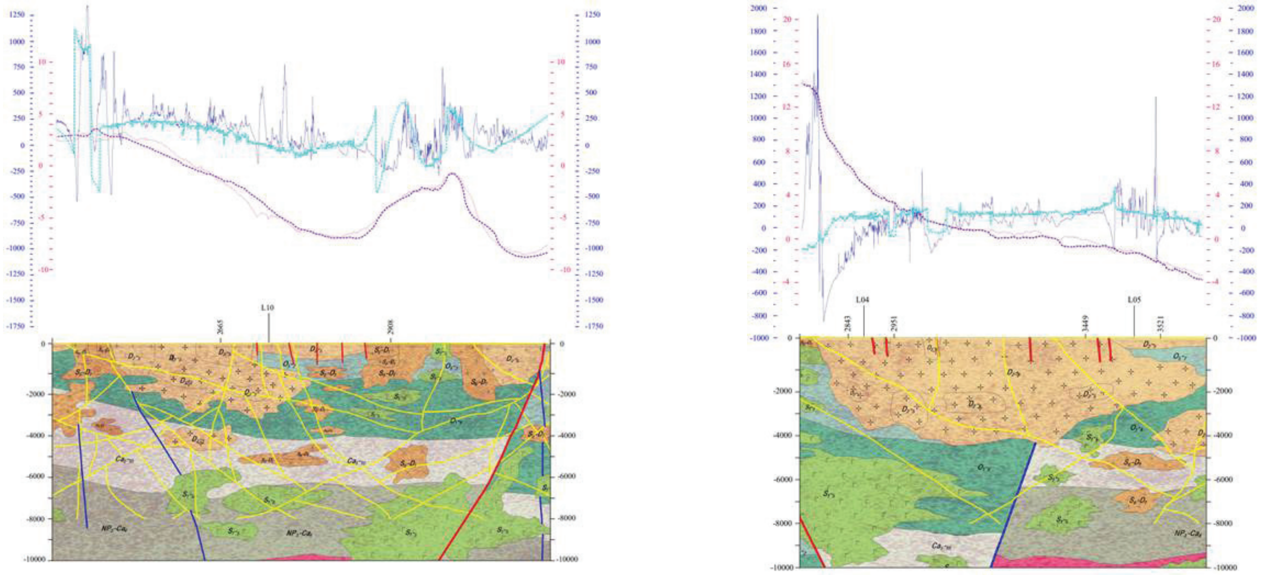
To compare the Karamendy (model), Terekty, and Kokkuduktobe intrusive complexes, diagnostic geological, structural, mineralogical, and geophysical features were summarized and ranked according to their prognostic significance, which were determined by expert assessments (Table 1).

In general, the Terekty intrusive complex is characterized by moderate ore prospects, realized in exocontact zones with a capacity of 10-50 m with a coincidence of crushing zones of 10-40 m, magnetic minima ΔZ = 100–200 NT, anomalies of resistance R_k = 300–600 ohms · m and increased polarizability n = 4–6%. Sites with this combination of features should be considered as the primary objects of further search and evaluation work.

For the Kokkuduktobe intrusive complex, the highest concentration of diagnostic features was established along profile L01, which features converging intrusive contacts, fault zones, increased fracturing, sulfide mineralization, and coordinated magnetic-gravity anomalies. This combination of features indicates favorable conditions for the development of hydrothermal mineralization. Profile L14 is assessed as moderately promising due to weaker manifestations of gravity-magnetic indicators and the remote influence of the intrusive body. Therefore, profile L01 should be considered a priority area for further exploration and appraisal work.

Conclusion

A comprehensive interpretation of new seismic, gravimagnetic, and electrical exploration data based on a system of extended profiles clarified the deep structure of the Terekty and Kokkuduktobe intrusive complexes and showed their close structural association with the system of regional and local faults in the southeastern part of the Sarysu-Teniz uplift. Intrusive bodies are characterized by a block structure, contrasting differentiation of magnetic and gravitational fields, and the presence of zones of increased electrical conductivity, reflecting tectonic disturbance and increased rock permeability, which are key conditions for the migration of hydrothermal fluids and the formation of ore mineralization. The most ore-favorable areas are associated with endo- and exocontacts of intrusions, crushing zones, and fault junctions of various kinematics, where consistent magnetic minima, local gravity depressions, and resistance/IP anomalies are recorded, interpreted as signs of hydrothermal processing and possible latent sulfide mineralization. Taking into account the previously established U-Pb geochronology of the Karamendy, Terekty and Kokkuduktobe complexes of the same age (418 ± 3-412



a) b)

Figure 5. Geological and geophysical sections by profiles: *a) L05; b) L10 (fragments within the Terekty intrusive massif).*
Сурет 5. Профильдер бойынша геологиялық және геофизикалық қималар: *а) L05; б) L10 (Теректі интрузивті массивіндегі сынықтар).*
Рис. 5. Геологические и геофизические разрезы по профилям: *а) L05; б) L10 (фрагменты в пределах Теректинского интрузивного массива).*

Table 1

Diagnostic features and their significance for assessing the ore prospects of intrusive complexes

Кесте 1

Диагностикалық ерекшеліктері және олардың интрузивті кешендер кенінің болашағын бағалаудағы маңызы

Таблица 1

Диагностические признаки и их значение для оценки перспектив рудообразования в интрузивных комплексах

Criteria	Karamendy (model)		Terekty		Kokkuduktobe	
	Sign	Signifi-cance	Sign	Signifi-cance	Sign	Signifi-cance
Contact area	Contact granites/granodiorites ↔ effusive O_3	5	Exocontacts of intrusion 10–50 m	5	Endo-/exocontacts of intrusion (marginal parts of the array)	5
Structural	Crushing and fracturing zones (315–345°); quartz veins (subparallel/spiral), 75–85° drop to the northeast	5	Crushing/ fracturing zones 10–40 m	5	Proximity to discontinuous faults; areas of increased fracturing/ crushing	5
Magnetic	Local minimum ΔZa 200-300 γ (above vein zones); bends of the isolines ΔZa (faults); mosaic field -250...+2310 γ	5	Minimum ΔZ = 100–200 NT in contacts/ faults	3,5	Local minimum/kinks of ΔZa and contrasting gradients in the marginal part of the intrusive	3,5
Gravity	-	-	Local decreases in g, coinciding with ΔZ-minimum	5	Local decreases in the gravitational field consistent with magnetic signs	5
Electric (ρ_k)	ρ_k 1000–1300 ohms · m (quartz zones and dense bodies)	3,5	ρ_k = 300–600 Ohms · m (contact areas)	3	-	-
Mineralog-ical	Sulfide mineralization(direct) Pyrite – chalcopyrite – molybdenum + hematite Gold is associated with pyrite (secondary)	5	Pyrite and chalcopyrite in the contact area Oxidized forms of copper Association of copper with silver and molybdenum	4	Sulfide mineralization Oxidized copper minerals	3,5
Comprehen-sive (key)	Combination: contact O_3-intrusions + crushing zones + quartz veins + ΔZa-minima + high NP (± EP-anomalies)	5+	Combination: contact + d crushing + ΔZ + ρ_k + η (± g- minimum)	5+	Combination: contact + the fault zone + consistent magnetic and gravitational anomalies (+ mineralogical features)	5

±3 million years) and their material and mineralogical similarity, the Terekty and Kokkuduktobe complexes are reasonably considered as products of a single Early Devonian magmatic stage and as potentially ore-bearing objects comparable in genetic terms with the Karamendy complex (Zhaltyrbulak site).

Analysis of rating indicators (Table 1) indicates that the proximity of the average criterion of the Terekty complex is more significant, 91.7% relative to the model (Karamendy complex) versus Kokkuduktobe, which is 90%. Thus, the Terekty intrusive complex is preferable for conducting geological and geophysical studies at the stage of exploration of structures, for assessing the resources of gold-sulfide mineralization. The results obtained form a system of criteria and justify the priority of further predictive prospecting and prospecting and evaluation work on copper-gold mineralization within the contact fault zones of these intrusive massifs.

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ПАЙДАЛАНЫЛҒАН ӘДЕБИЕТТЕР ТІЗІМІ

1. *Орталық Қазақстандағы девон жанартаулық белдеуінің зоналылығы, сегментациясы және палеогеодинамикасы / A. M. Kurchavov [және т. б.] // Geotectonics. – 2000. – Т. 34. – № 4. – Б. 284–293 (ағылшын тілінде)*
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