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THE NATURE OF THE KARASOR-LISAKOV MAGNETIC ANOMALY AND IDENTIFICATION OF PROMISING AREAS FOR MAGNETITE ORE DEPOSITS IN KAZAKHSTAN

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Abstract. This article presents the results of geological and geophysical investigations conducted to evaluate the prospects for magnetite deposits within the Karasor–Lisakov magnetic anomaly, located in the Yeltai–Korzhynkol ore district of northern Kazakhstan. The research was aimed at verifying previously identified magnetic field anomalies and providing a detailed examination of newly discovered anomalies, directly linked to delineating ore-bearing areas and increasing iron ore reserves. The origin and characteristics of the magnetic anomalies were determined through an integrated approach, combining borehole geophysical surveys with the reinterpretation of high-resolution ground magnetic field data. This integration enabled the development of a model describing the morphology of ore bodies and their spatial distribution. Detailed information was obtained on the deep structure of specific ore zones, as well as their magnetic properties. The combined interpretation of borehole and surface datasets allowed for the characterization of the physical properties of geological complexes and ores, the identification of new ore bodies, and an assessment of the spatial and vertical distribution of metal content. A comprehensive reinterpretation of the Lisakov and Karasor magnetic anomalies, incorporating newly acquired petrophysical parameters, revealed magnetite deposits that had previously been considered low-potential due to incomplete magnetic field compensation. The findings for the Yeltai–Korzhynkol ore district highlight the potential for expanding the resource base of the Korzhynkol mine, which is currently in its late stage of development. The results confirm the significant potential of iron ore resources in the region and underscore the need for further exploration using modern prospecting technologies, including advanced geophysical methods.

Key words: geophysical surveys, borehole logging, drilling, magnetic susceptibility, anomaly, magnetite, ore, deposit

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ҚАРАСОР-ЛИСАКОВ МАГНИТТІК АНОМАЛИЯСЫНЫҢ ТАБИҒАТЫ ЖӘНЕ ҚАЗАҚСТАНДАҒЫ МАГНЕТИТ КЕН ОРЫНДАРЫНЫҢ ПЕРСПЕКТИВАЛЫ УЧАСКЕЛЕРІН АНЫҚТАУ

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Аннотация. Мақалада Солтүстік Қазақстандағы Елтай-Қоржынкөл кенді ауданының Қарасор-Лисаков магниттік аномалиясы ауданындағы магнетит кенорындарының перспективаларын бағалауға бағытталған геологиялық-геофизикалық зерттеу нәтижелері ұсынылған. Зерттеулер бұрын анықталған магниттік өріс аномалияларын тексеруге және жаңа магниттік аномалиялардың табиғатын терең зерттеуге бағытталған. Бұл аномалиялар рудалы алаңдарды шектеу мен темір кендерінің қорларын арттырумен тығыз байланысты. Магниттік аномалиялардың табиғаты ұңғымаларда жүргізілген кешенді геофизикалық зерттеулер мен магнит өрісінің жерүсті детальды түсірілімдерін қайта интерпретациялау арқылы анықталды. Бұл мәліметтер рудалы денелердің морфологиясы мен кеңістіктік таралу моделін жасауға мүмкіндік берді. Жеке рудалы зоналардың тереңдік құрылысы мен олардың магниттік қасиеттері туралы нақты ақпарат алынды. Ұңғымалық және жерүсті деректерін кешенді интерпретациялау геологиялық кешендер мен кендердің физикалық қасиеттерін сипаттауға, сондай-ақ металлдың кеңістіктік және тереңдік бойынша таралу ерекшеліктерін анықтауға мүмкіндік берді. Лисаков және Қарасор магниттік аномалиялары мысалында олардың жаңадан алынған петрофизикалық сипаттамалар негізінде қайта интерпретациясы жүргізілді. Магнит өрісінің жеткіліксіз өтемделуінен бұрын болашағы аз деп бағаланған магнетит кендері туралы жаңа деректер алынды. Елтай-Қоржынкөл кенді ауданының перспективаларын зерттеу қазіргі таңда кен қорын игерудің соңғы сатысында тұрған Қоржынкөл кен орнының шикізат базасын кеңейтуге бағытталған. Алынған жаңа нәтижелер темір кенінің едәуір әлеуеті бар екенін көрсетіп, өңірде қазіргі заманғы іздестіру-барлау технологияларын қолдану арқылы әрі қарайғы зерттеулердің қажеттілігін дәлелдейді.

Түйінді сөздер: геофизикалық зерттеулер, ұңғыма, бұрғылау, магниттік қабылдағыштық, аномалия, магнетит, руда, кен орны

Б.Б. Амралинова, К.С. Тогизов, А. Нухұлы, Н.Ж. Жұмабай, А.Е. Есенгелдина, 2025.

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ПРИРОДА КАРАСОРСКО-ЛИСАКОВСКОЙ МАГНИТНОЙ АНОМАЛИИ И ВЫЯВЛЕНИЕ ПЕРСПЕКТИВНЫХ ПЛОЩАДЕЙ МЕСТОРОЖДЕНИЙ МАГНЕТИТА В КАЗАХСТАНЕ

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Аннотация. В статье представлены результаты геолого-геофизических исследований по оценке перспектив месторождений магнетита в районе Карасорско-Лисаковской магнитной аномалии Елтайско-Куржункульского рудного района в Северном Казахстане. Исследования, направленные на проверку ранее выявленных аномалий магнитного поля и детальное изучение природы новых магнитных аномалий, напрямую связаны с оконтуриванием рудоносных площадей и увеличением запасов железных руд. Природа магнитных аномалий определена на основе комплексных геофизических исследований скважин и переинтерпретации детальных наземных съёмок магнитного поля, что позволило построить модель морфологии рудных тел и их пространственного распространения. Получена детальная информация о глубинном строении отдельных рудных зон, а также об их магнитных свойствах. Интегрированный подход к интерпретации скважинных и наземных данных позволил охарактеризовать физические свойства геологических комплексов и руд, выявить новые рудные тела и особенности распределения содержания металла по площади и глубине. На примере Лисаковской и Карасорской магнитных аномалий осуществлена комплексная переинтерпретация магнитных аномалий с учётом вновь полученных петрофизических характеристик. Получена новая информация о магнетитовых залежах, недоизученных из-за недокомпенсации магнитного поля и считавшихся ранее малоперспективными. Изучение перспектив Елтайско-Куржункульского рудного района направлено на возможное расширение сырьевой базы действующего Куржункульского рудника, находящегося на поздней стадии разработки. Полученные результаты свидетельствуют о значительном потенциале железорудных ресурсов и необходимости дальнейших исследований региона с применением современных технологий поисково-разведочных работ, включая инновационные геофизические методы.

Ключевые слова: геофизические исследования, скважина, бурение, магнитная восприимчивость, аномалия, магнетит, руда, месторождение

Introduction. More than two hundred iron ore deposits and occurrences have been identified within the territory of the Republic of Kazakhstan. In terms of approved iron ore reserves, the country ranks seventh among nations with a developed mining industry. Three geological–industrial types of iron ore deposits are recognized here: magnetite, magnetite–hematite, and limonite (brown iron ore) types. The primary raw material base for mining enterprises is represented by magnetite ore deposits located in Northern Kazakhstan, which account for 85% of the explored iron ore reserves (Holmes, 2022: 56; Ericsson, 2021: 9; Karenov, 2016: 17).

Based on the results of regional ground-based magnetic surveys, as well as geological and profile-oriented integrated geophysical studies, an intensive belt of magnetic anomalies was identified in the region, which later became known as the Main Iron Ore Belt, or the Kostanay Iron Ore Zone. Detailed geophysical surveys, followed by drilling of the most intensive magnetic anomalies, led to the discovery of almost all currently known iron ore deposits in the region (Trushko, 2016: 8)

The object of the research presented in this article is the Karasor–Lisakov group of magnetic anomalies, identified in the southwestern part of the Yeltai–Korzhynkol ore district within the Kostanay Iron Ore Zone. Within the Karasor–Lisakov group of magnetic anomalies, the first magnetite ore deposit in the Turgay trough — the Korzhynkol deposit — and the martite ore deposit — the Kozyrev deposit — were discovered. The ore cluster area also hosts the Severo-Lisakov (North Lisakov) and Karasor deposits, as well as the Lisakov and Yuzhno-Lisakov (South Lisakov) ore occurrences. Several small deposits and ore occurrences have been identified, and the ore-bearing nature of many magnetic anomalies has been established (Fig. 1). The ores here are magnetite; in the northern and northwestern areas they occur in vein form, whereas in the southern areas they have a massive structure (Bekmukhametov, 2003, Kryazheva, 2018: 9; Kaskataeva, 2021:10).

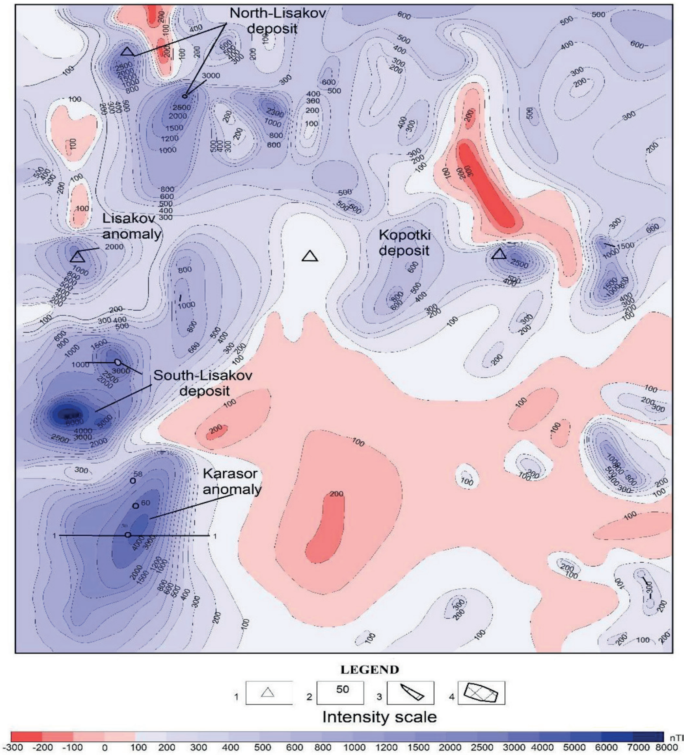

Figure 1 – Isodynamic map obtained as a result of variation control conducted at the Karasor-Lisakov magnetic anomaly. Scale 1:50 000.
1 - Geomagnetic field control points, 2 – boreholes, 3 - Ore body contour obtained by drilling, 4 - Additional ore body contour obtained from geophysical data.

Since 1983, the large Korzhynkol magnetite ore deposit has been under development in the region. Additional exploration conducted at the deposit revealed that it had not been fully studied at depth: ore bodies were not completely delineated along strike due to incomplete magnetic field compensation of the exposed ore bodies. Previous prospecting and evaluation work in the area was carried out by drilling shallow boreholes, which resulted in many ore occurrences being classified as low-potential (Bekmukhametov, 2003).

At the Lisakov site of the Karasor–Lisakov group of magnetic anomalies, surveys using the method of induced magnetization (IM) in an areal configuration, combined with an analysis of magnetic variation method results, revealed a number of new secondary magnetic field anomalies. Quantitative reinterpretation of the magnetic field made it possible to determine the contacts of the disturbing bodies, their depth of occurrence, and the estimated reserves (Kryazheva, 2018: 9). In combination with drilling in the southern part of the North Lisakovsk ore occurrence, this allowed the identification, alongside low-grade vein-disseminated ores, of massive ores with a total thickness ranging from 110 to 500 m. Within the Karasor anomaly, a significant lateral anomaly was established, caused by steeply dipping ore bodies.

Ongoing detailed magnetic and gravimetric surveys at scales of 1:2,000–1:10,000, along with the introduction of new technologies for recording, processing, analyzing, and qualitatively and quantitatively interpreting magnetic fields, have made it possible to identify additional local magnetic anomalies that require determination of their origin and assessment of their relationship to ferruginous mineralization. These data provided the basis for additional prospecting and evaluation works, and for classifying the Karasor–Lisakov group of magnetic anomalies as one of the most promising targets for the discovery of new ore bodies at depths of up to 600–800 m.

Thus, the application of innovative geological and geophysical methods, along with increasing the depth of exploration drilling, provides grounds for a new forecast evaluation of magnetite ore reserves within the Karasor and Lisakov groups of magnetic anomalies and justifies the resumption of exploration on previously low-potential areas. The relevance of this work is determined by the need to reassess the forecast resources of small deposits and occurrences of magnetite ores in Northern Kazakhstan, considered as a potential source for the additional raw material base of the operating Korzhynkol mine, which is currently exploiting several deposits at a late stage of development (Togizov, 2019: 8).

Materials. To determine the nature of individual anomalies within the Karasor–Lisakov group, geophysical data were analyzed to address the following objectives:

1. Localization and refinement of the depth of ore intervals, forecast evaluation of iron content in drill cores, and selection of intervals for chemical analysis.
2. Investigation of the near-borehole and inter-borehole space in order to identify ore bodies and determine their spatial distribution.
3. Identification of zones of rock fracturing and individual lithological heterogeneities.

To achieve these objectives, the results of integrated borehole geophysical surveys were analyzed, including magnetic susceptibility logging (MSL), three-component magnetometry, gamma-ray logging (GR), selective gamma–gamma logging (GGL-S), apparent resistivity method (AR), caliper logging, and inclinometry, with extensive use of drilling results. In addition, to interpret the nature of ground magnetic anomalies, results of the magnetic variation method were examined. Geological and geophysical data obtained over different years from field and office work conducted by various industrial companies were extensively used.

In the geological interpretation of geophysical anomalies, geological mapping data, lithological and stratigraphic characteristics of geological complexes, as well as petrographic and mineralogical studies of rock samples from collected drill core material were used. Modern technologies were applied for processing newly acquired and reprocessing previously obtained primary field data, utilizing geographic information systems (GIS). The quality of drilling operations and the reliability of interpretation were controlled through borehole geophysical surveys.

Additionally, the research incorporated archival and literature sources, including industrial reports on geological exploration, scientific publications on the geological structure and ore potential of the region, and results of previous studies on methods and technologies for forecasting and prospecting magnetite ores (Karenov, 2016: 17).

All collected materials were analyzed and used to determine the nature of magnetic anomalies and to identify promising areas for planning further prospecting and exploration activities.

Research Methodology. In the interpretation of geophysical data, the following maps were used: magnetic anomaly maps at scales of 1:5,000, 1:10,000, and 1:25,000; local Δg anomalies at a scale of 1:10,000; measurements of the vertical component of the magnetic field (Z_a) along boreholes; and diagrams of magnetic susceptibility logging (MSL), apparent resistivity (AR), selective gamma–gamma logging (GGL-S), and gamma-ray logging (GR). (Khramov, 1982, Sailymby, 2020 a: 6)

At the first stage, during the process of qualitative interpretation, the patterns of changes in magnetic (ΔZ, ΔT) and gravity (Δg) anomalies were analyzed in order to study in detail the geological structure of individual areas. The analysis included determining the intensity, shape, size, and gradients of anomalies, as well as identifying zones of sharp field changes. On magnetic anomaly maps, variations in the field are represented by isolines—lines of equal magnetic induction forming closed contours of various shapes and sizes. These isolines serve as a fundamental tool in the interpretation of geophysical data, enabling visualization of magnetic field gradients and the identification of areas with differing magnetic activity within the Karasor–Lisakov zone (Fig. 2) (Wang, 2015: 10). The density of isolines on the map varies according to the rate of change in the magnetic field intensity (Dyadkov, 2021:7).

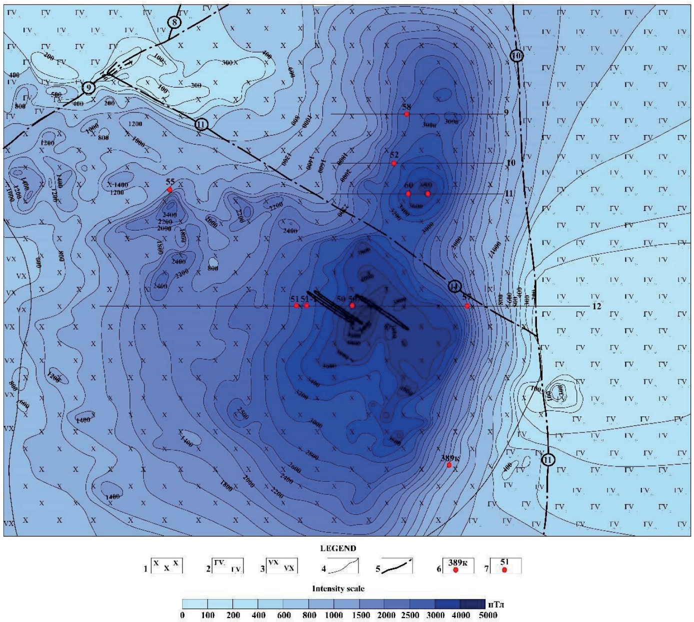

Figure 2 – Geological and geophysical scheme of the Karasor deposit
1 – diorites, 2 – andesite–basalt porphyrites, 3 – diorite porphyrites,4 – Za isolines, 5 – fault, 6, 7 – boreholes

Variations in the Z_a parameter along boreholes were analyzed to examine the depth-related characteristics of the magnetic field (Sailymby, 2022 b:6). As a result of the integrated analysis of these data and surface Z_a field surveys, local magnetic anomalies associated with prospective ore-bearing targets were identified (Fig. 3).

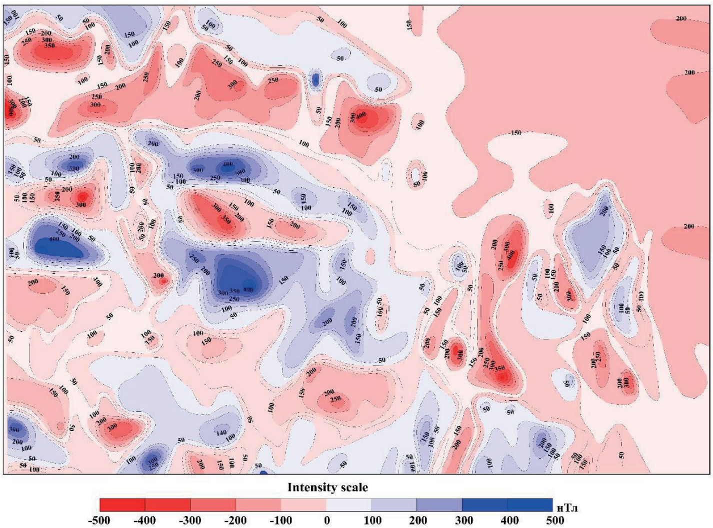

Figure 3 – Map of ΔZa isodynamic lines of the Lisakov magnetic anomaly

Quantitative interpretation involved determining the theoretical magnetic field that best fits the measured field data obtained from boreholes and the surface, based on modeling the dimensions and shapes of ore bodies. The magnitude and direction of the induced magnetization of the ore bodies were selected using magnetic susceptibility values derived from magnetic susceptibility logging (MSL) in boreholes evenly distributed across the study area of the anomaly (Dyadkov, 2021: 7).

Due to the so-called coercive force, ferromagnetic minerals retain remanent magnetization (J_n) upon cooling, the influence of which was taken into account during magnetic field modeling in the quantitative interpretation process. The magnitude and direction of the remanent magnetization vectors (J_i) were determined using the Königsberger ratio (Q), a quantitative parameter defined as the ratio of remanent magnetization (J_n) to induced magnetization (J_i). Typically, $Q = J_n / J_i$ ranges from 0 to 100 and may be either positive or negative. High Q values are characteristic of ferromagnetic minerals, lower values are typical for igneous rocks, even lower for metamorphic rocks, and values close to zero are common for sedimentary rocks (Dortman, 1992).

The true values of magnetic susceptibility for the geological section and productive horizons were determined from magnetic susceptibility logging (MSL) diagrams (Sailymby, 2020 a: 6). The MSL method was applied to investigate the magnetic properties of rocks and ores within the Karasor–Lisakovsk area, using boreholes drilled within magnetic anomalies considered promising for the detection of ore bodies. Variations in magnetic susceptibility were used to delineate anomalous zones associated with elevated magnetite content. For example, in the interpretation of MSL data for the ores of the Karasor anomaly, a plot was constructed showing the relationship between magnetic susceptibility and the content of total iron and magnetite-bound iron (Fig. 4). The dataset for this plot was derived from five boreholes exhibiting constant magnetic susceptibility values over intervals ranging from 0.8 to 10.5 m in thickness.

The coefficients were determined using the least squares method (Dyadkov, 2021: 7). The table below presents the parameters along with the regression equation (Table 1).

Table-1. Nature of Dependencies

$Fe_{total}=f(æ)$; $Fe_{mag.}=f(æ)$

Regression Level	**Number of Observations**	**Root Mean Square Error (RMSE)**	**Correlation Ratio**
$Fe_{total}=0,3774x^2+1,3291x+6,35$	128	3,03	0,979
$Fe_{mag.}= 0,3894x^2+1,6353x+2,54$	140	2,94	0,981

The application of this method made it possible to determine the distribution of magnetic minerals within the geological section and to quantitatively assess their content, which is particularly important for the exploration of magnetite ore deposits and other iron-bearing minerals. The results of magnetic logging were utilized to identify anomalous zones with elevated magnetic susceptibility, indicating the presence of magnetite and other magnetized components. Magnetic logging data, combined with MSL (magnetic susceptibility logging) results, were further employed to delineate ore-bearing intervals, zones of magnetite dissemination, and to estimate ore content within these intervals. (Sailymby, 2020 a: 6).

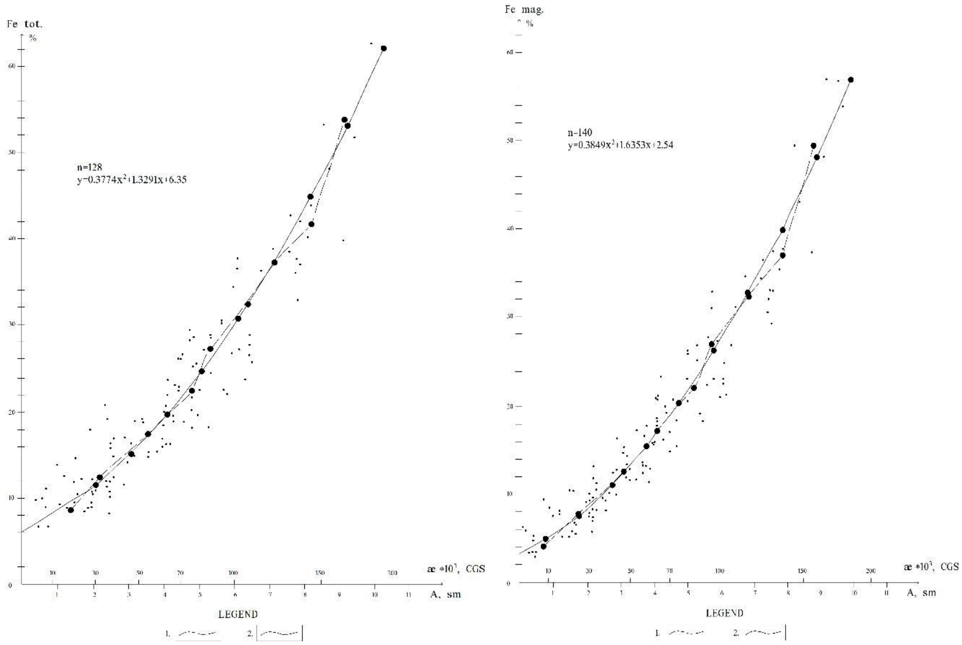

Figure 4 – Relationships between magnetite iron content and magnetic susceptibility for ores of the Karasor deposit: (a) total iron; (b) magnetite iron.
1 – empirical regression line, 2 – theoretical regression line

For all iron ore deposits of Northern Kazakhstan, there is a well-defined relationship between the effective atomic number of the medium (Z_{eff}) and the iron content, which serves as a direct indicator for delineating ore intervals and assessing their iron concentration (Garnit, 2017: 20). To establish this relationship, the results of the GGL-S method were interpreted, aimed at identifying magnetite, sulfide, and oxidized ores within borehole sections. In the geological profiles, iron ores are characterized by low values of scattered gamma radiation. The estimation of total iron content was based on the dependence of iron content on the GGL-S amplitude, described by the formula $Fe_{total} = 87.14 \times 0.04034 \times \chi^2$. Layer boundaries were determined at ½ J_{yy}(max).

An empirical formula for estimating the total iron content from GGL-S data can be simplified as $Fe_{total} = 3.515 \times \chi^2$, where the variable χ denotes the specific magnetic susceptibility of the rocks, measured in 10^{-3} SI units (m^3/kg). Refining this relationship improves the accuracy of quantitative iron estimation in ore intervals and ensures consistency with logging data and laboratory analyses. This formula is particularly effective for intervals dominated by magnetite ores, which exhibit high magnetic susceptibility (Dyadkov, 2021: 7).

Additionally, gamma–gamma density logging (GGD) was employed to determine the density of rocks and ores (Wang, 2015: 10). This method provided quantitative data on the density characteristics of ore bodies, which is essential for reserve estimation and the prediction of mining performance. Gamma logging (GL) complemented the study by supplying information on the radioactive properties of rocks, enabling the assessment of natural radioactivity levels and the identification of zones with elevated radionuclide concentrations.

The study also incorporated the analysis of resistivity logging (RL) curves, which provided valuable information on the electrical properties of the rocks (Togizov, 2019: 8). This method enabled the identification of variations in electrical conductivity and specific resistivity of both host rocks and ore bodies, reflecting their mineralogical composition and degree of mineralization. Elevated resistivity values are typically indicative of the presence of sulfide minerals, whereas lower values generally correspond to increased moisture content or clay-rich lithologies (Fig. 5).

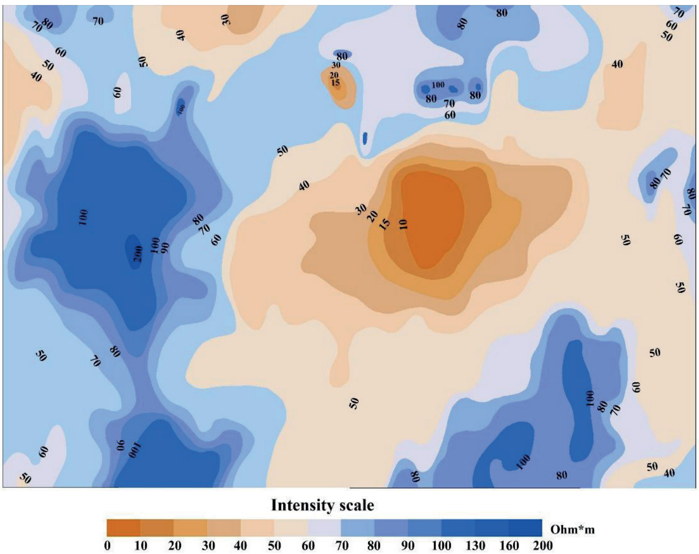

Figure 5 – Isoohm Map of the Lisakov site. Scale 1:10 000

All obtained borehole logging results were systematized and compiled into Table 2, enabling a comprehensive analysis and comparison of the physical properties of rocks and ores. This integrated approach to data interpretation not only allowed for a more accurate characterization of the physicochemical properties of geological formations, but also facilitated the identification of structural heterogeneities and patterns in the distribution of valuable components. Such a methodology significantly enhances the efficiency of mineral exploration and supports the rational planning of subsequent stages in deposit investigation and development.

The magnetic variation method was employed to investigate changes in the total magnetic field vector modulus (T) within the Lisakov and southern North Lisakov anomalies. The analysis of variations involved decomposing the magnetic field for each variogram into low- and high-frequency components, corresponding to fine-scale heterogeneities in the geological medium. For the Lisakov anomaly, during the observation period (from 14:17 to 16:20), the magnetic field increased by 4.6 gamma. The magnetic variation effect (η), defined as the ratio of variation amplitudes in the anomalous zone to those in the normal field ($\delta T_a/\delta T_0$), was calculated as 1.035 (Fig. 5). This value indicates a relatively compositionally homogeneous host environment.

The Königsberger factor was calculated considering magnetic field variations (medium heterogeneity) using the formula:

$$Q = \frac{\frac{Ta}{To} - \eta}{\eta - 1}$$

For the Lisakov anomaly, its value was found to be − 0.06. The negative value is attributed to inaccuracies in determining the Q-factor based on magnetic variations. Given the low remanent magnetization and geological characteristics of the area, the most probable causes of this phenomenon are inconsistencies between the parameters T_a, T_0 and η, as well as possible errors in approximating the background magnetic field.

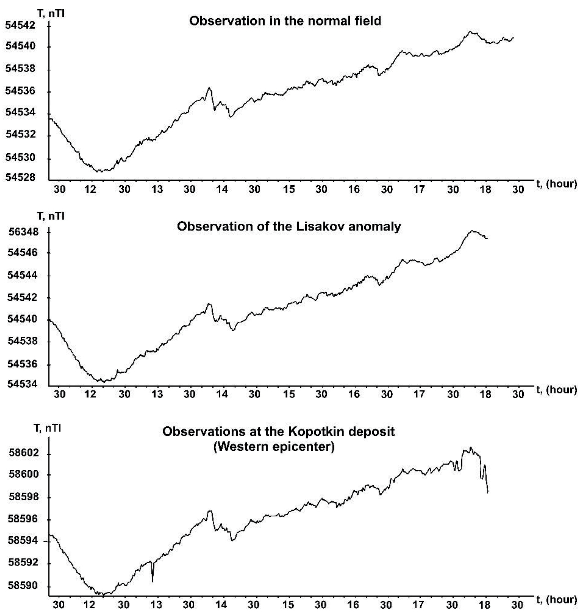

Figure 6 – Graphs showing the dependence of the magnetic field on time, constructed based on observations using the magnetic variation method.

To obtain a reliable estimate of remanent magnetization under such conditions, an integrated approach was employed, combining variation methods with logging data and modeling based on empirical measurements of the physical properties of rocks. In fact, the remanent magnetization of the ore-bearing Lisakov anomaly is negligible. This is confirmed by the calculated Q_{zk} factor derived from logging data of æ and Z_a. The actual calculated value of Q_{zk} was 0.1.

Table-2. Physical properties of rocks and ores of the Karasor-Lisakov area

Rock name	æ, 10^{-3} SI				ρ, Om*m				σ, g/sm^3				J, μR/h .		
	Quantity	min	max	average	Quantity	min	max	average	Quantity	min	max	average	Quantity	background	max
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Diorites, dioritic porphyrites	20	0	52	2,3	14	50	6600	1500	10	2,58	3,14	2,70	17	2	6
Diorites, dioritic porphyrites (ore-bearing)	12	0	65	17	12	0	3200	660	4	2,69	3,36	2,80	17	2	6
Porphyrites, andesitic	13	0	32	2,35	11	400	3900	1920	7	2,62	2,80	2,69	5	2	6
Porphyrites, andesitic (ore bearing)	8	2	38	14,4	8	150	950	690	4	2,70	3,06	2,76	5	2-3	6
Porphyrites, plagioclase, pyroxene-plagioclase	9	0	2,9	0,4	9	1400	4800	2590	9	2,57	2,74	2,68	8	2	6
Tuff of andesitic porphyrite	3	0,2	2	1,2	3	150	1250	550	-	-	-	-	12	2	9
Tuff of psammitic, aleuropsammitic	7	0	2,5	0,8	7	600	4000	2170	-	-	-	-	4	2	5
Metasomatites, albite, prenitite	10	0	30	3,4	10	720	4500	2180	10	2,64	2,82	2,70	6	1-2	4
Plagiogranite-porphyrites	10	0	10	0	10	230	4400	1230	2	2,63	2,72	2,66	10	12-19	21
Limestones	10	0	30	0	5	100	4000	2530	-	-	-	-	7	3-5	35
Magnetite ore														1-2	4
20-30%					10	10	550	188	3	3,0	3,42	3,17			
30-45%					10	1	220	660	6	3,27	4,00	3,58			
> 45%					6	0	150	18	3	4,10	4,36	4,20			

Results. The results of the geophysical investigations have been widely applied in subsequent exploration activities within the Karasor-Lisakovsk magnetic anomaly zone. They demonstrated the significant effectiveness of integrated geophysical studies in refining the direction of geological exploration, addressing the interpretation of magnetic anomalies, detecting and delineating ore bodies at depth, and identifying ore intersections within borehole sections.

Primarily, the outcomes of comprehensive borehole and field geophysical surveys at the study site enabled the differentiation of rock units based on their physical properties, which is particularly important for detailed characterization of geological structures and ore bodies. Magnetically, ore-bearing diorites, dioritic, and andesitic porphyrites are distinctly identified, exhibiting the highest magnetic susceptibility among all investigated rocks (Figure 6). This is attributed to their elevated content of magnetic minerals, predominantly magnetite, which strongly influences the magnetic field parameters. These rocks also exhibit the greatest density, reflecting their mineralogical composition and structural features.

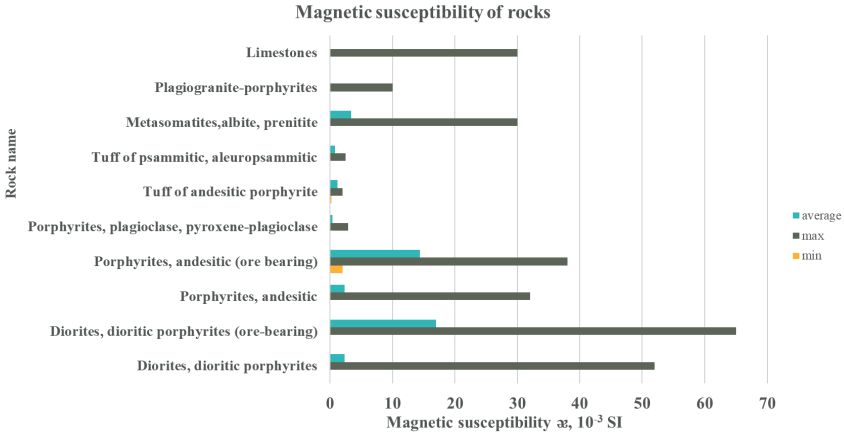

Figure 7 – Magnetic Properties of Rocks in the Karasor-Lisakov Ore District (æ, 10^{-3} SI)

In contrast, plagiogranite porphyries and limestones were found to be practically non-magnetic, exhibiting low magnetic susceptibility values. At the same time, plagiogranite porphyries are characterized by elevated natural radioactivity, with background levels ranging from 12 to 19 μR/h, which distinguishes them from other rock types (Figure 6). Such a radiometric anomaly may be associated with the presence of potassium feldspars and accessory minerals capable of accumulating radioactive elements.

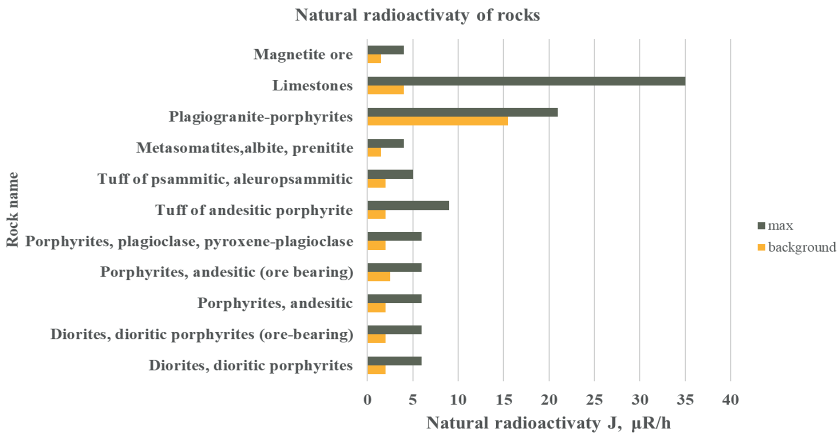

Figure 8 – Natural Radioactivity of Rocks in the Karasor-Lisakov Ore District (J, μR/h)

Based on electrical properties, limestones and plagioclase porphyrites are distinguished by their high specific electrical resistivity (ρk > 2000 Ohm·m). These rocks exhibit low conductivity due to their dense structure and lack of fracturing, which prevents the infiltration of groundwater. On the opposite end of the spectrum are andesitic tuffs, mineralized diorites, and dioritic and andesitic porphyrites, which display relatively low resistivity values, averaging around 550 Ohm·m (Figure 7). These parameters are associated with rock fracturing, increased moisture content, and the presence of sulfides and magnetic minerals.

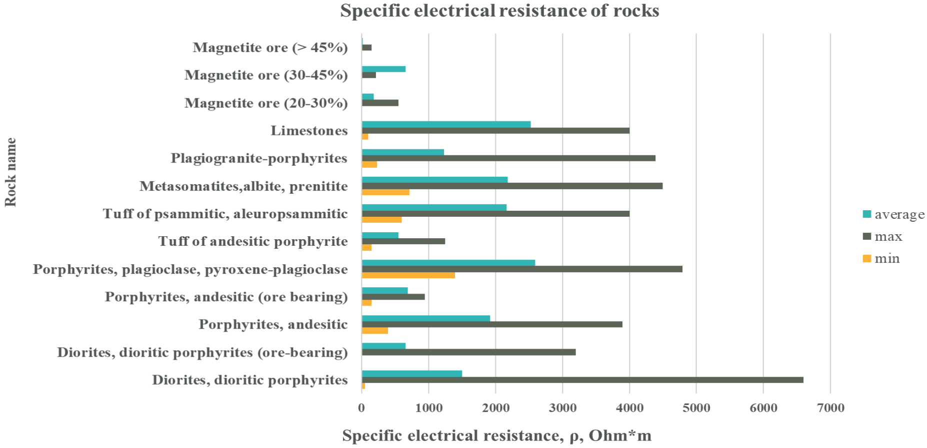

Figure 9 – Specific Resistivity of Rocks in the Karasor-Lisakov Ore District (ρ, Ohm*m)

It is important to note that rock resistivity is influenced not only by the concentration of magnetite, but also by the degree of fracturing. As a result, even weakly magnetic rocks can exhibit significant variations in resistivity. This is explained by both lithological differences and tectonic disruptions, which lead to changes in porosity and water saturation (Figure 8).

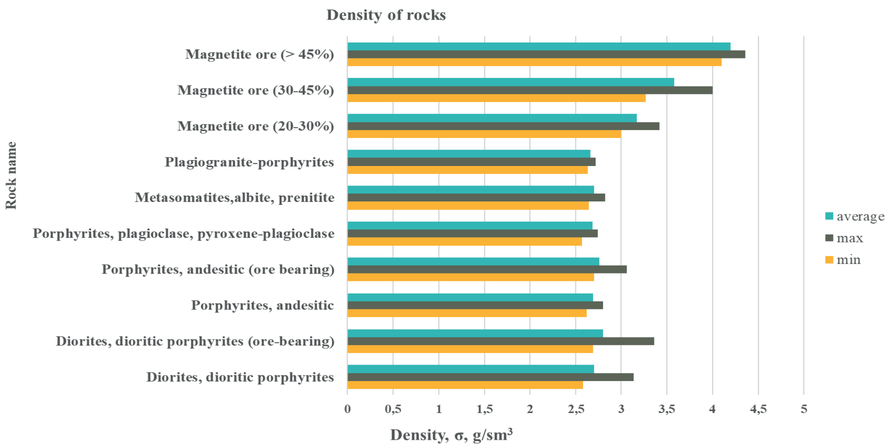

Figure 10 – Density of Rocks in the Karasor-Lisakov Ore District (σ, g/cm³)

The results of petrophysical studies formed the basis for the geological interpretation of geophysical anomalies, particularly in areas of intense magnetic anomalies within the Karasor-Lisakov zone.

On the magnetic field map (see Fig. 1), the most significant anomalous zones are concentrated in the Lisakov and Karasor anomaly regions, where magnetic induction values reach their maximum. Magnetic induction values range from 100 to 8000 nanotesla (nT). In zones with sharp changes in magnetic induction, isolines are densely spaced, nearly merging with one another. Such dense spacing indicates significant magnetic field gradients, which may signal the presence of localized ore bodies with high magnetite content or other strongly magnetized minerals (Khramov, 1982, Wang, 2015: 10, Sailymby, 2022 b: 6).

Conversely, magnetic fields with low gradients are characteristic of rocks with low concentrations of magnetic minerals or rocks lacking pronounced magnetic properties (Sailymby, 2020 a: 6, Stacey, 1972: 10).

At the Lisakov site, a gently dipping ore zone was hypothesized to occur in three levels: the upper zone at depths of 250–350 m, the middle zone at 450–550 m, and the lower zone at 700–900 m. The dimensions along dip and strike range from 500 to 1200 m. At the Karasor site, two gently dipping ore zones were preliminarily identified, each with a thickness of up to 200 m and dip lengths between 1200 and 1500 m. The upper zone is situated at depths of 200–300 m, while the lower zone lies at 700–1200 m. However, results from vertical drilling and logging did not confirm the initial assumptions regarding the morphology, occurrence conditions, and dimensions of the ore zones at these sites.

The ore nature of the Lisakov magnetic anomaly corresponds to the eponymous ore manifestation located southwest of the North Lisakov deposit. This corresponds to a magnetic anomaly measuring 700 by 500 m, with a maximum field intensity of 200 nT (Fig. 10).

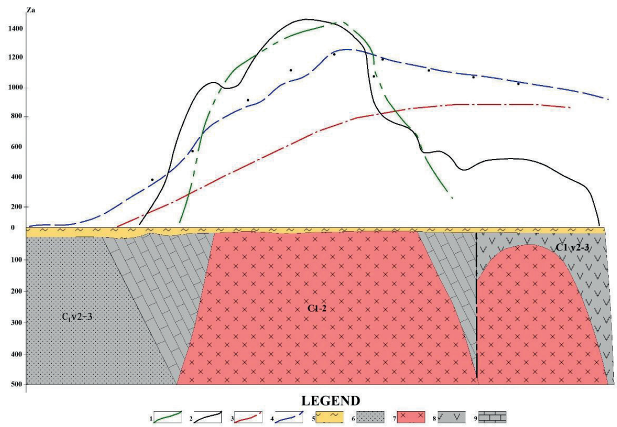

Figure 11 – Schematic geological and geophysical cross-section along line II–II at the Lisakovsk site.
1 – calculated Z_a field, 2 – observed Z_a field, 3 – regional Δg background, 4 – observed Δg field; 5 – clay, 6 – sandstone, 7 – diorite, 8 – andesitic porphyry, 9 – limestone

Previously, the anomaly was investigated using the magnetic remanence method, based on which it was classified as non-commercial mineralization and was not recommended for further verification. However, subsequent studies using the magnetic variation method revealed a variation coefficient of 7%, indicating the ore nature of the anomaly. Interpretation of ground magnetic surveys suggested that the anomaly is caused by a gently dipping ore body with an upper boundary at approximately 200 m depth and a lower boundary between 400 and 600 m. To verify the ore nature, a borehole was drilled at the epicenter to a depth of 920 m.

The drilled borehole intersected ore-grade mineralization at depths of 270–300 m, with an average iron content of 24% (Fig. 11).

The ore zone is represented by a stockwork-like body of vein and brecciated-vein magnetite ores, confined to a gently dipping zone of intensely fractured, partly crushed diorite and dioritic porphyrite rocks. Based on the character of the ground magnetic field south of the borehole, there is a possibility of an increase in the thickness of the ore body along the dip, with the lower boundary at a depth of approximately 600 m.

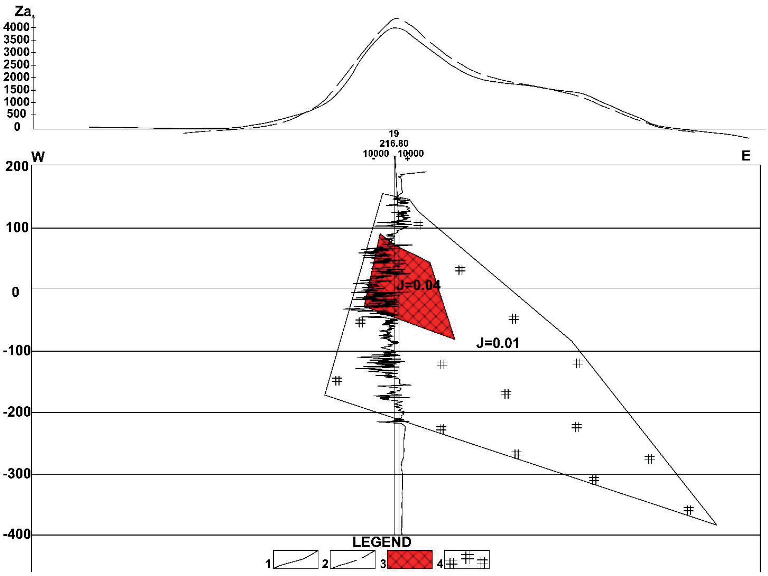

Fig. 12 – Geological and geophysical cross-section along line 15
1 – calculated Za magnetic field, 2 – observed Za magnetic field, 3 – magnetite ore zone, 4 –contour of magnetic rock distribution considered in magnetic field modeling, indicating magnetization values and average iron content in magnetite

The Karasor anomaly was detailed at a scale of 1:10,000 and investigated using the artificial magnetization method (AMM) in the vertical sounding mode, based on which it was classified as ore-bearing (Fig. 12). It is located in the southern part of the Karasor-Lisakov ore cluster and consists of two sections: northern and southern.

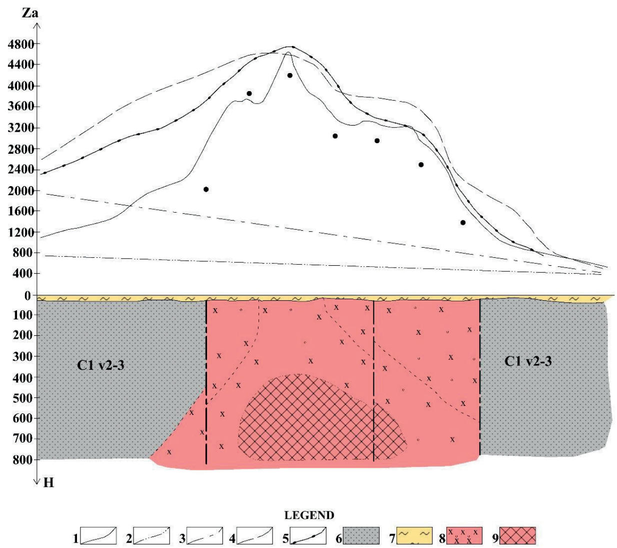

Figure 13 – Schematic geological and geophysical cross-section along line III–III at the Karasor site. 1 – observed Z_a field, 2 – calculated Z_a field, 3 – regional Δg background, 4 – anomalous Δg field, 5 – Δg derived from geological section, 6 – sandstone, 7 – clay, 8 – diorite, 9 – ore zone

According to drilling data to a depth of 505 m near the magnetic maximum of the southern section, intrusive rocks with weak vein-type magnetite mineralization were identified. Within the interval of 200–505 m, a strong lateral anomaly up to 25,000 nT was recorded, which was interpreted as an ore body located west of the borehole with a westward dip. The exposed weak vein mineralization corresponded to the eastern end of a large ore zone. Based on artificial magnetization method (AMM) results, the anomaly was assessed as prospective for the discovery of deeply seated ore bodies with high potential. Magnetic field modeling (Za) indicates that the upper boundary of the ore zone lies at a depth of 350–850 m, with a thickness of about 200 m and a westward dip of the ore body. Some ore bodies on the eastern flank may be displaced downwards to approximately 500 m by a tectonic fault. A second ore zone is predicted to the north, within magnetic epicenters of 3800–3000 nT. The depth of these ore bodies is about 450 m, with a thickness of 200–250 m, and they lie gently dipping to nearly horizontal.

Modeling results on the western and eastern flanks of the northern section indicate magnetic field undercompensation, attributed to the presence of additional ore columns—one intercepted by a borehole with an upper boundary at around 300 m, and a second hypothesized with an upper boundary at approximately 200 m (Fig. 13). Based on these data, all ore zones of the Karasor anomaly, as suggested by geophysical data, gradually deepen towards the east.

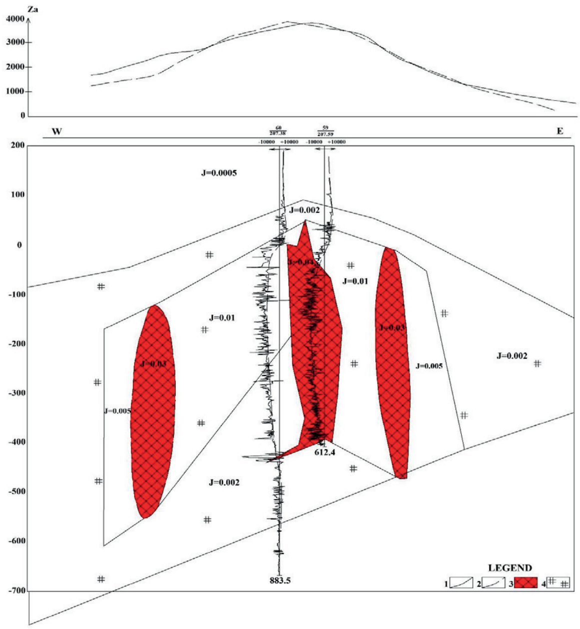

Figure 14 – Geological and geophysical cross-section along line 11
1 – calculated Za field, 2 – observed Z_a field, 3 – magnetite ore zone, 4 – contour of magnetic rock distribution identified during magnetic field modeling, indicating magnetization values and average iron content in magnetite

The results of the magnetic logging confirmed the presence of anomalous zones with elevated magnetic susceptibility, which allowed for the determination of the distribution of magnetic minerals in the section and a quantitative assessment of their content.

Due to changes in the conditions of ore body occurrence and shape, inclined drilling was applied to enhance the efficiency of exploration activities. The effectiveness of inclined drilling was demonstrated by a well drilled in the South Lisakov anomaly area, which revealed steeply dipping ore bodies previously undetected by vertical drilling. Prior to this, nine vertical wells had been drilled without encountering commercial ore bodies (Fig. 14).

Inclined wells intersected the ore zone of the Karasor anomaly, confirming the results obtained by the Artificial Magnetization Method (AMM) and the quantitative interpretation of magnetic anomalies.

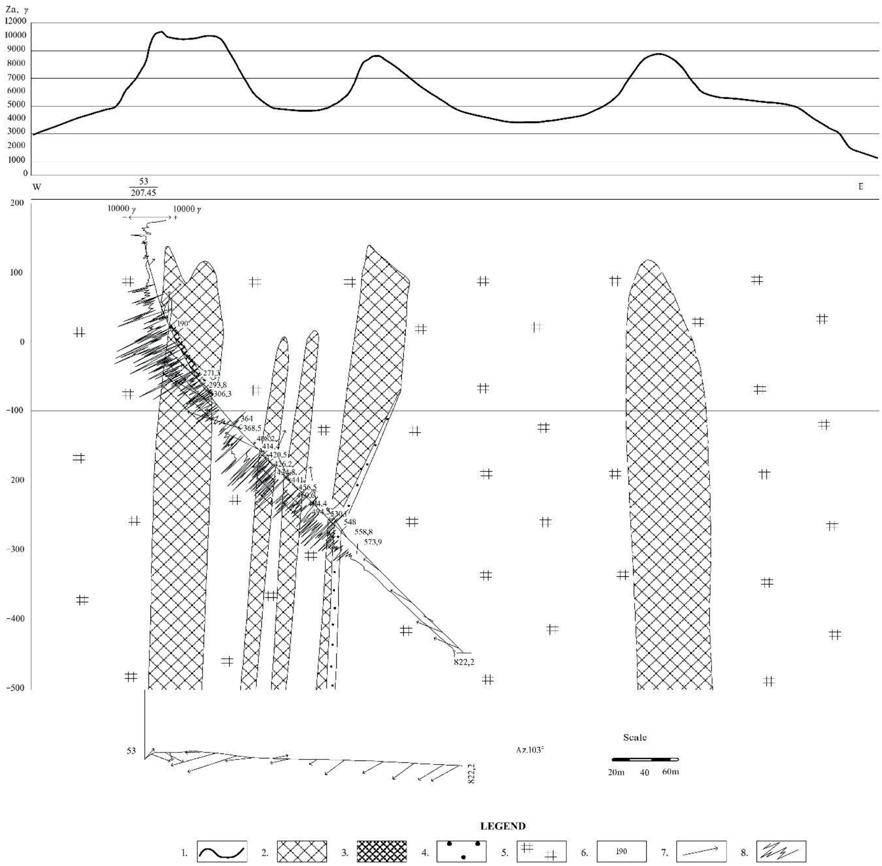

Figure 15 – Geological and geophysical cross-section of the South Lisakov anomaly
1 – Anomalous field curve, 2 – profile line, 3 – ore bodies, 4 – boreholes, 5 – contour of magnetic rock distribution identified during magnetic field modeling, indicating magnetization values and average iron content in magnetite, 6 – contour lines, 7 – section line, 8 – dip direction

According to data obtained from boreholes drilled at the Kopotki deposit, iron ore contours were identified within the geological section (Figure 15-16). In Borehole No. 102, within the depth interval of 302–456 meters, the iron concentration reached 44.04%, which is considered relatively high. Data from Borehole No. 8 were divided into several depth levels:

- At a depth of 93–142 meters, the iron concentration was 28.95%.
- At a depth of 194–207 meters, it was 23.51%.
- At a depth of 213–232 meters, it reached 31.39%.

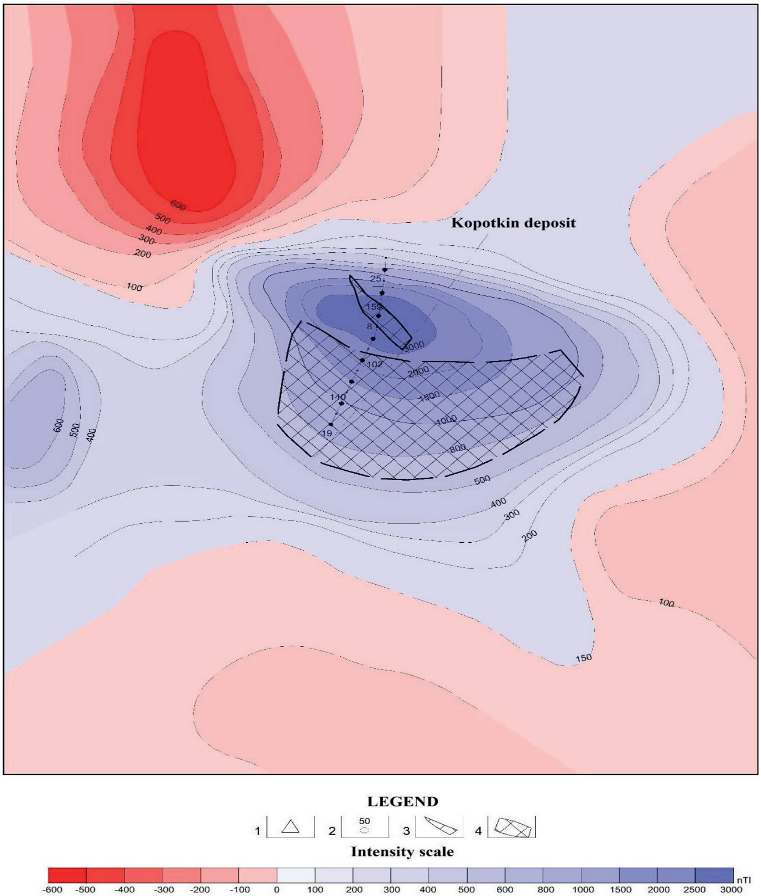

Figure 16 – Isodynamic map of the magnetic field of the Kopotkin deposit. Scale 1:5000
1 - Geomagnetic field control points, 2 – boreholes, 3 - Ore body contour obtained by drilling, 4 - Additional ore body contour obtained from geophysical data.

These results reflect the characteristics of iron distribution within the deposit and the variation of its content at different depths. The obtained data are crucial for assessing ore quality and developing an effective processing strategy.

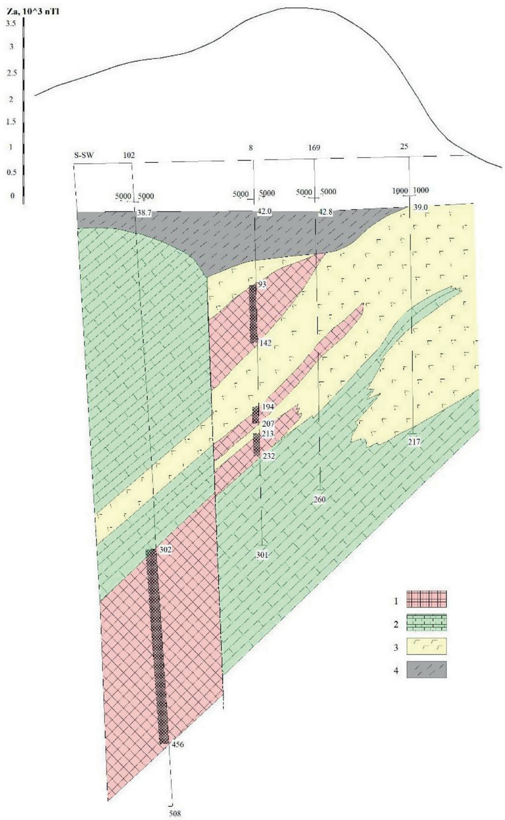

Figure 17. Geological cross-section of the Kopotki deposit. Scale 1:2000
1-Magnetite iron ores, 2- limestone, 3- basaltic porphyrites, 4-clay

Discussion. The geological and geophysical investigations have confirmed the ore-bearing nature of the Lisakov and Karasor anomalies. These targets have been recommended for verification through drilling. Within specific areas of the Karasor-Lisakov anomaly group, the extent of ore zones has been delineated, and the morphology and depth of ore bodies have been identified. The application of magnetic susceptibility logging and gamma-gamma logging enabled the prediction of iron content within the ore bodies. The magnetic variation method corroborated the ore-bearing character of the Lisakov and Karasor anomalies and formed the basis for recommending further drilling investigations of these ore targets.

The cases considered demonstrate the high effectiveness of integrated geological and geophysical studies at iron ore deposits formed under diverse structural and geological localization conditions.

The results obtained represent a significant advancement in geological exploration activities and provide a foundation for forecasting prospective ore-bearing areas of iron ores throughout the Kostanay iron ore belt.

Conclusion. The results of the conducted studies confirm the promising potential of the magnetite ores in the Karasor-Lisakov region, supporting the consideration of this area as a strategic target for further exploration and development. The integrated approach applied to the analysis of geophysical and geological data at the iron ore deposits of Northern Kazakhstan enables the determination of the morphology and deep distribution of ore bodies, as well as the acquisition of their petrophysical characteristics, which is especially important for planning subsequent exploration and mining operations.

The primary advantage of utilizing geophysical data lies in its high efficiency in refining the direction of geological exploration efforts, significantly reducing the volume of non-target investigations and optimizing the study of prospective areas.

Borehole geophysical methods played a crucial role in elucidating the nature of magnetic anomalies, allowing for a more precise geological interpretation and reliable identification of ore bodies. Furthermore, the use of geophysical data made it possible to accurately delineate ore body contours and identify ore intersections within borehole sections and inter-well spaces, substantially enhancing the quality of drilling data analysis.

These studies provide a solid scientific and practical foundation for refining ore body boundaries and developing strategies for further development of deposits at late stages of exploitation, thereby ensuring the efficient utilization of Kazakhstan's natural resources.

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