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Geophysical survey at the southern end of the Degtyarsky pyrite deposit

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Abstract

Research aim *is to study features peculiar to geophysical fields over the main geological features of the southern part of the Degtyarsky pyrite deposit at the Middle Urals.*

Methodology. *Electromagnetic survey included symmetrical electric profiling (SEP) with ERA-MAX equipment (ERA Research and Production Enterprise, St. Petersburg) and rapid audio-magnetotelluric sounding (ATMS) with OMAR-2m wideband receiver (Institute of Geophysics UB RAS, Ekaterinburg). Magnetic survey was carried out with the help of the proton procession magnetometer GSM-19T (GEM Systems, Canada), gamma field survey was carried out with a survey meter SRP-68-01 (Electron, Zhovti Vody).*

Results. *According to the results of observational analysis, high-quality sections of electrophysical parameters of the environment were constructed at the parametric profile together with the charts of other geophysical fields. The studies have shown significant changes of resistivity and potential fields anomalies over various geological features of the ore field.*

Summary. *Geophysical indications of border line of the main geologic features have been determined. Excessive electrical conductivity of ore control tectonic structures and radiation anomaly have been revealed in the promises of the ore body, which can serve a prospecting criterion for a similar ore body. Geophysical results are well within the existing geological data on the Degtyarsky mine.*

Key words: *integrated geophysical survey; pyrite deposit; audio-magnetotelluric sounding; distributed fault; ore field.*

Introduction. The discovery of such deposits as New-Uchalilnsky, Safianovskoe, Parnokskoe, Vorontsovskoe, and a number of other deposits testifies to the high potential of Ural subsoil. However, since the 1990s in the Urals, just as throughout Russia, no ore deposits of any real significance have been found, causing dramatic reduction in prospecting including total abolishment of additional site exploration of areas at a scale of 1: 50 000 (ASE-50) with general prospecting [1]. The reserve of explored mineral resources, including non-ferrous metals, reduces. Production growth rate of a number of metals has significantly exceeded growth rate of their mineral base. In order to reproduce the stock of copper it is required to discover new copper-sulphide and porphyry copper deposits. Some specialists reckon that even a limited set of geological and geophysical operations conducted in traditional ore districts may result in the discovery of new large deposits in the Urals [2]. That is why studying features of well-known ore districts, including their geographical fields, can provide valuable information for successful field prospecting in the conditions of reduced financing. The Degtyarsky deposit, which is the field under investigation, is the largest copper-sulphide deposit in the Middle Urals. The main aim of the research is integrated geophysical study in the southern part of the field along the east-west line crossing main geological features of the Degtyarsky ore field.

Research object. The Degtyarsky pyrite deposit has been known since 1888. At first, brown iron had been mined at that site; in 1906 sulphide ore was discovered underneath. The deposit is situated at the narrowest part of the Tagil-Magnitogorsk through and is represented by one ore body deposited in the hanging side of the Serov-Mauksky fault. The pyrite bed is accordant with the host volcanogenic and volcanogenic-sedimentary rock of the degtyarsk formation. In the west, the deposit contacts the tuffaceous sandstones, and it contacts quartz-sericite and quartz-chlorite-sericite schist saturated with pyrite impregnation in the east. Volcanogenic-sedimentary rock are of rhythmical structure, and geochemical and ore zoning give evidence of the ore hosting formation being fallen back westwards. Rock is penetrated with the bodies of rhyolites and forms a monoclonal structure which borders serpinites in the west and gabbro and plagiogranites of the Novoalekseevsky mass in the east. The ore body is complicated by swells, bendings and lateral shifts; it is about 5 km in length with the average thickness of 11 m; submeridional strike is accordant with the schistosity of the host rock; seam pitch at an angle of 55°–90°. Pyrite ore of the deposit are of two main types: massive and impregnated. To the main ore minerals refer pyrite, chalcopyrite and sphalerite [3]. Ore outcropping is represented by the limonites of oxidation zone or gossan. It is usually covered with diluvial deposits several meters in thickness. Vertical thickness of the gossan itself makes up 10–20 m and up to 25 m in the central part of the field. A layer of fine pyrite (3–5 m) is bedded underneath, which gradually develops into dense pyrites. The Degtyarsky deposit has been mined with underground method from 1914 to 1995. Before mine closure eight shafts were caved in, and four shafts stood. In the beginning of the 21st century the gossan between Kapitalnaya-1 and Kapitalnaya-2 shafts was cleared by an open pit.

Research methodology. When prospecting for conductive ore, electromagnetic methods of geophysical survey are most effective. In order to study the geoelectric structure of the pit, audio-magnetotelluric sounding (ATM) was applied, which had proved itself at middepths [4–6]. Field observations with the method of ATM were carried out with a 2-channel universal receiver OMAR-2m developed in the Institute of Geophysics UB RAS [7] and wideband sensors for electromagnetic signals. Measurements were taken within 3 minutes in frequencies from 100 to 16 000 Hz with 50 m interval. To record the horizontal component of a magnetic field H_x, active induction sensor was used with a linear frequency response and variable sensitivity. Electric component E_y was measured with the help of a nonsymmetrical capacitive line and the preamplifier. The ratio of the signal electric component amplitude and the orthographic magnetic component determines the impedance of the medium $Z = E_y / H_x$ which is proportional to electric resistance of rock. Measurement results are represented as a parameter calculated through the module of the input impedance and being equivalent to the apparent resistance [8]:

$$\rho_t = \left(1/2\pi\, f\mu\right)\cdot|\, Z\,|^2,$$

where f is the frequency of electromagnetic field, Hz; $\mu \approx \mu_0 = 4\pi\cdot 10^{-7}$ – magnetic permeability of the environment, H/m.

The calculation of the medium impedance frequency dependence was made transversally: $Z(f) = E_y(f)/H_x(f)$. Laboratory investigation of audio-magnetotelluric data included the following operations:

– filtration of industrial noise;

– obtaining frequency spectra based on fast Fourier transform;

– renewing genuine amplitudes of signals with the account of frequency characteristics of measurement channels and signaling sensors;

– determining the longitudinal impedance of the medium $Z(f)$;

– calculation of apparent resistivity and obtaining frequency curves $\rho_t(f)$;

– transformations of frequency curves into the deep-seated resistivity section $\rho_t\ (h)$ with the help of a particular transformation algorithm [9];

– recalculation and construction of effective lateral conductivity S_{eff} section.

These schemes make it possible to determine the character of electrophysical properties distribution by depth and singling out local anomalous objects.

In order to qualitatively and quantitatively compare electrophysical parameters, electrical exploration by the resistivity method was also made. It included symmetrical electric profiling (SEP) along the profile with the pace of 25 m and vertical electric sounding (VES) in particular points. Measurement were made with the help of an apparatus set ERA-MAX (ERA Research and Production Enterprise, St. Petersburg) at the frequency of 4.88 Hz according to the standard observation technique [10].

Magnetic survey was carried out with the help of the proton procession magnetometer GSM-19T (GEM Systems, Canada). The measurement of the full vectors of the main magnetic field (T) was made with the closure of the profile on the checkpoint (CP) without using magnetic-variation stations. Together with magnetic measurements, geodetic tie with the help of DGPS built-in module was made. Exposure rate survey of a gamma field was carried out with a survey meter SRP-68-01 (Electron, Zhovti Vody). Magnetic and radiation field survey interval was 10 m.

Research results. The research profile 1 m long was situated at the southern section of the Degtuarsky deposit not far from the closed down Komsomolskaya shaft. Profile marking has been made in the east-west direction transverse to the strike of the main geological features. The head of the profile is built up with the formations of the zuzelsky formation (O_3–S_1zz), which falls into the rock complex of the Tagilsky trough. The profile then crosses the zone the of the Serov-Mauksky fault with the polymictic mélange followed by the volcanogenic sedimentary rock of the Degtyarsk formation (D_2?dg) of the East Uralian Rise (*Kalugina R. D., Kopanev V. F., Storozhenko E. V., et al. Public geological map of the Russian Federation. Scale 1 : 200 000. 2nd edition. The Middle Urals series. Map sheet O-41-XXV. Explanatory note. Moscow: Moscow branch of the FSBI A. P. Karpinsky RGRI; 2017*).

The frequency of the audio-magnetotelluric sounding makes it possible to acquire the information about the pit at the depth of ten to several hundreds of meters. Electric profiling mainly reflects the properties of the upper part of the pit. The quantitative information on the resistivity of the original rock and loose deposits is obtained from the data of the center-pot vertical electric sounding. The features of the geoelectric structure of the pit are conditioned by diverse resistivity of rock; at the same time, electrical resistances can vary within one layer. An important role here is played by: the hydrothermal alterations, scattered sulphide impregnation, rock jointing and moisture content together with the pore moisture mineralization. The thickness of the crust of weathering makes up from 1 m in the beginning of the profile to 23 m in the area of the Serov-Mauksky fault. The superficial deposits containing clay are distinguished by the lowest values of the specific resistances (12–25 Ohm · m), comparable with the resistivity of ore (5–30 Ohm · m). At the growth of the sand and crushed stone fraction, loose rock resistances may grow up to 100–200 Ohm · m and higher. Original rock has much higher electrical resistances characterized by a wide scatter of values, from 150–200 Ohm · m to 5000–10 000 Ohm · m (fig. 1).

The territory of the Degtyarsky ore field has been studied by a number of geologists, so the main features of geological structure along the profile are well known in details.

The comparison of reliable data available [11] with the results of the geophysical study made it possible to specify the character of the tectonics and the main border lines of the main geological features. The research profile starts in the upland representing the dike of the gabbro-dolerites (Sta.0– Sta.15), distinguished by the profile's highest resistivity (4000–10 000 Ohm · m). They are followed by the co-magmatic basalts (Sta.15– Sta.30) with the resistance changing depending on the jointing from 500 to 3000 Ohm · m. The zone of fracture of the Serov-Mauksky fault (Sta.30– Sta.40) is distinguished by the lowest values of resistivity (50–200 Ohm · m), the fault's east dip at the angle of about 70° is determined precisely enough. Specific resistances of the zone of mélange (Sta.40–Sta.64) vary within the range of 300–2000 Ohm · m; at the same time, the serpentinites (Sta.52–Sta.64) determined with the help of magnetic survey (fig. 2, *a*) have the increased values of resistivity (1000–2000 Ohm · m).

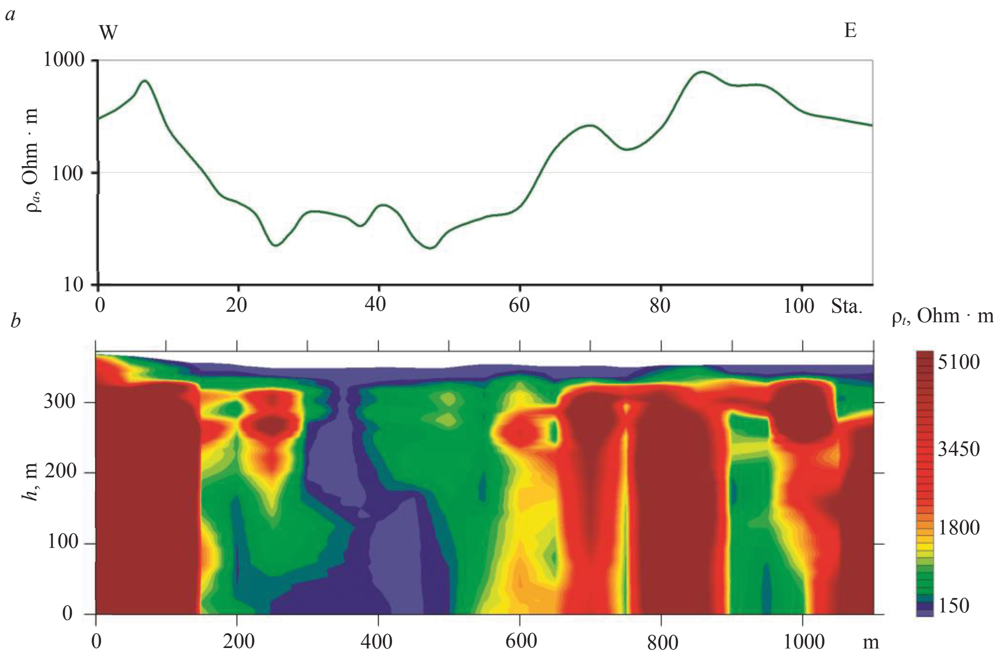

Fig. 1. The results of electrometric studies on the southern profile of the Degtyarsky site: a graph of apparent resistance according to the data of symmetrical electric profiling – *a*; a transformed section of audio-magnetotelluric soundings – *b*

Рис. 1. Результаты электрометрических исследований по южному профилю Дегтярского участка: график кажущегося сопротивления по данным симметричного электропрофилирования – *a*; трансформированный разрез аудиомагнитотеллурических зондирований – *b*

The outcropping of the ore body is timed to the waterlogged lowland and is situated within Sta.64–Sta.65 interval; at the present time the swamp is almost completely filled with the waste of the lime industry. At the geoelectric section the ore zone is not marked out as soon as the deposit has been fully-developed, and the underground mines have been caved in and stowed. However, at Sta.75 station, a vertical low-impedance anomaly is recorded, which is traced all the way down to the depth of sounding. It is associated with a disjunctive fault which can be considered base fault. According to the data from mine documents, it is a thrust faulting which cuts the ore body with displacement up to 10–15 m and which is typical for the central and southern parts of the deposit. Host rocks here are tuffstones and quartz-sericite shales (Sta.65–Sta.90), further followed by quartz-epitode-chlorite and chlorite- sericite shales (Sta.90–Sta.105); tuffstones are at found the end of the profile again. Resistivity of rock of the degtyarsky formation are rather consistent and make up 3000–8000 Ohm · m. Apparently, rock contact in and around Sta.88–Sta.90 is tectonic as soon as it is accompanied by a vast anomaly of reduced resistances which points to its intense jointing. It is well-known that tectonic faults are distinguished by increased electrical conductivity [12] because of the porosity extended by the joint and their saturation by water. The form of the abnormally conductive zones is observed best of all at the section of effective lateral conductivity (fig. 2, *b*).

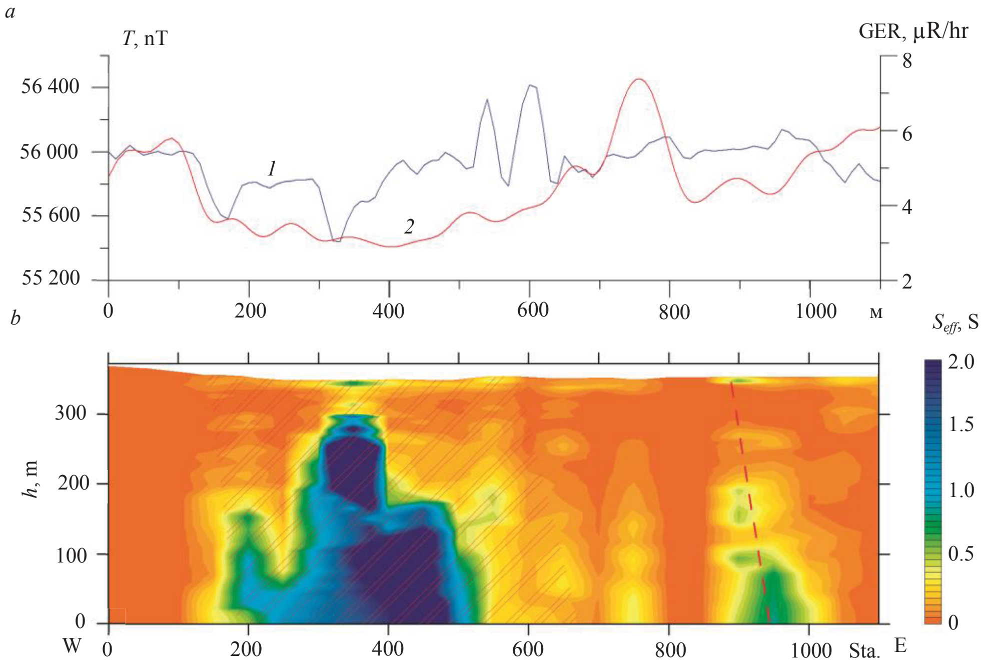

Fig. 2. Results of geophysical work on the southern profile of the Degtyarsky site: plots of magnetic (*1*) and radiation (*2*) fields – *a;* section of the effective longitudinal conductivity – *b*. The diagonal hatching marks the zone of influence of the regional fault, the dashed line indicates the tectonic contact

Рис. 2. Результаты геофизических работ по южному профилю Дегтярского участка: графики магнитного (*1*) и радиационного (*2*) полей – *a*; разрез эффективной продольной проводимости – *b*. Диагональной штриховкой выделена зона влияния регионального разлома, пунктирной линией – тектонический контакт

The mentioned tectonic contact (Sta.88–Sta.90) thus has east dip at the angle of 80° and is characterized by electrical conductivity up to 1 S. The most conductive feature of the site is the Serov-Mauksky fault, effective lateral conductivity of which makes up 1.0–6.5 S.

The results of other geophysical surveys are supplemented by the sections of electrometric parameters. As it has already been mentioned, magnetic survey allowed marking out the scope of serpentinite distribution (Sta.52–Sta.64) with anomalies ΔT up to +400 nT. Fault zone is characterized by reduced values of the magnetic field (ΔT = –100...–300 nT), with a negative anomaly at the axis of the tectonic fault (ΔT = –600 nT). Contact at Sta.15 and Sta.105 register themselves by the cascade drop of the field and local minima at the border lines. Radiometry, despite the low intensity of gamma rays, clearly differentiates the complexes of rock of the Tagilsky and East-Uralian megazones by the levels of the natural background. Minimum values of gamma field exposure rate are timed to the zone of the regional impact of the Serov-Mauksky fault. Positive radioactive anomaly is observed in the area of the ore body over the “base” disjunctive fault. The possible reason can be the metasomatic study of the tectonic fault and natural radioactive elements addition.

Summary. Qualitative and quantitative geophysical characteristics of a large copper-pyrite deposit of the Middle Urals are obtained as the result of the research. The research has shown significant variation of resistivity and the anomalies of potential fields over various geological features of the ore body. Geophysical indications of border line of the main geologic features have been determined. Excessive electrical conductivity of ore control tectonic structures and radiation anomaly have been revealed in the promises of the ore body, which can serve a prospecting criterion for a similar ore body. Geophysical results are well within the existing geological data on the Degtyarsky mine.

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Геофизические исследования на южном окончании Дегтярского колчеданного месторождения

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Реферат
Цель работы *– изучение характерных особенностей геофизических полей над основными геологическими структурами южной части Дегтярского колчеданного месторождения на Среднем Урале.*
Методология. *Электромагнитные исследования включали симметричное электропрофилирование (СЭП) с аппаратурой ЭРА-МАКС (НПП «ЭРА», г. Санкт-Петербург) и экспресс-вариант аудиомагнитотеллурических зондирований (АМТЗ) с широкополосным приемником ОМАР-2м (ИГФ УрО РАН, г. Екатеринбург). Магниторазведочные работы выполнены с помощью протонного магнитометра GSM-19T (GEM Systems, Канада), съемка гамма-поля проведена пешеходным радиометром СРП-68-01 («Электрон», г. Желтые Воды).*

Результаты. *По результатам обработки наблюдений на параметрическом профиле построены качественные разрезы электрофизических параметров среды и графики других геофизических полей. Проведенные исследования показали значимые изменения удельных электрических сопротивлений и аномалии потенциальных полей над различными геологическими структурами рудного поля.*

Выводы. *Определены геофизические признаки границ раздела основных геологических объектов. Выявлена повышенная электропроводность рудоконтролирующей тектоники и радиационная аномалия в районе рудного тела, что может являться поисковым критерием на сходное оруденение. Результаты геофизики хорошо согласуются с имеющейся геологической информацией по Дегтярскому руднику.*

Ключевые слова: *комплексные геофизические исследования; колчеданное месторождение; аудиомагнитотеллурические зондирования; зона разлома; рудное поле.*

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