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РЕЗУЛЬТАТЫ ИНТЕРПРЕТАЦИИ ДАННЫХ МАГНИТОРАЗВЕДКИ НА ЗОЛОТОРУДНОМ МЕСТОРОЖДЕНИИ КАРЦ-СУЛЬФИДНОГО ТИПА

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THE RESULTS OF INTERPRETATION OF MAGNETIC EXPLORATION DATA AT A QUARTZ-SULFIDE GOLD DEPOSIT

Introduction

Magnetic exploration is of great importance in the study of gold deposits due to the presence of ferromagnetic minerals in the composition of productive mineralized zones (pyrrhotite, magnetite). But, as a rule, the long history of the formation of any ore gold deposit, which includes several stages of geodynamic development, metamorphic and hydrothermal-metasomatic evolution of rocks impose their own characteristics of the manifestation of deposits in regional and local magnetic fields. In this regard, there is an urgent question of the need to combine geological, geochemical and petrophysical research results with field magnetic exploration data for a correct understanding of the nature of anomalies and their interpretation.

Using the example of the Blagodatnoye gold-quartz-sulfide deposit, which is part of the Central Block of the Yenisei Ridge, the reason for the heterogeneity of the productive mineralized zone is shown from the standpoint of the chemistry of pyrite-pyrrhotite paragenesis and pyrrhotite of two syngonies: monoclinic and hexagonal.

Magnetic anomalies: structure, nature and connection with gold mineralization

Due to the presence of pyrrhotite, the only ferromagnet in the ores of the mineralized zone, its rocks have increased magnetic susceptibility (c) and create DT anomalies. It is believed that the magnetic susceptibility of rocks of the studied area is proportional to the concentration of pyrrhotite in them [1].

The amplitudes of magnetic anomalies in the ore zone consistently decrease from 500 to 80 nT against the background of non-magnetic host rocks. The site with the highest amplitude anomaly of its northwestern flank directly borders the non-anomalous site (Fig. 1). Magnetic heterogeneity can also be traced in the deep horizons of the deposit (Fig. 2). In the direction of the fall of ore bodies, an increase in the magnetic susceptibility (c) of rocks is observed. Gold mineralization is concentrated in ores with anomalous c, but not in the most magnetic ones [2].

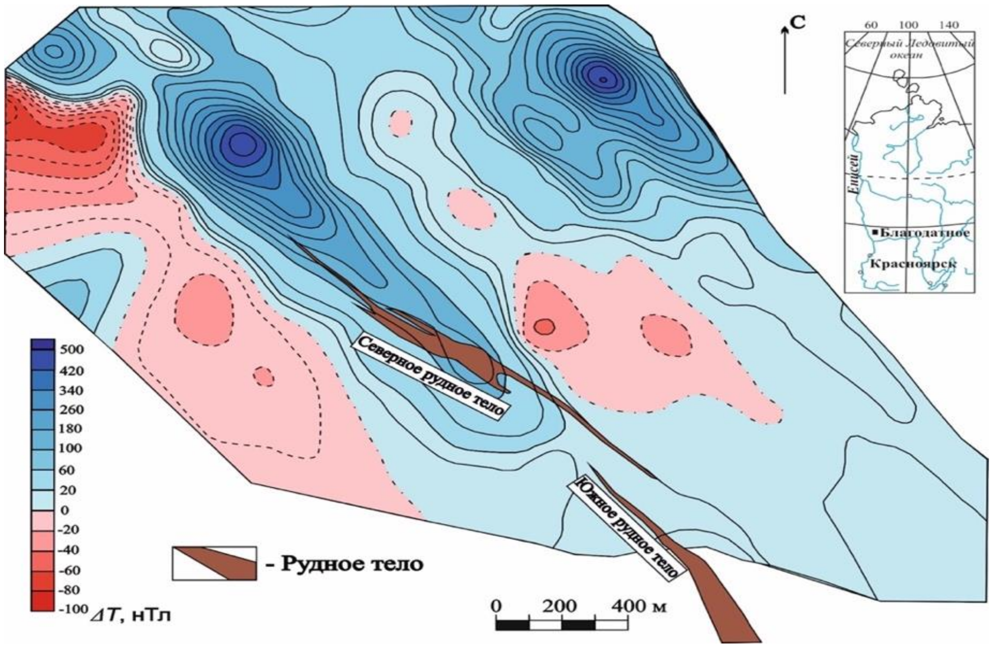

Figure 1. Map of the magnetic field ΔT of the Blagodatnoye deposit [3]

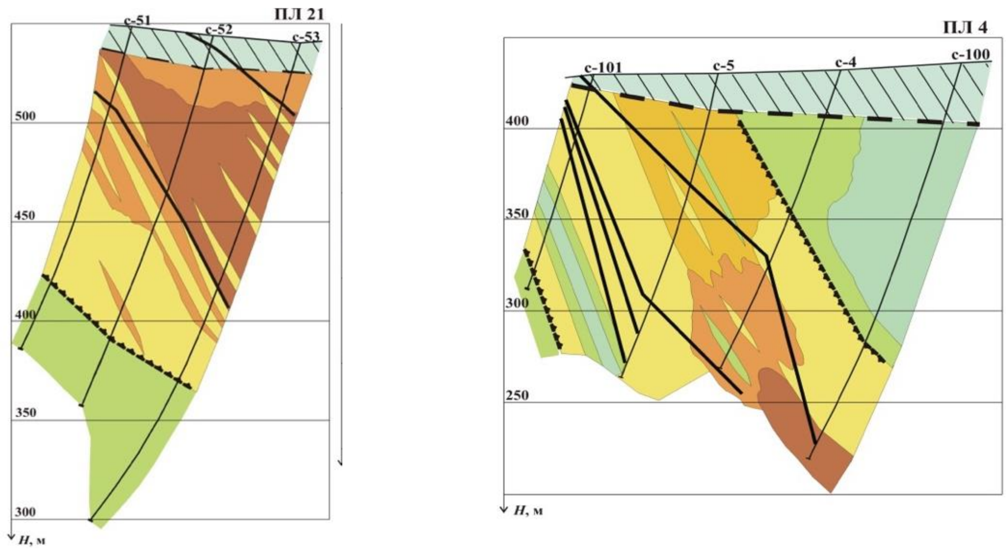

Figure 2. Petromagnetic sections of ore bodies [3]

In the course of geological and geophysical studies at the deposit, the chemical compositions of pyrite and pyrrhotite in pyrite-pyrrhotite and arsenopyrite-pyrite-pyrrhotite parageneses and the magnetic properties of the latter were studied in detail [1].

Among pyrrhotines, monoclinic and hexagonal modifications (with a wide range of Fe/S ratios in both) are found, the formation of which occurs under various physico-chemical conditions. Monoclinic pyrrhotites belong to the class of ferrimagnets and have magnetic properties that vary depending on their composition, hexagonal pyrrhotites are antiferromagnets, they are non–magnetic (Fig. 3).

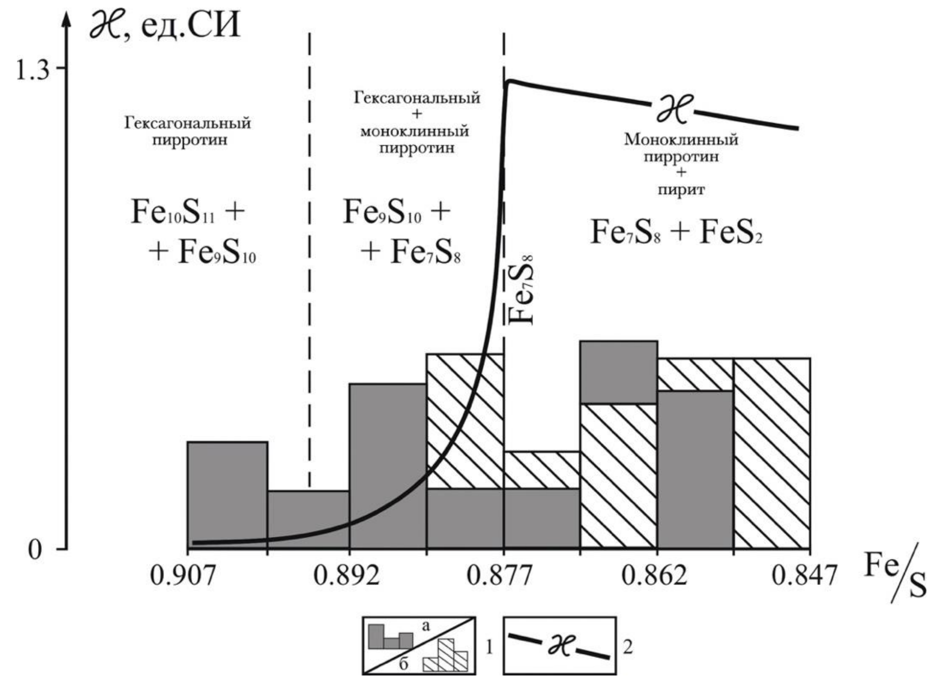

Figure 3. Chemical composition of pyrrhotines of ore bodies of the Blagodatnoye deposit, phase relations in the Fe-S system and magnetic susceptibility of natural pyrrhotines (1 – pyrrhotines of the northern (a) and southern (b) ore bodies; 2 – schematic diagram of the magnetic susceptibility of pyrrhotines)

The ferrimagnetism of monoclinic pyrrhotines is explained by the presence and orderly distribution of iron ion vacancies in the mineral structure. The ordering consists in the alternate distribution of iron layers with vacancies (layer B) and without them (layer A) (Fig. 4).

The antiferromagnetic interaction between the layers becomes not fully compensated, which leads to the appearance of ferrimagnetism. The theoretical saturation with ordered vacancies, taking into account the balance of charges, is expressed by the formula:

$$[Fe^{2+}_{0.5}](Fe^{3+}_{0.5-3\delta}\square_{\delta})S^{2-} \quad (1)$$

where [] and () are sublattices A and B, respectively, and are vacancies [4].

The theoretical saturation value δ (0.125) is in good agreement with the value δ (1/7 or 0.142) of natural "pure" monoclinic pyrrhotite with the stoichiometric formula Fe_7S_8. At δ > 1/7, pyrite formation begins. The rightmost region in the pyrrhotite compositions (Fig. 3) is considered as a solid solution of "pure" monoclinic pyrrhotite and pyrite, the decrease of which occurs with an increase in the proportion of pyrite

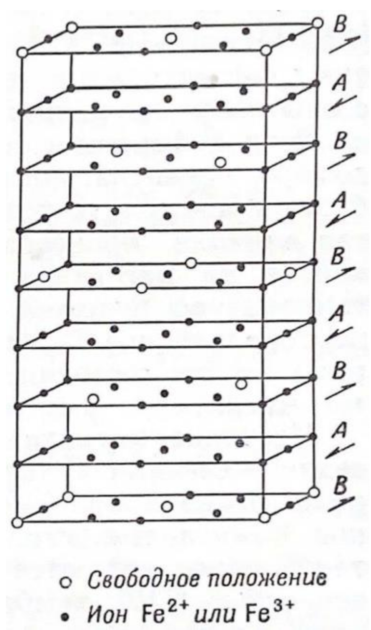

Figure 4. The position of vacancies in the pyrrhotite structure (according to Bertout)

mineral. The transition region is considered as a solution of hexagonal and monoclinic pyrrhotides.

The vast majority of hexagonal pyrrhotites were selected in the northern ore body at its deepest horizons. Monoclinic pyrrhotites and pyrrhotites of the transition zone, which are as close as possible to monoclinic ones, are mainly found in the southern ore body (Fig. 1, 2).

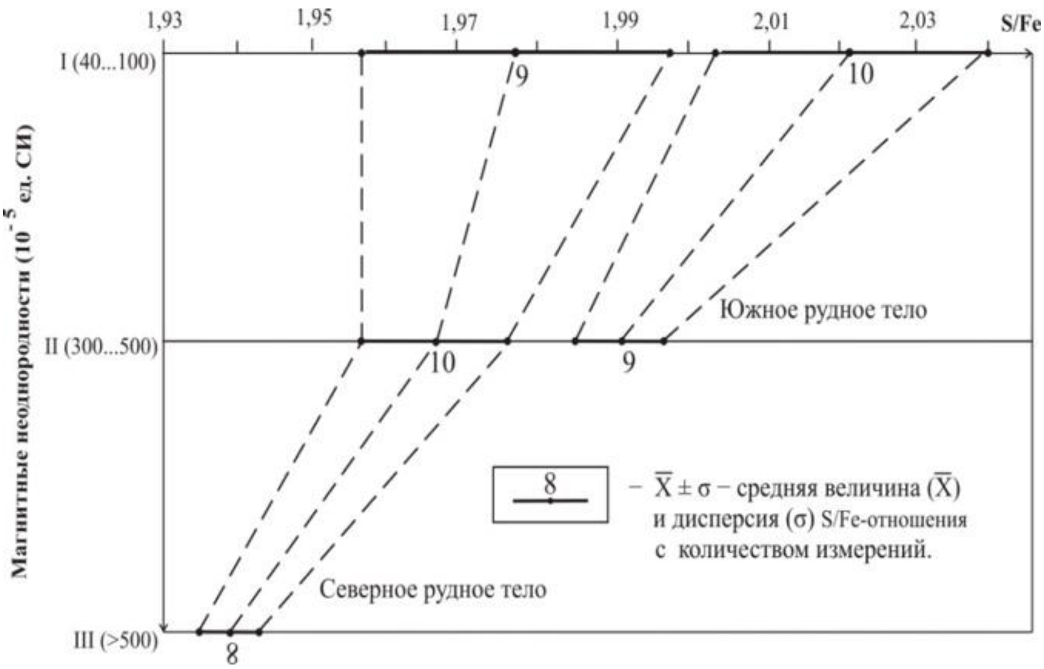

Figure 5. Stoichiometry of pyrites in magnetic inhomogeneities of sulfide parageneses [2]

The temperature in the Fe-S-O-H_2O system is the most important factor of phase equilibrium in pyrite-pyrrhotite paragenesis. Variations in the compositions of pyrite and pyrrhotite can be considered as indirect indicators of the temperature of hydrothermal solutions. An increase in the S/Fe ratio in pyrite directly correlates with its amount in pyrite-pyrrhotite paragenesis, which is due to an increase in sulfur fugitivity against the background of a decrease in temperature. On the contrary, an increase in temperature and, as a result, suppression of sulfur sulfide activity is more favorable for pyrrhotite crystallization. Along with the shift of equilibrium towards pyrrhotite, the proportion of pyrite mineral in its very composition decreases, and it approaches stoichiometrically "pure" monoclinic pyrrhotite Fe_7S_8 – its maximum magnetic phase. Hexagonal pyrrhotites are a higher temperature modification than monoclinic ones.

A decrease in the stoichiometric ratio of pyrites by the fall of ore bodies, the dominance of pyrrhotite in sulfide paragenesis and an increase in magnetic susceptibility suggest a higher temperature of the mineral-forming system at its lower horizons. The growth of the χ and amplitude of the ΔT anomaly in the northwestern part of the ore-bearing zone is interpreted by deepening the level of its erosive section. Where the maximum temperature was reached, non–magnetic hexagonal pyrrhotite crystallized, which explains the close connection of the magnetic site itself with the non-magnetic one (Fig. 1).

Gold migration in hydrothermal solutions with sulfide sulfur is carried out in the $AuHS^0$ and $Au(HS)_2^-$ complexes. The accumulation of Au in medium- and low-magnetic ores is caused by an increase in the activity of sulfide sulfur with a decrease in temperature, its mass binding in pyrite and arsenopyrite, and the destabilization of $AuHS_0$ and $Au(HS)_2^-$ [5].

Conclusion

The magnetic heterogeneity of the Blagodatnoye deposit is due to the distribution and composition of pyrrhotides in gold-sulfide parageneses of the mineralized zone. The most magnetic are the root sections of ore bodies with the widest possible distribution of stoichiometrically "pure" monoclinic pyrrhotite Fe_7S_8, which is replaced in the sub-ore zone by a non-magnetic hexagonal modification. The main gold reserves are concentrated in medium- and low-magnetic ores.

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