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# Geological and geophysical interpretation of induced-polarization data on gold depoits in the Yana–Kolyma orogenic belt

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## Abstract

This paper presents induced-polarization (IP) data on a number of gold deposits and occurrences in the Magadan Region. Geophysical works are effective for the study of gold-quartz deposits of different morphological types (vein, veinlet-vein, and veinlet-disseminated). It is shown that multifrequency IP sounding reliably identifies zones of carbon metasomatism, a reliable indicator of promising gold mineralization areas and zones in northeastern Russia. Evidence of carbon metasomatism is the typical shape of phase frequency response curves for graphite and graphitized rocks.

*Keywords:* induced polarization; phase frequency response; two-frequency phase parameter; graphitization; carbon metasomatism

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## Introduction

To date, the induced-polarization method based on the study of fields produced in the ground by secondary electric charges during passage of direct or alternating low-frequency electric current is of great importance and has a unique position among geophysical electrical exploration methods as it provides direct detection of sulfide mineralization associated with gold mineralization. The presence of carbon-bearing material hinders the identification of areas and zones of hydrothermally altered sulfidized rock, but it is often a reliable indicator of gold mineralization.

The main objective of the present work was to develop methodical procedures for reliable identification of areas and zones of carbon metasomatism, which is an indicator of gold mineralization of various morphogenetic types associated with sulfide mineralization and widespread permafrost in northeastern Russia. The mining conditions in most survey areas make it impossible to use nonpolarizable electrodes, so that all IP surveys were performed in the frequency domain.

## Relationship between IP frequency responses and the material composition of polarizable bodies

This issue has attracted the interest of many researchers abroad (Hubbard et al., 2014; Pelton et al., 1978; Weller et al., 2010; Zonge, 1980), in the Soviet Union (Chelovechkov et al., 1972; Kormil'tsev and Zhavoronkova, 1972; Lemets et al., 1983; Sarbash et al., 1980; Ulitin et al., 1972), and in Russia (Kulikov and Yakovlev, 2008). These studies have shown that the shape of frequency response curves depends on the material composition of polarizable bodies and the type of ore mineralization (disseminated, veinlet, massive), which can be used to classify polarizability anomalies according to their geological nature.

A large amount of research was carried out in the Kazakh Branch of the All-Union Institute of Exploration Geophysics (VIRG) in the 1980s (Lemets et al., 1983, 1986). These papers describe a method for studying phase frequency responses (hereinafter, PFRs) based on analysis of the parameters $f_{\max}$ and $K_\varphi$, where $f_{\max}$ is the frequency of the peak of the phase frequency response, the coefficient $K_\varphi$ is proportional to the slope of the dependence of the phase parameter on the frequency according to the following expression:

$$K_\varphi = \frac{\log_{10}\varphi_2/\log_{10}\varphi_1}{m} \times 10^2.$$

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Here $\varphi_2$ and $\varphi_1$ are, respectively, the values of the two-frequency phase parameter on the upper ($f_2$) and lower ($f_1$) operating frequencies of the frequency range used to determine $K_\varphi$, and $m$ is the number of octaves in the range $f_2$–$f_1$ (one octave corresponds to an operating frequency ratio equal to 2) (Lemets et al., 1983, 1986).

Studies were conducted using an EVP-203 apparatus in the frequency range from 0.3 to 156 Hz under both laboratory and field conditions.

Figure 1 shows phase frequency responses of the two-frequency phase parameter on pure metals, electro-graphite, and rock and ore samples over various geological features in natural environments. For greater clarity, the PFRs are normalized to the value of the phase parameter at the extrema of the curves, so that the sign of the ratio is positive, whereas the sign of the phase parameter is actually negative.

For metals of uniform composition, there is a clear relationship between the frequency of the peak $f_{\max}$ and the position of these metals in the electrochemical reactivity series (Fig. 1*a*). For graphite, the value of $f_{\max}$ is below 0.3 Hz, and in this frequency range, it has the opposite slope ($K_\varphi < 0$). For chalcopyrite-pyrite ore samples, $f_{\max}$ has a tendency to increase with increasing sizes of polarizable inclusions (Fig. 1*b*). Whereas for samples with disseminated sulfides, the value of $f_{\max}$ is higher than 156 Hz, for massive ores, the frequency of the peak of $\varphi_{\mathrm{IP}}$ is 0.3 Hz or less. In some cases, two peaks $f_{\max}$ can be observed in frequency responses (Fig. 1*c*), which reflects two different IP process.

Results of laboratory measurements on samples of sulfide ores (Lemets et al., 1983, 1986) have led to the conclusion that the position of the peak of $\varphi_{\mathrm{IP}}$ on the frequency axis and the value of $K_\varphi$ are dependent on the structural and textural factors to a greater extent than on the material composition. For massive ores, the peak frequency response is observed in the low-frequency region, outside the frequency range studied. For veinlet-disseminated ores, the frequency response peak is observed in the frequency range 1–10 Hz, and for disseminated ores, it is located in the high-frequency region, often also outside the frequency range under study.

In the range of 0.3–156 Hz, the frequency responses $\varphi_{\mathrm{IP}}$ over natural sulfide formations and graphitized rocks are usually monotonic curves (Fig. 1*d*). Observed PFR portions in these cases are well approximated by straight lines with different slopes. In some cases, the frequency responses $\varphi_{\mathrm{IP}}$ have a more complex shape with a negative $K_\varphi$ in the range of 0.07–0.3 Hz and a positive value in the range of 1.2–156 Hz. Judging by the results of laboratory studies, this is due to the heterogeneous composition of the body, one of whose components has a negative coefficient, and the other a positive coefficient.

From the data of a large number of field measurements at polarizability anomalies in Kazakhstan ore regions, the lowest values of $K_\varphi$ are observed over skarn copper-magnetite and veinlet pyrite ores, and the largest values of this coefficient are obtained over pyrite dissemination zones. Graphitized carbonaceous rocks are characterized by negative values of $K_\varphi$ (Lemets et al., 1983, 1986).

## Problem description

First of all, it should be noted that the authors were able to identify almost all PFR types described in papers of KazVIRG researchers.

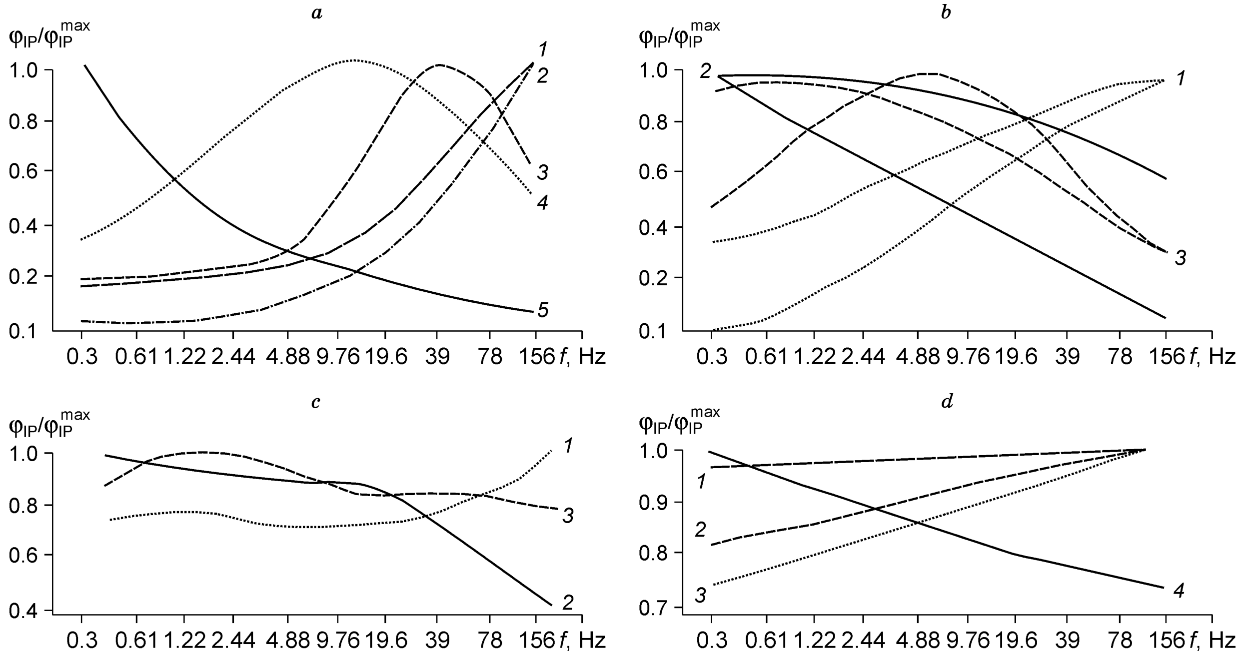

Fig. 1. Phase-frequency responses of pure metals and electro-graphite (*a*), samples of skarn copper-magnetite ore (*b*) and porphyry copper ores (*c*) over various geological features in natural environments (*d*) (based on KazVIRG data, 1983). *a*: *1*, lead; *2*, aluminum; *3*, copper; *4*, silver, *5*, graphite; *b*, *c*: *1*, disseminated ores, *2*, solid ores, *3*, vein-disseminated ores; *d*: 1, copper-magnetite ores, 2, porphyry copper ores, 3, pyritized rocks, 4, carbonaceous graphitized rocks.