Spectral induced polarization in mineral exploration

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Investigation of time (frequency) characteristics of the induced polarization (IP) process is one of the priority areas in today's electrical explorations. The velocity and duration of the IP process are additional independent parameters which can provide further information on the nature of the polarized objects.

Russian company North-West uses a multi-frequency phase measurement technology (INPHASE-IP) developed in the Soviet Union in the 70's of the past century to study the IP characteristics (Kulikov and Shemyakin 1978).

In the INPHASE-IP method, the rock polarizability level is determined based on the differential phase parameter (DPP). Use of DPP was suggested to suppress electromagnetic inductive component which, just like induced polarization, can lead to significant phase shifts in the signal. In the near-field zone approximation, the inductive phase is proportional to the frequency. The differential phase parameter is designed to completely suppress the linear component of the phase without changing the constant component.

$$DPP(\omega_1, \omega_2) = \frac{\phi(\omega_1)\cdot\omega_2 - \phi(\omega_2)\cdot\omega_1}{\omega_2 - \omega_1}$$

where ω_1 and ω_2 are the frequencies, $\phi(\omega_1)$ the full low-frequency phase shift and $\phi(\omega_2)$ the full high-frequency phase shift.

If a square-wave signal (bipolar rectangular pulse) is used in the current line, DPP can be calculated based on phases 1 and 3 of the measured signal harmonics:

$$\Delta\phi(\omega, 3\omega) = \frac{3\phi(\omega) - \phi(3\omega)}{2}.$$

DPP is often converted into apparent polarizability (η_κ^{DPP}) by empirical coefficient $\kappa = -2.5$. This allows converting the resulting data from the negative phase degree dimension to a more conventional unit of measurement used in the IP methods – polarizability percentage.

According to the Cole-Cole formula, the apparent resistivity modulus decreases progressively as the frequency increased, and the phase has one minimum and two symmetrical ascending branches. The phase curve minimum position is determined primarily by time constant τ, the phase amplitude by polarizability value η, and the spectrum width by parameter C. The DPP shape almost exactly follows the shape of the phase curve, but has a more pronounced minimum as well as a minor minimum shift along the x axis (Zorin 2013).

Difference between the DPP values at two frequencies can be used as a simple and reliable method for evaluation of time characteristics of induced polarization. Since the DPP frequency characteristic graphs are virtually symmetrical, the operating frequencies can be selected so that the difference between two DPPs calculated for those frequencies would be negative above one rock and positive above another. This parameter will be proportional to time constant τ (Fig. 1).

The results of INPHASE-IP surveys performed at multiple mining objects showed that DPP can be successfully used in advanced modern applications involving separation of objects with different time characteristics of induced polarization.

Areal electrical surveys based on the electric profiling – induced polarization (EP-IP) method carried out at the Kola Peninsula showed (Fig. 2) that use of multi-frequency DPP measurements enables identification of local intrusive bodies with copper-nickel sulphide mineralization localized in the field of propagation of highly conductive and polarisable carbonaceous shales of the Solenoozerskaya Series (Kulikov 2013).

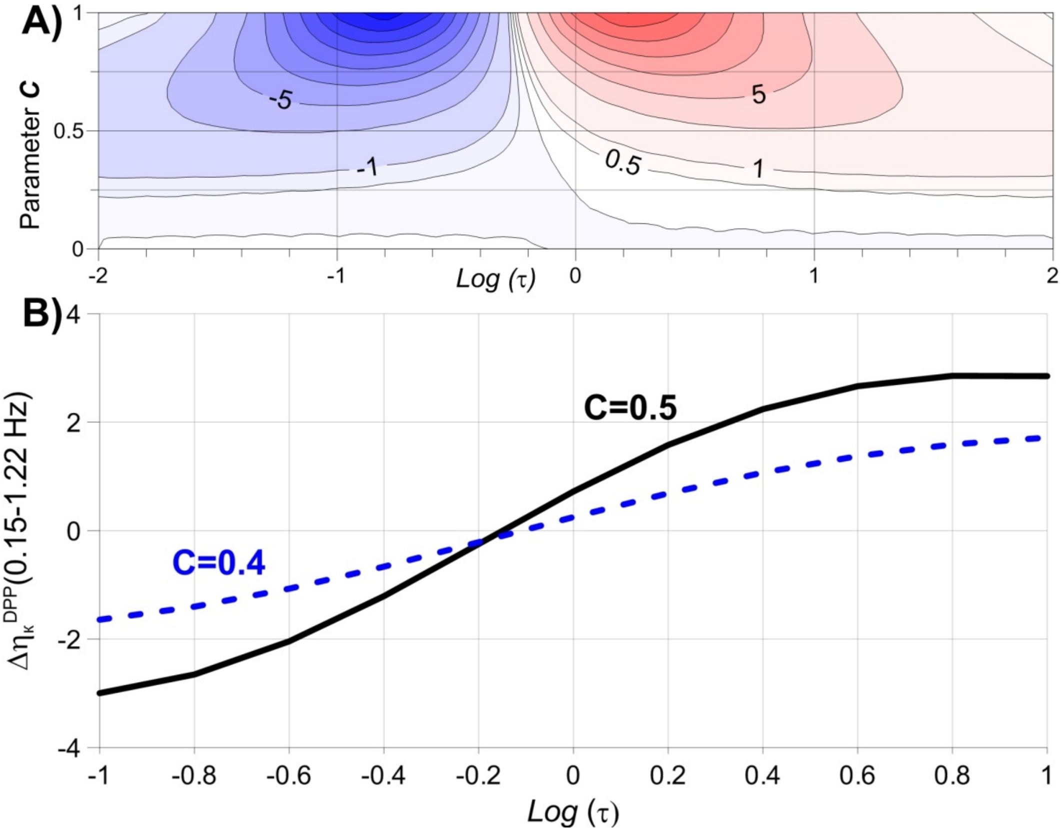

Fig. 1: A) Map of the difference $\Delta\eta_\kappa^{DPP}$ at frequencies 0.15 and 1.22 Hz above the homogeneous polarized half-space, depending on the parameters log(τ) (n = 20%);B) The diagrams of dependence of $\Delta\eta_\kappa^{DPP}$ from log (τ) at various parameters C.

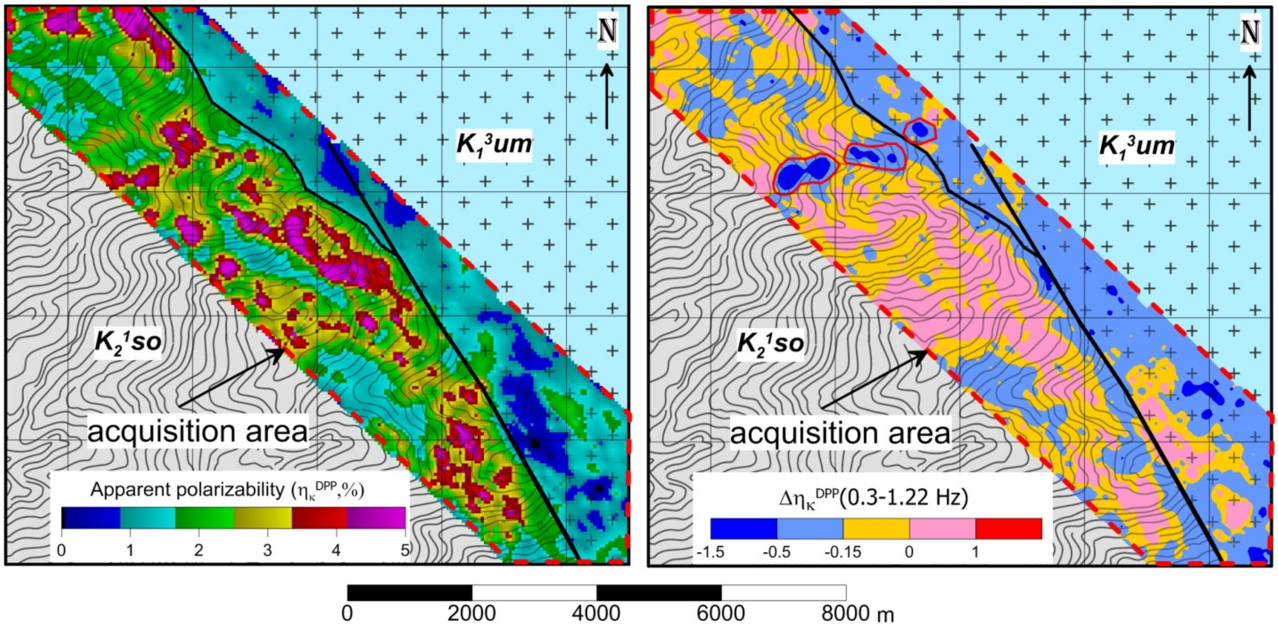

Fig. 2: Map of apparent polarizability η_k^{DPP} (left) and parameter $\Delta\eta_k^{DPP}$ (0.3-1.22 Hz) (right).

Explorations carried out at the skarn deposits in Transbaikal using the mean gradient – induced polarization (MG-IP) modification of the method allowed separating silicate and magnetite skarn bodies based on the DPP maps at different frequencies. Skarns with prevailing sulphides (pyrite, chalcopyrite) feature a longer IP field decay time compared to pure magnetite varieties.

Multi-frequency downhole DPP measurements performed within the ore of the Norilsk Intrusion showed that a higher copper-to-nickel ratio in the ore composition causes a shift of the DPP frequency characteristic maximum towards the low-frequency domain, resulting in an increase of induced polarization time parameter *τ* (Kulikov 2013).

Conclusions

There are many practical methods for evaluation of time (frequency) characteristics of induced polarization in rocks. Information obtained through various measurement methods is essentially equivalent. Here we have an additional parameter of the medium which, together with apparent resistivity and apparent polarizability, can be used in subsequent geological interpretation of geophysical data.

However, in our opinion, the differential phase parameter has a number of technical advantages over other methods.

First of all, phase measurements allow achieving more accurate results. Secondly, DPP substantially suppresses any phase shifts associated with electromagnetic induction shift, which is especially important when working with large spreads.

In addition, as shown by field exploration results, the DPP frequency characteristic maximum for the most common polarisable rocks – carbonaceous shales, sulphide ores etc. is usually located within a limited medium-frequency range, making it convenient for field registration (0.1 – 5 Hz).

The differential phase parameter (DPP) has a simple relation to the Cole-Cole formula parameters. Increase in time constant τ causes a shift of the DPP modulus maximum towards the low-frequency domain, while its width depends on the value of power parameter C.

Having an additional parameter in the form of DPP difference at several frequencies, we can, under certain favourable conditions, separate induced polarization anomalies from carbonaceous and magnetite-containing rocks, various sulphide ore assemblages, and anomalies related to ground water capillary fringes.

References

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