New electromagnetic and induced polarization technology: interpretation and results of field experiments

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The electromagnetic and induced polarization (EMS-IP) was developed and intensively used at the Siberian School of Geoscience. Irkutsk National Research Technical University, Russia. This method combines two groups of methods: the transient EM method at time off and the DC and IP methods during time on.

In the EMS-IP method, the source of electrical current is a series of rectangular bipolar pulses transmitted to a long grounded electrical line AB. It allows to calculate the transient process at given time windows, normalized it to the potential difference ΔU taken before turning off the current pulse. This technology allows us to simultaneously determine the measured apparent electrical resistivity of the medium (ρ_k), the inductive component of the signals (TEM methods), and the IP effects, more likely can be distinguished using a multi-electrode grounded receiving arrays. This approach significantly increases the information compare of traditional direct current methods and makes it possible to study the lithological structure of the section in more detail.

Registration of electromagnetic signals is carried out in the time domain by galvanically grounded dipoles located in accordance with the selected arrays: dipole axial array A-MN-B, AB-MN, or median gradient array. The receiving dipoles MN can be orientated parallel to the line AB l for recording the horizontal electrical component Ex and perpendicular to register the horizontal electrical component Ey (Fig. 1).

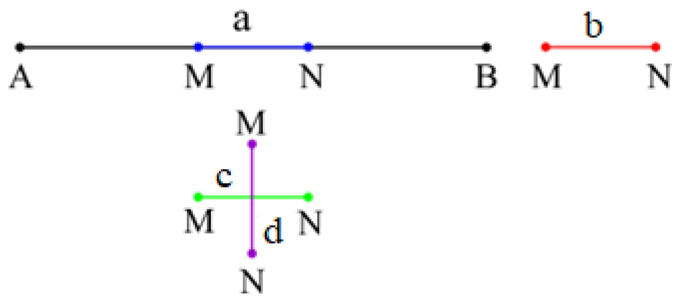

Figure 1. Different types of arrays for the EMS-IP method: a – symmetrical axial array AMNB; b – dipole axial array ABMN; c and d – array of a median gradient for recording the horizontal electrical component E_x and E_y, accordingly.

In the TEM methods only the secondary EM field is measured: after turning current flowing in the AB line off an attenuated magnetic field $\vec{H}_1$ propagated in the media and induces a secondary electric field $\vec{E}_2$, which in its turn produces eddy currents. However the horizontal electric line is a source of mixed type: besides the pair of grounded electrodes AB produces a transverse magnetic field and the transmission electrical field $\vec{E}_1$, will be also propagated in the ground. Then the EM fields are superimposed near the transmitter line AB, the total strengths E of the electric and/or H magnetic field are recorded (Figure 2).

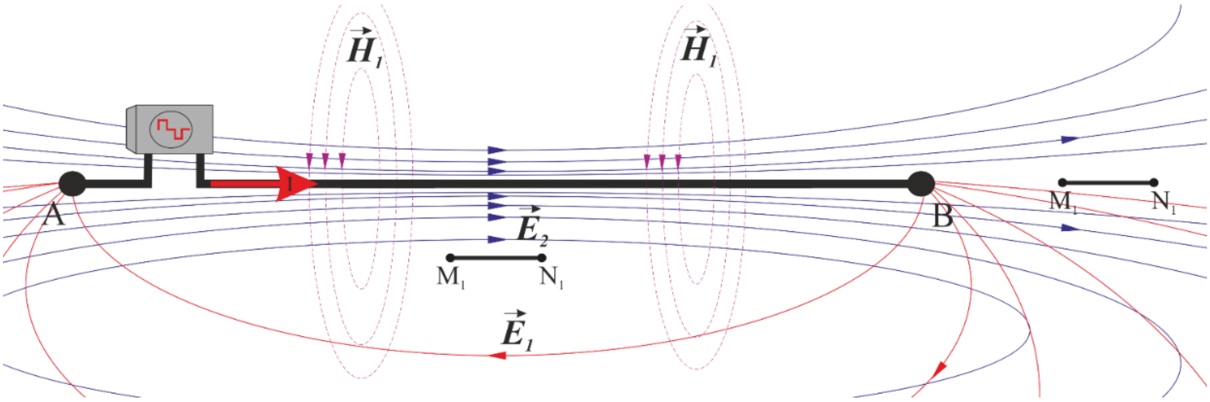

Figure 2. Galvanic method of excitation of non-stationary electromagnetic fields

Field works are carried out using specially developed instrument MARS. It is composed of transmitter and receiver modules

The transmitter module consists of a current source, a switch of opposite-polar pulses and a current line AB. The receiver module consists of a potential difference receiver, a collection device and a multi-channel measuring cable; and a satellite time synchronization unit.

For interpretation of EMS-IP data the method of "flowing" S-plane was adapted to the used arrays. The equation for the potential U recorded at point M (or N) is equal to

$$U = \frac{Iab}{2\pi S}\frac{1}{2\widetilde{m}r_0}\frac{cos_M{}^2\varphi}{[1+4\widehat{m}^2]^{1/2}}, \qquad (1)$$

where $r_0 = r \cdot cos\varphi$, $2\widehat{m} = (h_1/r + |z_1|/r + 2t/\mu S r)$, ab – is an element of AB line, φ is an angle between center ab and point M (or N), I is a current in the line AB, S is the conductance of S-plane.

The potential difference between the electrodes M and N is equal:

$$\Delta U = U_M - U_N = \frac{Iab}{2\pi S r_0}\left(\frac{1}{2\widehat{m}_M}\frac{cos_M{}^2\varphi}{[1+4\widehat{m}_M^2]^{1/2}} - \frac{1}{2\widehat{m}_N}\frac{cos_N{}^2\varphi}{[1+4\widehat{m}_N^2]^{1/2}}\right). \qquad (2)$$

The equation 2 contains two unknown parameters, namely, the S and $\widetilde{m}_M$ and $\widetilde{m}_M$, the latter also includes the unknown parameter of the "floating plane" h. In order to exclude S from the calculations, we perform the following steps. Let us write down the ratio of the derivative of the potential difference to the square of the potential difference of the observed signal ΔU_{H} and theoretical function ΔU_T and divide both by $K = 4\pi/IAB\mu$,

$$\Theta(t) = \frac{1}{K}\frac{(\Delta U_{\text{H}})'}{\Delta U_{\text{H}}^2} \text{ and } \Phi(t) = \frac{1}{K}\frac{(\Delta U_T)'}{\Delta U_T^2}. \qquad (3)$$

where μ is magnetic permeability (H/m). Comparison of the $\Theta(t)$ (calculated using field data) with the theoretical one $\Phi(t)$allows us to determine the value at each time of transient EM field. The apparent longitudinal conductance of "floating" S-plane is equal to

$$S(t) = \frac{Iab}{2\pi r_0 \Delta U}F(\widehat{m}_{MN}), \qquad (4)$$

where

$$F(\widehat{m}_{MN}) = \left(\frac{1}{\widehat{m}_{MN}}\frac{cos_{MN}{}^{2}\varphi}{[1+\widehat{m}_{MN}^{2}]^{1/2}}\right)$$

The software for the S_τ inversion is written in Matlab and Python. Time required for calculation apparent longitudinal conductance as a function of depth H ($S_\tau(H)$) for one profile (approximately 100 stations) takes a few seconds.

Let's consider one example of application of S_τ technique for interpretation EMS-IP data. Figure 3 shows a small portion of geological map areas of Eastern Siberia where location of profiles is shown. Red colors show two lines AB, shifted relative to each other. Blue color indicates 46 profiles EMS-IP The distance between points of observation (length MN) is 25 m, the length of the AB line is 2.4 km. The aim of this survey is to delineate dykes contain of sulfides. The work was carried out in permafrost conditions and some signals were distorted by IP effect.

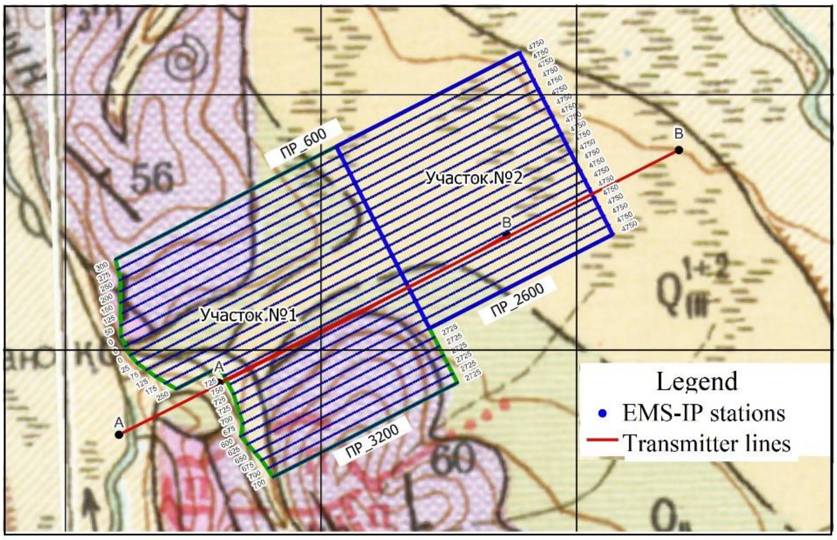

Figure 3. Geological map of investigated area and location of EMS-IP profiles.

Figures 4 and 5 show the change in apparent longitudinal conductivity along profiles 600, located in the north of the site and 2900, located in the south of the site.

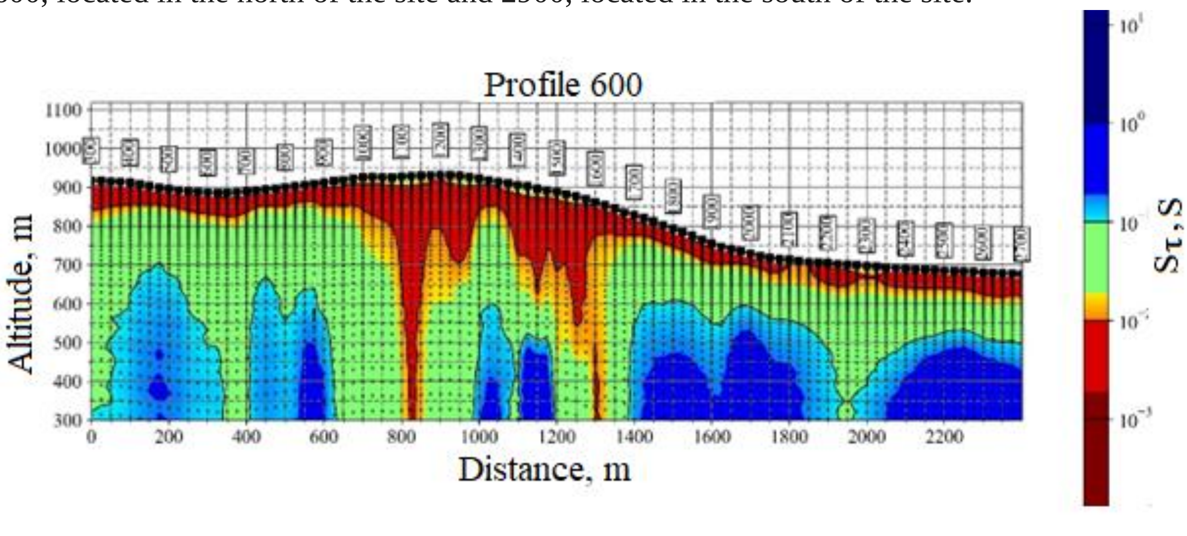

Figure 4. Geoelectric section along the profile 600.

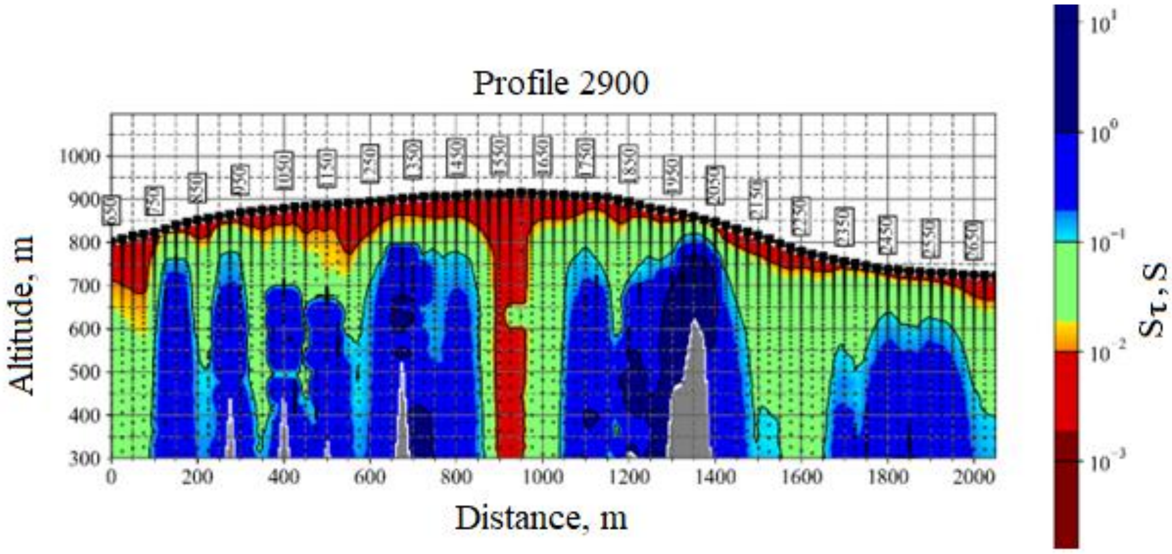

Figure 5. Geoelectric section along the profile 600.

The survey area is composed of metamorphic rocks. The upper part of the section with high rocks’ resistivities corresponds to the presence of permafrost. The conductance of rocks increases with depth due to the presence of free moisture in the pores of the rocks. On both profiles, vertical zones of high resistivity coincide with plan with the presence of sulfide dikes. In these zones, EMS -IP signals are distorted by induced polarization processes. Such anomalies can serve as a prospecting indicator for dispersed sulfide ores. Similar anomalies were discovered at one of the copper-nickel deposits in South Africa (Hondekloof).

Thus, the use of the EMS-IP method has shown its high efficiency in delineation of the structural features of sections and electrical properties of rocks and dispersed sulphide ores exploration.