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Corresponding Member of the Academy of Sciences of the USSR A. N. TIKHONOV and B. S. ENENSHTEIN

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Abstract

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GEOPHYSICS

Corresponding Member of the Academy of Sciences of the USSR A. N. TIKHONOV and B. S. ENENSHTEIN

ON ONE METHOD FOR DETERMINING THE DEPTH OF OCCURRENCE OF THE CRYSTALLINE BASEMENT (FOUNDATION) FROM PHASE CURVES OF FREQUENCY ELECTROMAGNETIC SOUNDINGS

§ 1. The method of frequency electromagnetic soundings for determining a geoelectric section has a number of fundamental advantages in comparison with the direct-current sounding method (*1*). In this connection we posed the question of parameter-free interpretation in frequency soundings (f.s.). The essence of parameter-free interpretation consists in determining the characteristics (thicknesses and average resistivities) of individual layers or packets of layers (blocks) directly from sounding curves, without invoking any data on the geoelectric section obtained by other means at this point or at other points.

At present, with the aid of a field station for frequency soundings (*2*), f.s. curves have been obtained under various geoelectric conditions. A current problem is the development of methods for interpreting f.s. curves in order to determine the characteristics of the geoelectric section and, in particular, to determine the fundamental characteristic of the section—the depth of occurrence of the top of the crystalline basement. Real geoelectric structures are complex—multilayered; therefore, the development of relatively simple methods of interpretation that do not require the use of multilayer theoretical curves is of great importance.

This article describes a parameter-free method for determining the depth of occurrence of the top of the basement from phase f.s. curves. This method is based on analysis of chart material (§§ 2 and 3). In § 4 the application of this method is described for f.s. curves obtained on complex, multilayer geoelectric sections.

§ 2. Let us define the characteristics that we wish to use for interpreting practical f.s. curves.

Figure 1 presents a two-layer chart of theoretical frequency-sounding curves for

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

the phase of the electric component (φ_e) for the case $\rho_2 = \infty$ (equatorial array). The theoretical curves given in the article were obtained by A. N. Tikhonov, V. M. Shakhsuvarov, and L. L. Van' yan.

The index of the curves is the quantity r/H_1 (0; 2; 2.8; 4; 5.6; 8; 11; 16 and 22), where r is the sounding length and H_1 is the layer thickness. The curve with index $r/H_1 = 0$ corresponds to a homogeneous half-space ($H_1 = \infty$). From this curve it is seen that the normal phase field over a wide frequency range is a horizontal straight line coinciding with the zero-phase axis. Consequently, the formation of the right ascending branches AB of the two-layer curves, associated with the influence of the second layer, occurs against the background of a horizontal straight line (the normal phase field) up to a ratio r/H_1 equal to 2.8. In this case the amplitudes of these branches AB, in degrees, depend only on the value of r/H_1 and do not depend on the conductivity of the section. Thus, knowing the value r and determining the amplitude of the right branch of the curve AB, one can unambiguously determine the value of H_1.

Curve *I* in Fig. 2 characterizes the dependence of the quantity r/H_1 on the amplitude of the right ascending branches of the φ_e curves, in degrees, for a two-layer section ($\rho_2 = \infty$). This curve was constructed from the chart in Fig. 1.

Everything said above applies equally to phase curves for the magnetic components of the field. Curve *II* in Fig. 2 characterizes the analogous dependence of the quantity r/H_1 on the phase curves φ_m of the vertical component of the magnetic field for a two-layer section of the type $\rho_2 = \infty$. This curve was compiled from the two-layer φ_m chart.

Fig. 1

Fig. 2

Fig. 3

§ 3. Let us now clarify some characteristic features of the phase curves of frequency soundings. For two-layer sections of the type $\rho_2 < \rho_1$. Figure 3 presents the phase curves of frequency soundings for the component E_x for

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

$\rho_2/\rho_1 = 1/8$ (curve *I*) and $\rho_2/\rho_1 = 1/16$ (curve *II*). The φ_e curves have short, inclined left branches,

lying within a narrow frequency range (for $\rho_2/\rho_1 = 1/8$, from $\lambda_1/r = 0.35$ to $\lambda_1/r = 1$), then there follows a broad minimum and a comparatively gentle rise of the curve toward the value $\varphi = 0^\circ$, corresponding to the frequency $f = 0$ (direct current). The slope of the left branches of the curves is determined by the value of ρ_2/ρ_1.

From the form of the two-layer phase curves of the type $\rho_2 = \infty$ (Fig. 1) and $\rho_2/\rho_1 < 1$ (Fig. 3), one may obtain an idea of the structure of three-layer and multilayer frequency-sounding curves. In Fig. 4, *I* shows a three-layer theoretical frequency-sounding curve for the phase of the vertical component of the magnetic field φ_{M} for the case $\rho_2/\rho_1 = 1/8$, $\rho_3 = \infty$, $H_2/H_1 = 2$, $r/H = 3.8$ ($H = H_2 + H_1$). Let us note that the right branch AB of the three-layer curve *I* in Fig. 4, following the minimum, is similar to the right branch AB of the two-layer curve shown in Fig. 1.

Fig. 4

The circumstance that two-layer phase curves with $\rho_2 < \rho_1$ are characterized by a broad minimum (Fig. 3) leads to the fact that, for a three-layer section of the type $\rho_2 < \rho_1$ and $\rho_3 = \infty$, at $H_2/H_1 \sim 1.5$—2 and greater, the right ascending branch AB of the curve, associated with the influence of the third layer ($\rho_3 = \infty$), is formed beyond the limits of the left inclined branch. For values of ρ_2/ρ_1 within the range 1—1/8, the right ascending part of the curve AB is formed against the background of a gentle minimum (Fig. 3). In the case of a two-layer section ($\rho_2 = \infty$), the amplitude of the right branch AB of the frequency-sounding curve does not depend on the conductivity of the section. It is natural to assume that, for a multilayer section, the amplitude AB is also determined only by the total thickness of the section. This assertion will be checked below. For values of $\rho_2/\rho_1 < 1/8$, the part of the curve following the minimum begins to deviate appreciably from the horizontal, which makes it necessary to introduce corrections.

Let us check the proposed method on the three-layer theoretical curve shown in Fig. 4, *I*. The data for this curve were given above. The amplitude of the right ascending branch of curve *I* is 33°. From curve *II* of Fig. 2 we find that 33° corresponds to $r/H = 3.6$. Since in fact $r/H = 3.8$, the error in determining the value H—the thickness of the conducting stratum—is $(3.8 - 3.6) : 3.8 = 5\%$. A check on other theoretical curves gives analogous results.

§ 4. Let us carry out, by the described method, an interpretation of experimental phase frequency-sounding curves obtained near boreholes that have penetrated the top of the basement. These soundings were carried out under conditions of multilayer geoelectric sections. Curve II in Fig. 4 is a frequency-sounding curve for the phase of the electric component φ_{e}, obtained at a borehole that penetrated the basement at a depth of 1950 m. The sounding length was $r = 10$ km. In its general form, the curve is five-layered. The right ascending branch AB of the curve, reflecting the influence of the basement, is formed against the background of a straight line close to horizontal.

In accordance with the considerations set forth above, determination of the depth of occurrence of the basement from the amplitude AB of the right branch of the curve does not require the introduction of corrections. Indeed, the amplitude of the right branch of the curve is

60°. From curve I in Fig. 2 we find that 60° corresponds to $r/H = 5$; since $r = 10$ km, $H = 2000$ m. The error in determining the value of H in this case is very small (2.5%).

Curve III in Fig. 4 represents frequency sounding by the phase of the vertical component of the magnetic field φ_m, carried out near a reference borehole with spacing $r = 8.5$ km. The depth to the basement according to the borehole is 1830 m. In its general form the curve appears to be four-layered. The sedimentary complex overlying the basement rocks is characterized by a very low resistivity. The ratio of the resistivity of this complex to the average resistivity of the overlying rock complex is of the order of 1/30. In the upper part of the section there is a nonconducting layer, which is reflected on curve III by the left maximum. This layer does not allow the electric components to be used for determining the depth to the basement. The amplitude of the right branch is equal to 58°. From curve II in Fig. 2 we find that 58° corresponds to $r/H = 5.3$, and $H = 8500 : 5.3 = 1600$ m; thus, the error in determining H is $(1830 - 1600) : 1830 = 12.5\%$.

We noted above that, for very small values of ρ_2/ρ_1, the right branch AB of the curve is distorted because its formation takes place against the background of the inclined part of the curve, and this leads, as we see in the last example, to appreciable errors in determining the value of H. One may try to improve the interpretation results by introducing appropriate corrections.

The method we use for introducing corrections is based on the assumption that the change in the amplitude AB of the right branch due to the nonhorizontality of the segment within which it was formed is equal to the difference between the ordinates of points A_1 and B_1 of this portion of the curve.

The slope of the line A_1B_1 is determined by matching the left branch of the experimental curve with a two-layer theoretical curve having a suitable order of magnitude of the modulus ρ_2/ρ_1. The course of the line A_1B_1 is indicated in Fig. 4 by a dashed line. Curve III has two minima. The first of them is associated with the influence of the overlying low-resistivity sequence, and the second with the influence of the basement. It is therefore natural that the course of the line A_1B_1 is determined by the first minimum. The difference between the ordinates of points A_1 and B_1 in our case (curve *III*) is 10°. Thus, the amplitude of the right branch of the curve, with the correction taken into account, is $58 - 10^\circ = 48^\circ$. From curve *II* in Fig. 2 we find that 48° corresponds to $r/H = 4.5$, and $H = 8500 : 4.5 = 1900$ m. Thus, the error in determining H decreases from 12.5 to 3%.

Modern apparatus for frequency sounding makes it possible to obtain values of phase angles with an accuracy of up to 1° in the course of field measurements. This provides a real possibility, by means of the method described, of carrying out a parameter-free determination of the depth to the top of the crystalline basement even for a complex geoelectric section (including in the presence of nonconducting screens) directly in the course of field measurements.

Magnetic Laboratory
Academy of Sciences of the USSR

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REFERENCES

1. A. N. Tikhonov, D. N. Shakhsuvarov, E. V. Rybakova, *Izv. Akad. Nauk SSSR*, Geophys. Ser., No. 8 (1959).

2. B. S. Enenshtein, A. P. Ivanov, M. A. Ivanov, in: *Collected Problems of the Theory and Practice of Electrometry*, Publishing House of the Academy of Sciences of the USSR, 1961.

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