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NEW RESULTS IN THE FIELD OF DEEP MAGNETOTELLURIC SOUNDINGS

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The theory of magnetotelluric soundings, developed by A. N. Tikhonov and L. Cagniard, indicates the possibility of applying this method to deep investigations of the Earth. The question is the study of the electrical properties of the upper mantle, determined mainly by its thermal state.

In recent years deep magnetotelluric soundings have been carried out in many countries. However, the reliability of the material obtained still remains a subject of discussion, since it contains many contradictions (instability of the results, their strong dependence on the position of the measuring setup, etc.).

These contradictions are apparently connected with the fact that real natural conditions (the conditions of the sources and of the media) differ from the ideal conditions of the Tikhonov-Cagniard mathematical model, in which a plane wave is incident from above on a horizontally homogeneous medium.

Here it is important to note two principal points: 1) in deep magnetotelluric soundings, long-period field disturbances are recorded, the primary part of which cannot always be approximated by a plane wave; 2) horizontal inhomogeneities of the Earth' s crust can strongly distort the secondary part of the field.

If these contradictions can be resolved, magnetotelluric soundings will take a prominent place in the arsenal of geophysical tools used in deep investigations of the Earth. Below are presented some new materials testifying to favorable prospects in this field.

The investigations were carried out at 4 points along the Ashkhabad—Bakhardok profile, crossing the Predkopetdag trough perpendicular to its axis (Fig. 1). The total length of the profile is 90 km. The northern end of the profile falls on the slope of the Karakum arch, while the southern end adjoins the main thrust of the Kopet-Dag. The geoelectrical section of the study area is rather simple. In the upper part of the section there are Quaternary and Tertiary conducting rocks with a resistivity of 1-2 ohm · m. Below lie high-resistivity formations of the Lower Cretaceous, Jurassic, and Paleozoic basement, dipping from north to

Fig. 1

Figure 1: Fig. 1

south from 2 to 5 km. Immediately beyond Ashkhabad these rocks rise steeply and at the foot of the Kopet-Dag come out onto the Earth' s surface.

The method of investigation differed in the following features. First, disturbances of a definite type were analyzed, namely the initial phases of electromagnetic storms, whose magnetic fields varied according to a law close to a step function. These disturbances, as is known, have a broad frequency spectrum and near the Earth (in middle and low latitudes, where polar effects may be neglected) are well approximated by plane waves ([1]).

Second, in processing sudden onsets, instead of the ordinarily used Fourier transform, the Laplace transform with real parameter p was used ([2])

$$\mathbf{E}, \mathbf{H}(p) = \int_0^\infty \mathbf{E}, \mathbf{H}(t) e^{-pt}\, dt.$$

This reduced the errors of analysis in the absence of information on the behavior of the field during the storm build-up at large t, and greatly simplified the integration as well as the analysis of the results obtained. The values of p were chosen in the interval from 8 to 0.25 hour^{-1} (which corresponds to information on the section obtained in the interval of periods from 0.8 to 25 hours).

Fig. 1. Geological section along the Ashkhabad—Bakhardok profile. **1**—surface of the Lower Cretaceous according to drilling and seismic-survey data; **2**—surface of the conducting layer of the upper mantle according to deep magnetotelluric sounding data

Third, in determining impedances, the horizontal inhomogeneity of the Earth' s crust was taken into account. It was assumed that

$$\mathbf{E}(p) = [Z]\mathbf{H}_{\text{hor}}(p),$$

where $[Z]$ is the impedance tensor with real components Z_{xy}, Z_{yx} (the principal impedances) and Z_{xx}, Z_{yy} (the supplementary impedances), depending on the parameter p, the direction of the axes x, y, and the distribution of electrical properties in the Earth ([3,4]). The components of the impedance tensor were found from the equations

$$E_x(p) = Z_{xx}H_x(p) + Z_{xy}H_y(p), \qquad E_y(p) = Z_{yx}H_x(p) + Z_{yy}H_y(p),$$

solved by the method of least squares. The accuracy of determining the components of the impedance tensor was $\pm 5\%$. From the values $Z_{xx}, Z_{xy}, Z_{yx}, Z_{yy}$,

Fig. 2

Figure 2: Fig. 2

polar diagrams of Z_{xy}, Z_{xx} were constructed, characterizing the dependence of the principal and supplementary impedance on the direction of the axes x, y ([4]).

Fig. 2. Polar diagrams of the principal and supplementary impedances, $p = 4$

An example of polar diagrams of the principal Z_{xy} and supplementary Z_{xx} impedances is given in Fig. 2. The Z_{xy} diagrams are two-lobed curves elongated along the axis of the Pre-Kopetdag trough; the Z_{xx} diagrams have the form of four-lobed curves (the lobes meet at the origin). The configuration of the polar diagrams makes it possible to regard the Pre-Kopetdag trough as a two-dimensional structure, whose axis of homogeneity coincides with the axis of the trough. In this case, the major and minor semidiameters of the Z_{xy} diagrams, directed along the axis of the trough and perpendicular to the axis of the trough, may be regarded as the principal values of the impedance tensor, corresponding respectively to the E- and H-polarizations of the field ([4]).

Fourth, the depth to the conducting (heated) layer of the upper mantle was determined from curves of apparent resistivity,

$$\rho_p = \frac{0.4\pi}{p} Z_{xy}^2,$$

obtained from the large semidiameters of the polar diagrams Z_{xy}, i.e., for the E-polarization of the field (Fig. 3).

This corresponds to the case when telluric currents flow along the axis of the trough, i.e., along the strike of the rocks. It is known from theory that in this case the high-resistivity basement has almost the same transparency as in a horizontally homogeneous medium, and irregularities of its relief do not introduce substantial distortions into the results of deep magnetotelluric soundings ([4]). The obtained ρ_p curves agree well with theoretical curves calculated for a horizontally homogeneous medium. They are represented by a distinct maximum and a descending branch inclined at an angle close to 63°. Their interpretation gave the following results:

Point no.	1	2	3	4
S, mho	4200	3600	3000	2700
h, km	320	300	290	250

Here S is the total longitudinal conductance of the sedimentary deposits, and h is the depth to the conducting layer of the upper mantle. The values of S and h decrease monotonically along the profile. However, the changes in h cannot be

Fig. 3. Curves of apparent resistivity

Figure 3: Fig. 3. Curves of apparent resistivity

regarded as the result of distortions caused by changes in S. Indeed, a decrease in S should have caused an increase in Z_{xy} and, consequently, an increase, not a decrease, in h. The absence of a causal relation between the changes in S and h argues in favor of the geological reliability of the data obtained. Even if the value of h at point no. 4, located near the Kopet-Dag overthrust, is called into question, on the whole it may be accepted that in the Ashkhabad—Bakhardok region the conducting layer of the upper mantle lies at depths of about 300 km.

Fig. 3. Curves of apparent resistivity

In conclusion, let us note that the ρ_p curves obtained from small semidiameters of the polar diagrams of Z_{xy} have a distorted form and give unstable values of h (from several kilometers to several tens of kilometers). This is the case of H-polarization of the field, when telluric currents flow perpendicular to the axis of the trough, i.e., across the strike of the rocks. In this case the transparency of the high-resistivity basement decreases, and inhomogeneities of the sedimentary sequence may strongly distort the results of deep magnetotelluric soundings. It is significant that as p decreases (i.e., as the frequency is lowered), the small semidiameters of the polar diagrams of Z_{xy} decrease and at $p = 0.25$ are practically equal to zero (the electric field is polarized along the axis of the trough). This is explained by the fact that the high-resistivity rocks exposed at the earth' s surface at the foot of the Kopet-Dag prevent the occurrence of currents in the direction perpendicular to the axis of the trough. This edge effect is manifested the more strongly, the lower the field frequency.

The measurement scheme considered can be recommended for deep magnetotelluric studies in regions with linear tectonics (in piedmont troughs, elongated depressions, etc.).

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Note: Figure translations are in progress. See original paper for figures.