Some Results of the Deep Magneto-telluric Investigations in the U.S.S.R.

By A.N. TIKHONOV, N.V. LIPSKAYA

Institute of Physics of the Earth, Moscow

and

B.M. YANOVSKY

University of Leningrad, Leningrad

The development of methods, which give us an opportunity to have information about the physical structure of the Earth core deep layers is of great importance.

Magneto-telluric sounding is based on a comparison of variations of the magnetic and electric natural fields and practically uses their range from hundreds of c/sec to a diurnal wave. This makes it possible to study the conductivity changes from the very surface layers of the Earth to the depth of hundreds of km.

In theory, on which quantitative processing is based, a plane or a running wave is adopted. The wave falls on a layered medium, characterized by $\rho(z)$ function, which represents the geoelectric section.

It is shown that $\rho(z)$ function in this case is determined by the impedance or the apparent resistance:

$$Z = \frac{E_x(T)}{H_y(T)} \quad \text{or} \quad \rho_k = \frac{T}{S} |Z|^2 \quad (1)$$

where E_x and H_y are the amplitudes of the simultaneously recorded oscillations of the two mutually perpendicular components of the electric and magnetic fields with a period T .

Experimental curves ρ_k interpretation is made by their comparison with the theoretical curves computed for the sections with different electric parameters. The program for multi-layered media is in operation at the Computing Centre of Moscow State University. By means of this program it is possible to make interpretation just on electronic computers, choosing by means of repeated tests a section which reproduces the experimental curve in a best way. For the preliminary interpretation it is possible to use tables for three-layered media published by the Moscow University Computing Centre.

It is necessary to note that the experimental curves character in a number of cases makes it possible to get some idea about the medium structure.

In previous papers we formulated the following important interpretation features of curves of the apparent resistance:

1. If an arbitrary bench of horizontal layers with a common thickness h lies on a highly-conductive basement, in such a case ρ_k curve, drawn in a bilogarithmic scale ($\xi =$

$lg \sqrt{T}$, $\eta = lg \rho_k$), has a dropping asymptote in large periods range with an angle coefficient equal to -2 . An equation of the curve in this case is of the form:

$$\eta + 2\xi = lg \frac{4\pi^2}{5} + 2lg h \quad (2)$$

i.e. it contains h and does not depend on other parameters of the section.

2. If an arbitrary bench of horizontal layers with a summary longitudinal conductivity $\Sigma_0 = \int_0^h \sigma(z) dz$ lies on a highly-resistant basement, in this case ρ_k curve has an ascending asymptote in large periods range with an angle coefficient equal to 2. This curve equation has the form:

$$\eta - 2\xi = lg \frac{20}{(4\pi)^2} - 2lg \Sigma_0 \quad (3)$$

i.e. contains the summary longitudinal conductivity and does not depend on other parameters of the section.

Thus, from the co-ordinates values of an arbitrary point on one of the asymptotes it is possible to get the summary thickness of layers lying over the zone with the high conductivity in the first case and the summary longitudinal conductivity of the layers, lying on the base of great resistance in the second case.

While studying the mantle structure it happens to deal with the sections, which represent the bench of layers lying on a highly conducting basement. It follows from the given above, that in this case in low frequency range there is an asymptote which makes it possible to determine the depth of the conducting basement independently on the structure of the section upper part.

The main reasons which prevent deep electromagnetic sounding from developing are the recording difficulties of geomagnetic variations in horizontal components in the range of periods from seconds to some hours. At the present time this problem has been solved by means of magneto-static and induction variometers. Instruments fit for the field recording began to be exploited during the preparation for the I.G.Y. At approximately the same time the first experimental magneto-telluric investigations were made for a limited range of periods. Characteristics received of the sedimentary strata and of the crystalline base depth were in good agreement with the data of other geophysical methods and with the boring data. This was the reason of the elaboration and wide popularization of the prospecting modifications of the magneto-telluric methods. These methods use variations with periods from seconds fractions to the first tens of minutes at the solving the structural prospecting problems at the depth from some hundreds of metres to 10-15 km.

The first curves of magneto-telluric sounding at the period range from a few seconds to 2-3 hours were plotted according to the data from geophysical station Alushta (The Crimea) and Borok (Yaroslavskaya district).

The Alushta curve was extended to the long periods range. Some points found from the harmonics of a diurnal wave for Shatsk (Rjasan district) which are in agreement with its (Alushta's curve) right asymptote were added to the curve. In such a form the Alushta's curve was interpreted by means of a four-layered section model. The optimum section,

which reproduces the experimental curve in the best way, was obtained in Computing Centre of Moscow University by means of a number of tests.

The following mean section characteristics were received:

1-st layer: resistance is 30–40 ohm.m., the thickness is 4–5 km

2-nd layer: „ „ 1500 „ „ „ 150 km

3-d layer: „ „ 250 „ „ „ 350 km.

The Borok curve was interpreted approximately by three-layered pallets. The following characteristics have been obtained:

1-st layer: resistance is 2 ohm.m., the thickness 2.7–2.8 km

2-nd layer: resistance is infinitely great, the thickness 270 km.

In 1961–1962 the work on the deep magneto-telluric sounding was enlarged sufficiently and was carried out not on isolated sites, but on the profiles.

Investigations were carried out in different geological regions: on a Middle-Russian platform, Dneprovso-Donetskaya and Middle-Russian depressions, in Georgia, in the Turkmen Republic and other regions. The field investigations were carried out by the Institutes of the Russian, Byelorussian, Ukrainian, Georgian and Turkmen Academies of Sciences, as well as by the Leningrad University and All-Union Geophysical Institute of Ministry of Geology.

Fig. 1. The curves of the magneto-telluric sounding. Institute of physics of the Earth.

P_1, P_2 —observatory Pleschenitzi (Minsk)

K_2 —Koretz,

$A_{1,2}$ —Alushta (the Crimea),

O_1 and O_2 —Odessa observatory,

C_1 —a site situated 25 km from Odessa observatory.

Curves with an index 1 are plotted for a components pair, E_x, H_y ; with an index 2 for components E_y, H_x .

Fig. 2. The curves of the magneto-telluric sounding. Leningrad State University.

1—Borok observatory,

1-4 are the curves plotted along the section through the Middle-Russian depression.

The curves are plotted for the mean impedance values for two components pairs.

Some of the curves of the apparent resistance are plotted in Fig. 1 and Fig. 2.

These curves have some peculiarities, which are in agreement with each other and which are conditioned by the section deep part properties. In the interval from a few seconds to minutes they have an ascending branch caused by the transition from the surface layers with the low resistance to the underlaying stratum with high resistance.

In the part of "middle periods" the curves have a strongly pronounced maximum, which form and value make it possible to get an idea about the conductivity distribution in the matter, which constitutes the lower part of the Earth crust and the mantle upper layers.

In the right side of the curves there is a distinct dropping tendency.

There is a descending branch on the curve of Pleschenitzi station (Minsk), plotted for periods including a diurnal wave. This branch characterizes the transition to the zone with the lower resistance.

Despite the well qualitative agreement of the experimental and theoretical curves, their quantitative interpretation is complicated because of the following circumstance:

ρ_k curves plotted for the near sites of observation or for different components pairs, recorded at one site of observation, are shifted along the vertical, the form of the curves is approximately preserved (see for instance the curves of Odessa observatory O_1 , O_2 and C_1 -curve for the site situated 25 km from the observatory. Fig. 1).

The difference in the curves position can be explained neither by the Earth's interior non-uniformity nor by their anisotropy and is no doubt conditioned by the presence in the found ρ_k values of some parameter which does not depend on the deep structure of the Earth.

We consider that this parameter appearance is caused by the presence of the horizontal non-uniformities in the conductivity of the upper sedimentary stratum and these non-uniformities distort the electric field. The sharp variation of the current orientation from one point to another can be also explained by this fact. In the cases given above, the difference between the curves has a parallel shift character which testifies to the constant parameter value in a wide frequency range and to the deep non-uniformities absence. Under more difficult geological conditions the picture can be much more complicated.

The complete quantitative interpretation of the curves can be made after their true position on the coordinates grid is determined. This determination can be made by the agreement of the ordinate values of the curve left side with the upper layers electric characteristics obtained by other auxiliary methods.