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Abstract

Full Text

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GEOPHYSICS

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RESULTS OF MAGNETOTELLURIC SOUNDINGS IN THE AREA OF THE DRIFT OF THE STATION NORTH POLE-13

(Presented by Academician A. N. Tikhonov on 22 III 1967)

Some geophysical methods for studying geological sections on land can be successfully applied for the same purposes in investigations at sea. Among them may be named the method of magnetotelluric soundings, which uses the Earth' s natural variable electromagnetic field as an energy source. Analysis of variations of the natural field makes it possible to obtain information on the distribution of electrical conductivity with depth and, consequently, provides information on the structure of the underlying medium.

According to published data ([1], [2]), the first magnetotelluric investigations at sea were carried out in the region of the Arctic Ocean in 1959–1960 and 1961 at the American drifting stations Arlis-1 and Charlie, and in 1962 at the Soviet drifting station SP-10. The results of these works are considered in detail below. Here we shall note only that the data obtained proved to be very incomplete—the field observations were conducted over a limited range of periods and therefore could not provide sufficient material for a correct interpretation of the section.

Fig. 1. Area of drift of station SP-13

At the beginning of 1965, a cycle of magnetotelluric investigations was carried out at the Soviet station SP-13 over a broad range of periods, which made it possible to obtain more complete information. The area of drift of station SP-13 is shown in Fig. 1. The drift area of station SP-10 and the locations of the American stations Arlis-1 and Charlie are also plotted there.

Along the entire drift path, the values of the parameters of the upper layer were determined: the ocean depth and the conductivity of seawater. During the drift of SP-13, during which the electromagnetic field was recorded, the ocean depth varied from 250 to 330 m; the electrical resistivity of the water averaged 0.4

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Fig. 2. Magnetotelluric sounding curves obtained at SP-13

Figure 2: Fig. 2. Magnetotelluric sounding curves obtained at SP-13

ohm · m. Along the path of station SP-13, four sectors with somewhat different depths were distinguished, for which separate interpretation of the data was carried out. Each sector covered an area of radius 10–15 km. The distance between sectors varied within the range from 50 to 80 km.

The recording of the field components was carried out with the aid of several variational installations with partially overlapping bands in the range

recorded periods. The total width of the pass band was determined within the limits 0.2–10^5 sec. The division values could be varied over a wide interval from 0.001 (short periods) to 1–3 γ/mm (long periods) for the magnetic channels and, correspondingly, from 0.025 to 0.30 mV/mm · km for the electric channels.

The method of processing and interpreting the experimental material was based on the solution of the Tikhonov–Cagniard problem on the propagation of a vertically incident plane electromagnetic wave in a horizontally homogeneous layered medium with plane interfaces. The homogeneity of the upper layer (ocean water) created conditions most favorable for interpreting the observational results: this was reflected in the fact that, over the entire range of periods used, the field vectors **E** and **H** proved to be mutually orthogonal, and the scatter in the values of the impedance at fixed values of the period T, caused by inhomogeneities of the upper layer, was very small. The noted features of the behavior of the field over a horizontally homogeneous medium are in accord with the expectations of the theory and are very interesting from a methodological standpoint.

Fig. 2. Magnetotelluric sounding curves obtained at SP-13

Certain difficulties were created by the generally elevated disturbance of the field, characteristic of regions of high latitudes and caused by the proximity of some sources. Against the disturbed background, diurnal variations were distinguished with difficulty and not quite reliably. The field of bays, associated with the ionospheric current ring in the auroral zone, could not in general be regarded as homogeneous. In view of the above, disturbances with periods exceeding 10^3 sec were not used in constructing the sounding curves. Variations of the P_c type were taken as the initial data; in form they are closest to sinusoidal and are caused by sufficiently distant sources. Their field could be assumed homogeneous and, taking into account the high conductivity of the underlying medium and the limited frequency spectrum, in calculating the impedance the corrections introduced by Price (3) could be disregarded.

In one of the selected intervals, the volume of experimental material proved sufficient for constructing a sounding curve with a well-developed left-hand part (Fig. 2). Its interpretation, carried out with the aid of master curves without introducing any additional data, leads to a three-layer section:

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Fig. 3. Diagram of a section through the drift region of station SP-13.

Figure 3: Fig. 3. Diagram of a section through the drift region of station SP-13.

$$\rho_1 = 0.4\ \Omega \cdot \mathrm{m}, \qquad \rho_2 = 0.8\ \Omega \cdot \mathrm{m}, \qquad \rho_3 = \infty,$$

$$h_1 = 0.25\ \mathrm{km}, \qquad h_2 = 2.0\ \mathrm{km}, \qquad h_3 = \infty,$$

where ρ_i are the electrical resistivities of the layers, and h_i are their thicknesses. The obtained values of the parameters of the first layer coincide with the true values of the specific resistivity of seawater and the ocean depth in the sounding area. The second layer, of low resistivity and considerable thickness, apparently corresponds to the sedimentary sequence. The third layer corresponds to a poorly conducting crystalline basement of great thickness.

The geoelectric section obtained in the interpretation of the magnetotelluric sounding curves is in full agreement with general ideas about the existence of sufficiently thick sedimentary deposits in marine basins near coastlines.

For the remaining three sounding sites the left-hand parts of the curves could not be constructed. The right-hand ascending branches of the curves made it possible to determine only the value of the total longitudinal conductance S_{exp}. The difference between S_{exp} and S_1 (the longitudinal conductance of the ocean water column) gives the value of the longitudinal conductance of the sedimentary layer. Assuming that along the entire drift path the resistance of the sediments is constant and equal to $\rho_2 = 0.8\ \Omega \cdot \mathrm{m}$, one can find the thickness values of the second layer for the remaining sounding sites. They proved to be 3700, 2850, and 2620 m.

Fig. 3. Diagram of a section through the drift region of station SP-13.

The section diagram in the direction from northwest to southeast through the drift area is shown in Fig. 3. A noticeable decrease in sediment thickness is observed with a general monoclinal rise of the crystalline basement toward the Lomonosov submarine ridge.

The results obtained for station SP-13 make it possible to approach in a new way the interpretation of the materials from stations Arlis-1, Charlie, and SP-10. In the work of the American investigators (1), the analysis of the experimental material was carried out using a two-layer model consisting of a layer of sea water covering a poorly conducting basement. The values of the thickness of the first layer found by the authors, close to 2.1–2.2 km for Charlie and 1.0–1.2 km for Arlis-1, gave good agreement with the actual ocean depths in the first case (2300 m) and diverged considerably in the second (400–450 m). This discrepancy, in the authors' opinion, could have been due to the proximity of

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the deep-water part of the ocean, located several hundred kilometers from the drift area of the station.

A geological interpretation of the SP-10 materials was not carried out. The author of the study limited himself to constructing the impedance curve in a range of periods bounded below by 60 sec. (2). Using these data to determine the section parameters of a two-layer model, we obtain a thickness of the upper layer 2.5–3 times greater than the actual ocean depth. The drift of SP-10 took place in a zone of shallow depths far from the deep-water part of the ocean, and the influence of the latter could not have affected the sounding results. Consequently, the explanation of the reasons for the discrepancy between the interpretation results and the factual data proposed by the American investigators must be called into question.

Table 1

Station	Ocean depth h, m	T, sec.	E/H	$S_1 = h_1/\rho_1$, mho	S_{exp}	S_2	h_2
Arlis-1	400	300–1200	0.24	3000	3300	2300	1840
SP-10	130	60–1000	0.60	325	1350	1025	820
	240	60–1000	0.45	600	1750	1150	320

The discrepancy between the experimental data and the actual ocean depths disappears with the transition to a three-layer model of the section. Assuming the sediment layer to be homogeneous and the value of the resistivity to be unchanged over the entire area of work of the named drifting stations, one can reinterpret

···to interpret the data from SP-10 and Arlis-1 and to obtain the values of the section parameters given in Table 1.

The table gives: the mean values of the ocean depth in the area of the stations' drift; the range of periods for which the impedance values remained constant; the impedance values themselves; the values of the longitudinal conductances of the water layer S_1, of the aggregate of the two upper layers S_{exp}, and of the second layer

$$S = S_{\text{exp}} - S_1.$$

A comparison of the results of interpreting the data considered makes it possible to suppose that the thickness of the sedimentary layer is greatest in the transition zone from the shallow-water to the deep-water part of the basin.

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In the region of great depths far from the shore, according to the results of interpreting the materials from Charlie station, the sediment layer becomes insignificant, and the section is well described by a two-layer model.

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

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