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Abstract

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EXPERIMENTAL DATA ON A HIGH-VELOCITY LAYER IN THE UPPER MANTLE OF THE EARTH

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Recently, as a result of investigations by the DSS method, information has appeared on the vertical inhomogeneity of the uppermost parts of the mantle. On the continent, velocities of longitudinal seismic waves of 8.4–9.0 km/sec have been found at comparatively small depths beneath the Mohorovičić surface (^1, ^5). In the western part of the Pacific Ocean, on a detailed DSS profile, a boundary with a velocity of 8.6–8.8 km/sec was identified at a depth of 22 km (approximately 10 km below the Mohorovičić surface) (^2). In comparison with the known Gutenberg curves, the indicated velocities are elevated.

In 1966–1967 the Institute of Oceanology of the Academy of Sciences of the USSR and the Department of Physics of the Earth of the Faculty of Physics of Moscow University carried out a large volume of marine investigations by the DSS method using bottom seismographs. These instruments made it possible to realize a high effective sensitivity and ensured the recording of deep waves from explosions at relatively large distances. As a result of analysis of the kinematics and dynamics of refracted waves on certain DSS profiles in the Black Sea and the Indian Ocean, new information was obtained on a high-velocity layer beneath the Mohorovičić surface.

Fig. 1. Velocity section of the Earth' s crust and the upper mantle for the western part of the Black Sea basin according to DSS data. The numbers 1–7 are layer numbers. The best agreement between the experimental and theoretical wave fields was obtained for the following model parameters (by layers from top to bottom): densities 1.0; 1.8; 2.2; 2.8; 3.3 and 3.4 g/cm^3; absorption 0; 0.1; 0.08; 0.06; 0.02; 0.001 and 0.001 km^{-1}; velocity gradients 0; 0.2; 0.05; 0.03; 0.05; 0.017 and 0.015 sec^{-1}.

On DSS profile No. 27 in the western part of the Black Sea basin (^3), good records of deep refracted waves were obtained at distances up to 160 km with a TNT charge of 130 kg. Waves P_1^{m} from the Mohorovičić surface are recorded in the first arrivals from distances of about 40 km. Their apparent velocity is 8.0–8.2 km/sec; the travel-time curves are rectilinear. At a distance of about 120

Figure 2

Figure 1: Figure 2

km from the shot point, a break is observed in the travel-time curve of the first arrivals, and the apparent velocity increases to 8.8 km/sec. On this basis, and from the dynamic characteristics, a replacement of the wave P_1^{m} by the wave P_2^{m} is established here, the latter being recorded in the first arrivals to the end of the profile.

From the system of reciprocal travel-time curves of the waves P^{m} and waves corresponding to the principal layers of the Earth' s crust, a seismic section was constructed. An averaged version of the section in the form of the graph $V(H)$ is given in Fig. 1. The surfac—

the Moho discontinuity is located at a depth of 19 km, and the boundary with a velocity of 8.8 km/sec is at a depth of approximately 30 km.

In order to analyze the dynamics and determine the nature of the principal waves, amplitude graphs were constructed and compared with theoretical calculations for models of media close to real ones (Fig. 2).* The best agreement between the experimental and theoretical wave fields was obtained for a model of an inhomogeneous layered medium with absorption. According to the calculations of B. S. Chekin ([8]), the attenuation of refracted waves in weakly

Fig. 2. Amplitude graphs of P^m waves for the western part of the Black Sea basin. **1** —experimental graph obtained from records of the bottom seismograph; **2** —the same, from records of the hydrophone of an anchored vessel; **3** —theoretical graph for the head wave from the sixth layer G_6; **4** —theoretical graphs of refracted waves from the sixth layer R_6 and the seventh layer R_7, calculated for gradients of 0.01 and 0.02 sec^{-1}

gradient media at small distances from the source is close to the attenuation of head waves G. But, beginning at a certain distance, the change in the amplitudes of the first waves will follow the law for refracted waves R (see Fig. 2, curves for G_6 and R_6). Thus, the approximate theoretical amplitude graph of a weakly refracted wave will consist of two branches: at first it follows the graph for the head wave, and then (when the refracted wave, calculated by asymptotic formulas, becomes more intense than the head wave) it follows the graph for the refracted wave.

The experimental amplitude graph of the wave P_1^m, constructed from records of the bottom seismograph, corresponds well to the regularity described above. Thus, this wave is a weakly refracted wave in the subcrustal layer. The vertical velocity gradient can be estimated by comparing the experimental and theoretical graphs. Its mean value is 0.017 sec^{-1}.

The maximum of the experimental amplitude graph of the first waves at a distance of about 120 km is associated with the arrival among the first onsets

Fig. 3. Velocity section of the Earth' s crust and upper mantle for the rift valley of the Arabian-Indian Ridge according to DSS data. The best agreement between experimental and theoretical wave fields was obtained for the following model parameters (by layers from top to bottom): densities 1.0; 2.5; 3.0 and 3.3 g/cm^3; absorption 0; 0.06; 0.01 and 0.001 km^{-1}; velocity gradients 0; 0.03; 0.04 and 0.03 sec^{-1}

Figure 2: Fig. 3. Velocity section of the Earth' s crust and upper mantle for the rift valley of the Arabian-Indian Ridge according to DSS data. The best agreement between experimental and theoretical wave fields was obtained for the following model parameters (by layers from top to bottom): densities 1.0; 2.5; 3.0 and 3.3 g/cm^3; absorption 0; 0.06; 0.01 and 0.001 km^{-1}; velocity gradients 0; 0.03; 0.04 and 0.03 sec^{-1}

of the wave P_2^m. In the interval 120-135 km the intensity of this wave decreases rather rapidly with distance (according to the law for head waves), and then the amplitudes again increase regularly. From the character of the amplitude graph, the wave P_2^m should be regarded as weakly refracted. The velocity gradient below the 8.8 km/sec boundary is approximately 0.015 sec^{-1}.

* The calculations were performed by B. V. Kholopov on a computer using T. B. Yanovskaya' s program ([9]).

A high-velocity layer in the upper mantle has also been discovered beneath the floor of the rift valley of the Arabian-Indian Ridge as a result of DSS in the joint expedition of the ships *Akademik Kurchatov* and *Vityaz* ([4]). The DSS profile, 84 km long, was located above the axial part of the rift valley. Charges of TNT weighing 25 kg were detonated. A system of reciprocal and pursuing hodographs of refracted waves from 5 recording stations was obtained. As a result of analysis of the seismograms and hodographs on the profile, three waves with boundary velocities of 5.0, 7.4, and 9.0 km/sec were identified. The corresponding seismic section is shown in Fig. 3. The structure obtained differs substantially from the structure of oceanic basins. Normal velocities of 8.0-8.2 km/sec, characteristic of the Mohorovičić discontinuity, were not found at all beneath the floor of the rift valley.

Fig. 3. Velocity section of the Earth' s crust and upper mantle for the rift valley of the Arabian-Indian Ridge according to DSS data. The best agreement between experimental and theoretical wave fields was obtained for the following model parameters (by layers from top to bottom): densities 1.0; 2.5; 3.0 and 3.3 g/cm^3; absorption 0; 0.06; 0.01 and 0.001 km^{-1}; velocity gradients 0; 0.03; 0.04 and 0.03 sec^{-1}.

The wave P_2^M, with a boundary velocity of 9 km/sec, is recorded in the first arrivals at distances greater than 40 km, and over the interval 28-40 km it is identified in subsequent arrivals. Comparison of the experimental and theoretical amplitude curves shows that, by the character of attenuation with distance, the wave P_2^M may be regarded as refracted in a layer with a velocity gradient of about 0.03 sec^{-1}.

The high-velocity layer in the upper mantle of the Black Sea basin at a depth of 30 km probably indicates processes of densification of mantle material, as a result of which prolonged intense subsidence of the basin and accumulation of a thick sedimentary sequence occurred. It should be noted that a similar suggestion about densification of the upper mantle beneath the Black Sea (only at much greater depths) was made earlier by S. I. Subbotin ([6]), on the basis of analysis of the gravity field and seismic data on the thickness and structure of the Earth’ s crust.

The high-velocity layer beneath the floor of the rift valley of the Arabian-Indian Ridge at a depth of about 15 km indicates an upwelling of upper-mantle material in the rift zone, which is also confirmed by the petrography and physical properties of rock samples raised from the ocean floor in this region ([7]).

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CITED LITERATURE

[1] I. P. Kosminskaya, *Method of Deep Seismic Sounding of the Earth’ s Crust and Upper Mantle*, “Nauka,” 1968.
[2] I. P. Kosminskaya, S. M. Zverev, in: *Structure and Development of the Earth’ s Crust in the Soviet Far East*, “Nauka,” 1969.
[3] Ya. P. Malovitskii, Yu. P. Neprochnov et al., DAN, 186, No. 4 (1969).
[4] Yu. P. Neprochnov et al., DAN, 185, No. 4 (1969).
[5] V. B. Sollogub, *Geophysical Collection of the Academy of Sciences of the Ukrainian SSR*, issue 25, 1968.
[6] S. I. Subbotin, *Geophysical Collection of the Academy of Sciences of the Ukrainian SSR*, issue 1 (12), 1965.
[7] G. B. Udintsev, DAN, 185, No. 4 (1969).
[8] B. S. Chekin, *Izvestiya of the Academy of Sciences of the USSR, Physics of the Earth Series*, No. 3 (1965).
[9] T. B. Yanovskaya, in: *Problems of the Dynamic Theory of Propagation of Seismic Waves*, vol. 8, “Nauka,” 1966.

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