Structure of the Upper Part of the Earth’ s Mantle from Observations of Earthquakes with Intermediate Focal Depth

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Structure of the Upper Part of the Earth's Mantle from Observations of Earthquakes with Intermediate Focal Depth

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The study of the structure of the Earth' s mantle was carried out using earthquakes of the Pamir-Hindu Kush epicentral zone. A specific feature of the latter is its local spatial extent and the presence of frequently occurring and fairly strong ($M = 5$—6.5) earthquakes, whose foci are located at depths from 70 to 270 km. In order to increase the accuracy of determining the geometric coordinates of foci directly in the epicentral zone, five temporary seismic stations were installed. Registration of elastic oscillations was carried out along a profile of stations passing through Central Asia, eastern Kazakhstan, the Altai, and the Sayan Mountains to the Lena River. The mean interval between stations was 70-100 km. The total length of the station profile was 3500 km. All observation points were equipped with standardized apparatus with SK-III-M seismometers and GB-4 galvanometers (2). The seismic channels had a flat characteristic in the frequency range from 10 to 0.7 Hz, with an average amplification of about 50,000.

Earthquake epicenters were determined by the method of K-epicenters (1), independent of the velocity section of the medium; focal depths were determined by a somewhat modified method of theoretical hodographs (6).

The study of the velocity section was carried out in two stages. Initially, at distances up to 1000 km, the structure of the subcrustal layer—the upper mantle —was determined down to depths of 240-250 km. The interpretation was conducted by a comprehensive method, the basic principles of which were borrowed from well-developed methods of seismic prospecting (3) and were based on data from 240 earthquakes.

The starting points of this method were: the method of the longitudinal vertical hodograph, the method of non-longitudinal hodographs, the method of time fields, "fields" of horizontal hodographs, and the method of vector subtraction of hodographs.

For great depths—down to 1400 km—earthquakes with different focal depths were used, recorded by all seismic stations located along the profile, and additionally, records from stationary seismic stations of the USSR. The velocity section of the

Figure 1

Figure 1: Figure 1

mantle was obtained from longitudinal waves by the Herglotz-Wiechert method. The experimental materials also made it possible to identify waves reflected from the principal discontinuity boundaries in the upper part of the mantle. Data on reflected waves were correlated with the results of interpretation by other methods. In addition to kinematic data, certain dynamic features of the identified waves were used. The use of the totality of all kinematic and dynamic features of the seismic records substantially increased, in comparison with works (4,5,8—13), the reliability of the velocity section obtained.

The velocity section of the mantle to a depth of 1400 km is schematically presented in Fig. 1. Examination of the section shows that in the subcrustal

in the layer below the base of the crust, at a depth of 85 km, a discontinuity is distinguished, characterized by an abrupt increase in velocity. Below this discontinuity the velocity remains practically constant or has a very slight positive gradient. In the depth interval 110-150 km, a channel with reduced values of the velocities of body waves is distinguished.

Fig. 1. Velocity section of the upper mantle for P- and S-waves. 1—according to Jeffreys, 2—according to Gutenberg, 3—our data

The reliability of identifying the channel is due to the use of the method of non-longitudinal vertical hodographs and vector subtraction of hodographs.

Deeper than 150—to 200 km—there is a gradual, very slight increase in the velocity of body waves, and at a depth of 200 km a fairly clear discontinuity is noted, with a jump in velocity toward an increase. The depth interval from 200 to 400 km has a different velocity pattern for longitudinal and transverse waves. For longitudinal waves, over the entire depth interval considered, there is a weak increase in velocity from 8.6 to 9.0 km/sec. For transverse waves, from a depth of 240 to 400 km a second channel of reduced velocity values is indicated. From 400 to 700 km the velocities of body waves increase regularly. In the region of 700 km the gradient of the velocity increase rises sharply down to a depth of 780 km. The boundary at this depth is characterized by a change in the gradient of velocity increase toward a significant decrease. At a depth of 900 km there is indicated, though very uncertainly, a boundary with some increase in the velocity gradient of longitudinal waves; as for transverse waves, this boundary is not traceable in them.

Let us briefly discuss the substantiation of the section obtained. The boundary at 85 km is clearly distinguished from reflected, head, and exchange-type sP-waves, as well as from the abrupt change in the character of the seismic record of earthquakes located above the boundary and immediately below it.

Fig. 2. Comparison of theoretical (thin solid line) and experimental (black

Figure 2

Figure 2: Figure 2

Fig. 3. Summary kinematic hodograph for a focal depth of 200 km

Figure 3: Fig. 3. Summary kinematic hodograph for a focal depth of 200 km

dots) isochrons for the section of the subcrustal layer. At left—the graph of the velocity section

As an illustration proving the existence of the first waveguide, Fig. 2 gives theoretical and experimental isochrons,

constructed along the section of the mantle under consideration down to a depth of 200 km. The decrease in the velocity of longitudinal waves in the waveguide, by 0.2 km/sec, adopted in the theoretical calculations proved insufficient to reconcile the calculated and experimental data. Apparently, the velocity discontinuity here is somewhat larger and reaches approximately 0.4 km/sec. It should be noted that the maximum discrepancy between the theoretical and experimental time fields does not exceed 0.8–1.0 sec at distances up to 1000 km, which indicates that the adopted scheme of the section of the upper mantle is sufficiently correct.

In Fig. 3 a kinematic hodograph is presented for the principal wave groups for a focus with a depth of 200 km. The kinematic data indicate the following principal regularities of the wave pattern. The hodograph of the first arrivals of longitudinal waves is practically rectilinear in the distance interval from 300–500 to 1600–1800 km, depending on the focal depth. At distances of 1800–2200 and 2600–2700 km two characteristic break points are observed on the hodograph. These points correspond to two loops of the hodograph, clearly traceable from the amplitude characteristics of the waves. The first loop is followed in the second arrivals at distances from 1200 to 2900 km, the second from 2000 to 3000 km. The first of them is associated with the 400-km boundary, the second with the 700-km boundary.

Fig. 3. Summary kinematic hodograph for a focal depth of 200 km

The kinematics of transverse waves differs substantially from the kinematics of longitudinal waves, which indicates a difference in the velocity section of the mantle for these two principal types of body waves. The hodograph of the transverse wave terminates abruptly at the 1000-km distance, and beyond this transverse waves are traced at later times, with a delay of 20–35 sec. This character of the hodograph indicates the existence of an abrupt decrease in velocity at a certain depth. In the same Fig. 3 are shown transverse waves reflected from depths of 240, 300, and 390 km, which correspond approximately to the roof, axis, and base of the second waveguide. For both longitudinal and transverse waves, the 700-km boundary is clearly distinguished from the reflections.

When the hodograph is discontinuous, the Herglotz-Wiechert method is not applicable for determining the velocity section, and therefore the velocity section from transverse waves was obtained by recalculation from the section from longitudinal waves through the curve of the ratio of layer velocities, obtained by an independent method.

On the whole, the upper part of the section—down to 240 km—was constructed with considerably greater detail than the deeper part. The accuracy of determining the depths of discontinuity boundaries in the mantle for the upper part of the section may be estimated at $±$5 km, and the velocity values at $±$0.1-0.15 km/sec. In the lower part of the section the accuracy of determining boundaries varies from $±$10 to $±$25 km, and the velocity values from $±$0.15 to 0.25 km/sec. It should be noted that cha

the character of the transitional boundaries in the section and the shape of the channels of lowered velocity values are presented schematically, since the available material does not permit a more detailed assessment of these characteristics of the section.

The observation system used did not make it possible to identify waves reflected from the Earth' s core, although they should have been fairly clearly distinguished beginning at 3000 km. The reason for the absence of such reflections remains, for us, unexplained.

Thus, the principal features of the mantle section in the region under consideration consist in the presence of: a layer of reduced velocity at a depth of 110-150 km for longitudinal and transverse waves, a second waveguide only for transverse waves at depths of 240-400 km, and a high-gradient layer at a depth of 700-780 km. The mantle section obtained pertains to the region studied and does not claim universality. Apparently, it differs somewhat in different regions of the globe, and one of the most important tasks of seismological research should be considered the need to study regional differences in the structure of the upper part of the Earth' s mantle, which is responsible for the development of geological processes recorded at the daytime surface.

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