A SET OF FEATURES DETERMINING THE PRESENCE OF A WAVEGUIDE IN THE EARTH' S CRUST OF THE GARM REGION OF CENTRAL ASIA

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A SET OF FEATURES DETERMINING THE PRESENCE OF A WAVEGUIDE IN THE EARTH' S CRUST OF THE GARM REGION OF CENTRAL ASIA

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The question of the existence in the Earth' s crust of layers of reduced velocities —waveguides—was first raised by Gutenberg. However, his intuitive assumptions for a long time did not find reliable confirmation. Only recently, owing to the broad development of methods of detailed investigation in seismology and in deep seismic sounding, have new data been obtained on the presence of low-velocity layers in the crustal section ([1], [2], [4]).

The basic information on the presence of a waveguide in the Earth' s crust of the Garm region was obtained by the method of sounding the medium with a set of plunging sources, analogous to seismic-prospecting shooting. Owing to the high level of seismic activity within the area under study, it was possible to select two earthquake zones, sufficiently localized in space, separated from one another by a distance of ~ 150 km, in each of which there were foci at different depths (from 5 to 30 km). The signals were recorded at seismic stations which, together with the epicentral zones under consideration, formed an almost rectilinear profile. The average distance between seismic stations was 15–30 km. Interpretation of the seismological material was carried out using elements of seismic prospecting —systems of reversed and overtaking hodographs were constructed. Earthquake epicenters were determined with the aid of circular templates of isochrons constructed from the difference in arrival times of transverse and longitudinal waves. The accuracy of epicenter determination was, in class A, ± 1–2 km; in class B, ± 3–5 km; and in class C, ± 10 km. In the present work, earthquakes determined with the accuracy of classes A and B were used predominantly. Processing of the experimental material consisted in constructing individual hodographs, which were then combined into averages. The root-mean-square error in constructing individual hodographs was 0.3-0.4 sec for P-waves and 0.4–0.5 sec for S-waves; the magnitude of the root-mean-square deviation of the mean hodograph from the true one was ~ 0.1 sec for P-waves and ~ 0.15 sec for S-waves; the values of the confidence intervals were 0.12–0.15 sec for P-waves and 0.2–0.35 sec for

Figure 1. Family of mean hodographs of P- and S-waves from observations of earthquakes from the western and eastern focal zones

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Figure 2 and Figure 3

Figure 2: Figure 2 and Figure 3

S-waves at a confidence level of 0.9.

The set of mean hodographs of different depths constitutes a family, or, as we shall call it, a field of horizontal hodographs. The field of hodographs of P- and S-waves is the principal element of the interpretation method, making it possible to judge the character of the velocity section of the medium under study. Figure 1 shows experimental families of hodographs of longitudinal and transverse waves from earthquakes in the western and eastern epicentral zones. Examination of the figure shows a "breakaway" of the hodographs of subsequent depths ($H = 15, 20$ km) from the preceding ones by up to 0.5 sec for P-waves and up to 0.8–1.0 sec for S-waves. We can explain such an effect in the disturbance of the regularity of the field by nothing other than the presence, in the crustal section, of a layer of reduced velocities.

Fig. 1. Family of mean hodographs of P- and S-waves from observations of earthquakes from the western and eastern focal zones

Consequently, the revealed peculiarity in the behavior of the family of hodographs became the principal criterion for distinguishing a low-velocity layer in the Earth' s crust of the region under study. With the aid of subsequent methodological operations, including longitudinal vertical hodographs, time fields, and isolines of Δt (the difference between the observed and theoretical longitudinal hodographs for a homogeneous crust with velocity $V_P = 6.0$ km/s), the approximate parameters of the waveguide were outlined: the depths of occurrence of its boundaries and the values of the velocities of P- and S-waves in the layer [2].

The optimal variant of the velocity section of the Earth's crust was sought by the system of experimental hodographs using a machine-search method (Fig. 2). As can be seen from consideration of Fig. 2, the optimal variants contain a decrease in the velocity of longitudinal waves by 0.4–0.5 km/sec and of transverse waves by 0.25-0.3 km/sec. The upper boundary of the waveguide in the west lies at a depth of (12 ± 2) km, in the east at a depth of (17 ± 2) km; the lower boundary of the waveguide in the west is located at a depth of (28 ± 2) km, in the east (26 ± 2) km. Let us note that in this same depth interval (15-25 km)

Fig. 2. Optimal velocity section of the Earth' s crust for P- and S-waves

Fig. 3. Curves of the ratios $v_P/v_S(H)$; $A_S/A_P(H)$, and the curves $A(H)$;

$v(H)$. 1 –for the eastern part of the region, 2 –for the western part

A. N. Semenov discovered a decrease in the ratios of the velocities of longitudinal and transverse waves v_P/v_S and in the ratios of the maximum amplitudes of transverse and longitudinal waves A_S/A_P. The coincidence of the depths of decreased velocities of P- and S-waves and of decreased ratios v_P/v_S and A_S/A_P (Fig. 3) makes it possible to conclude that the waveguide is correlated with a layer of decreased ratios v_P/v_S and A_S/A_P.

In order to obtain more detailed ideas about the character of the wave field in a medium including a low-velocity channel, the dynamic characteristics of direct longitudinal waves were considered. As a parameter, the amplitude of the first arrivals of the P-wave was chosen, as the quantity most sensitively responding to the presence in the crust of a layer of reduced velocities. Dynamic criteria indicating the presence of a waveguide in the section of the medium were formulated from model studies by O. G. Shamina (3). The experimental amplitude curves $A_P(\Delta)$ confirmed that these conditions are fulfilled. On the graphs of $A_P(\Delta)$ in the interval of epicentral distances 120–140 km, corresponding to the shadow zone, a minimum is clearly distinguished, the probability of whose existence is 0.95. A displacement of the amplitude minimum with a change in source depth is noted. On the curve $A(H)$, constructed for an epicentral distance of 120 km, a minimum of amplitudes is also noted in the depth interval 15–25 km (Fig. 3).

Additional evidence in favor of the existence of a waveguide in the Earth' s crust was provided by analysis of the subsequent arrivals of wave groups. For the velocity model of the Earth' s crust with the inclusion in it of a layer of reduced velocities, a theoretical hodograph of refracted waves was calculated. In this case, two branches are observed in the subsequent arrivals.

travel-time curves, owing their existence to the low-velocity layer. These travel-time curves have a common initial point at a distance of ~ 160 km and then diverge at an angle toward larger epicentral distances, with different velocities. The upper branch of the travel-time curve corresponds to the wave reflected from the lower boundary of the waveguide; it can be traced to distances of ~ 270 km with a velocity of 6.0–6.1 km/sec, corresponding to the average velocity in the medium above the channel. The lower branch of the travel-time curve represents the result of refraction of seismic rays in the crust below the waveguide; at distances greater than 300 km, this wave merges with the wave reflected beyond the critical angle from the Mohorovičić boundary.

From observations of explosions and earthquakes, empirical travel-time curves were constructed with lengths up to 500–600 km. Analysis of the observed travel-time curves shows the presence, in the subsequent arrivals, of two groups of waves P_1' and P_1''. From comparison of the theoretical and experimental material it is seen that the travel-time curves P_1' and P_1'' are identical to the two branches of the angle of the calculated travel-time curve. Therefore, in accordance with the above, the formation of the wave groups P_1' and P_2'' can be explained by the presence of a layer of reduced velocities. The structure of the experimental travel-time curves in the subsequent arrivals does not contradict the structure of the travel-time curves when a waveguide is present in the cross section of the medium.

In conclusion, we list the principal features characteristic of crustal waveguides, identified by comparing the low-velocity channel in the Garm region with channels in other regions of the globe: 1) a decrease in the total number of earthquakes and in their total energy, 2) a decrease in the ratios of the velocities of longitudinal and transverse waves, 3) a decrease in the ratios of the maximum amplitudes of longitudinal and transverse waves.

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