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Abstract

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ON THE QUESTION OF A WAVEGUIDE IN THE EARTH’S MANTLE AND ITS PHYSICAL NATURE

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The question of the existence of a waveguide in the upper parts of the Earth’ s mantle has been discussed in the literature for a number of years (1-3); however, sufficiently reliable proof of its existence has not been given. Below we present some results of investigations of this question using data from seismic stations of the USSR.

In all, 9 earthquakes were used, the data on which are given in Table 1. Records were used only at such epicentral

Table 1

Date of earthquake	Coordinates of epicenter and region	Depth of focus, km	M	α, km^{-1}
11 X 1956, O: $02^h24^M32^s$	$\lambda = 151.3$ E, $\varphi = 45°4$ N, east of the Kuril Islands	100	$7^1/_4$—$7^1/_2$	0.000143
18 VIII 1954, O: $04^h42^M25^s$	$\lambda = 175°$ W, $\varphi = 21.5°$ S, region of the Tonga Islands	170	$7^1/_4$—$7^1/_2$	0.000146
23 V 1956, O: $20^h48^M28^s$	$\lambda = 178.5°$ W, $\varphi = 15.5°$ S, Fiji Islands	400	$7^1/_4$—$7^1/_2$	0.000139

Date of earthquake	Coordinates of epicenter and region	Depth of focus, km	M	α, km^{-1}
7 VI 1954, $O: 10^h 15^M 36^s$	$\lambda = 152.5°$ E, $\varphi = 4°$ S, New Britain Islands	460	$6^3/_4$—7	0.000156
20 II 1954, $O: 18^h 35^M 01^s$	$\lambda = 125°$ E, $\varphi = 7.5°$ S, Banda Sea	520	$6^1/_2$—7	0.000184
16 VIII 1955, $O: 11^h 47^M 03^s$	$\lambda = 155°$ E, $\varphi = 6°$ S, Solomon Islands	200	$6^3/_4$—$7^1/_2$	
31 III 1955, $O: 18^h 17^M 07^s$	$\lambda = 124°$ E, $\varphi = 8°$ N, Philippines	50	$7^1/_4$	
29 III 1954, $O: 06^h 17^M 06^s$	$\lambda = 3.5°$ W, $\varphi = 37°$ N, Spain	640	$7^1/_4$—$7^1/_2$	
21 III 1954, $O: 23^h 42^M 12^s$	$\lambda = 95°$ E, $\varphi = 24.5°$ N, Burma	170	7—$7^1/_2$	

distances where there was no danger of the sought phase being overlapped by any other of the known ones. In this it was assumed, in accordance with the latest data (4, 5), that the layer of reduced velocities, which can serve as a waveguide, lies at depths of the order of 100 km.

Figure 1 gives an example of a record of the phase P_a, obtained at the Sverdlovsk station on 18 VIII 1954, $O: 04^h 42^M 25''$, $\Delta = 126°$.

Figure 2 gives the travel-time curves of the phases P_a and S_a obtained in the present work. The rectilinear form of the travel-time curves is evident, despite the scatter of the points.

The equations of the travel-time curves have the form (t in minutes, Δ in degrees)

$$\begin{aligned} P_a: &\quad t = 0.85\ (\pm 0.08) + 0.223\ (\pm 0.001)\,\Delta; \\ S: &\quad t = 0.96\ (\pm 0.03) + 0.403\ (\pm 0.002)\,\Delta. \end{aligned}$$

For the velocities of the P_a and S_a waves we obtain, respectively:

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

$$\begin{aligned} P_a:&\quad 8.30\ (\pm 0.03)\ \text{km/sec};\\ S_a:&\quad 4.57\ (\pm 0.03)\ \text{km/sec}, \end{aligned}$$

which agrees quite well with the data of previous investigations. The periods of the P_a waves were in the range 5-12 sec., and the periods of the S_a waves in the range 7-30 sec.

Fig. 1

In addition to studying the form of the hodographs of the phases P_a and S_a, in order to prove that the phases under consideration represent waves that have passed through a waveguide, the law of attenuation of the amplitudes of the corresponding waves was investigated. The law of amplitude attenuation is determined by the formula:

$$\frac{\ln \dfrac{A_0}{A}}{\ln \dfrac{r}{r_0}} = n + \alpha \frac{r - r_0}{r \ln \dfrac{r}{r_0}},$$

where α is the absorption coefficient, and n is the exponent of geometrical spreading. For the case of a waveguide (cylindrical wave) $n = 0.5$.

We obtained, for the earthquake of 11 X 1956, $n = 0.52$, $\alpha = 0.00014\ \text{km}^{-1}$. For other earthquakes it was necessary to take into account the sphericity of the Earth; in doing so $n = 0.5$ was taken, and only α was determined; the obtained values of α are given in Table 1.

Thus, the waves studied have an evidently cylindrical character. The values of the velocities do not permit assigning them to surface waves or to Stonely waves, and they could have passed only through a waveguide.

Fig. 2

As for the possible cause of the origin of the waveguide, Magnitskii ([6]) showed that a waveguide may be due to a temperature effect if the temperature gradient at the corresponding depth has a value of 7-10° per 1 km. Zharkov, considering such an assumption unlikely, proposed an explanation following from relaxation effects ([7]). However, it is easy to show that if one takes into account the dependence thermal conductivity on temperature ([8]), the geothermal gradient will reach 18°/km at a depth of 100 km beneath the continents and 15°/km at a depth of 50 km beneath the oceans.

In work ([6]) an explanation was proposed for the nature of the waveguide by a polymorphic transition in $MgSiO_3$. However, taking into account the entire body of data on the state of matter at the depths under study, the older suggestion that the layer of reduced velocities is associated with amorphization of the material would be of greatest interest. For a quantitative estimate of this hypothesis we have adopted for the excess volume the expression

$$\frac{V - V_0}{V_0} = e^{-E/kT},$$

whence for the change in the bulk modulus we obtain

$$\frac{\Delta K}{K_0} = \frac{\Delta V}{V_0} \ln \frac{\Delta V}{V_0} \frac{\partial \ln E_0}{\partial \ln V}.$$

Thus, the change in the velocity of seismic waves will be

$$\frac{dv}{v} = \frac{1}{2} \frac{\Delta V}{V_0} \left(1 + \ln \frac{\Delta V}{V_0} \frac{\partial \ln E_0}{\partial \ln V} \right).$$

Since, according to Zharkov ([7]),

$$\frac{\partial \ln E_0}{\partial \ln V} \simeq 2.5,$$

we obtain the change in the velocity of elastic waves upon amorphization:

$$dv/v \simeq 6\%,$$

which agrees sufficiently well with observational data ([1],[4],[5],[9]).

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