

ON DETERMINING THE FREQUENCY DEPENDENCE OF THE ABSORPTION COEFFICIENT OF LONGITUDINAL SEISMIC WAVES PROPAGATING IN THE EARTH' S MANTLE

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Abstract

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GEOPHYSICS

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ON DETERMINING THE FREQUENCY DEPENDENCE OF THE ABSORPTION COEFFICIENT OF LONGITUDINAL SEISMIC WAVES PROPAGATING IN THE EARTH' S MANTLE

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Until the present time, estimates of the absorption coefficients of longitudinal seismic waves P_n and P , propagating in the Earth' s mantle, have been made on the basis of an analysis of the change in the amplitudes of maximum oscillations in these waves with epicentral distance ⁽²⁻⁶⁾. This method, in its modern form, does not make it possible to investigate with sufficient accuracy the dependence of the absorption coefficient on frequency. In the present work, by methods based on studying the character of the change with epicentral distance Δ of the amplitude spectra ⁽¹⁾ of the waves P_n and P , an attempt is made to estimate the values of the amplitude absorption coefficients and their dependence on frequency. The solution of these questions is of general geophysical and applied significance, in particular in estimating the possibility of recording the short-period components of the waves P_n and P .

In the work the following assumptions are made: 1) The attenuation of the waves P_n and P due to the phenomenon of absorption is expressed by the factor $e^{-\alpha\Delta}$, where α is the absorption coefficient, dependent on frequency f , and Δ is the distance along the seismic ray. 2) The characteristics of the seismograph-ground system and the structure of the Earth' s crust at all observation points at different Δ are assumed to be identical, and the changes in the amplitudes of oscillations in the waves P_n and P due to the heterogeneous structure of the upper mantle and crust are assumed not to depend on frequency. 3) Absorption in the lower mantle can be characterized by some mean approximate value of the absorption coefficient α , independent of depth; in reality, α is apparently a function of depth, but because of the limited experimental data it does not seem possible in the present work to take this dependence into account.

Under the assumptions made, the absorption coefficient of the waves and its dependence on frequency can be determined from the character of the change in the spectra of the waves with epicentral distance by the method described in work ⁽¹⁾. This same method is applied to determine the boundary absorption

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

coefficient as a function of frequency in the P_n waves from observations on a single profile with a horizontal Moho boundary.

Data used. To compute the amplitude spectra of the waves P_n and P , seismic records obtained in the USA and the USSR from underground nuclear explosions carried out in Nevada in 1958 were used ^(2,3,8).

The spectra of the waves P_n and P were computed on electronic computers by the method of parabolic interpolation in the frequency range from hundredths of a hertz to 20–30 Hz. However, in calculating the absorption coefficients, because of the small amplification of the equipment at frequencies below 0.3 Hz and the errors introduced when digitizing records at frequencies above 3–4 Hz, only portions of the spectra lying in the range from 0.33 to 3.3 Hz were used. The spectra of the waves P , obtained in the USSR on equipment different from that used in the USA, were first, by multiplication

them to the corresponding magnification ratios of the seismographs were reduced to the form of the spectrum obtained on the apparatus indicated above.

Determination of α_{P_n} and α_P . From the amplitude spectra of P_n waves, observed along a single profile in the range Δ from 203 to 736 km for the Logan and Blanca explosions, carried out under identical conditions, and from

Fig. 1. Dependence on frequency of the difference of absorption coefficients $\delta\alpha_{P_n}(f)$ (1) and of the values of the absorption coefficients $\alpha_{P_n} = (1.9 \pm 0.12) \cdot 10^{-3}f$ (2) of P_n waves recorded in the range Δ from 203 to 736 km. a —experimental values of $\delta\alpha_{P_n}$, b —experimental values of α_{P_n} , c —limits of the values of α_{P_n} determined from amplitude curves in ^(2,3)

Fig. 2. Dependence on frequency of the difference of absorption coefficients $\delta\alpha_P(f)$ (1) and of the values of the absorption coefficients $\alpha_P = (2.8 \pm 0.27) \cdot 10^{-4}f$ (2) of P waves recorded in the range Δ from 1968 to 9170 km. a —experimental values of $\delta\alpha_P$, b —experimental values of α_P , c —limits of the values $\alpha_P = 6 \cdot 10^{-5} \text{ km}^{-1}$ for oscillations with periods from 2 to 12 sec according to ^(4,6)

the spectra of P waves observed in the range Δ from 1968 to 100 080 km for the Blanca explosion, the values of the ratios of the amplitudes of the spectral components $A(f_k)/A(f_i)$ were determined. The value for f_k was taken equal to 1 cps, and the values f_i were taken at the frequencies: 3, 33; 2.5; 1.67; 1.25;

Fig. 3

Figure 3: Fig. 3

0.83; 0.71; 0.62; 0.55; 0.50; 0.40; 0.33 cps. From the ratios $\ln \frac{A(f_1)}{A(f_i)} : \Delta$ in the above-mentioned ranges Δ , the slopes of straight lines approximating these experimental values of the ratios were determined by the method of least squares. The slopes of these straight lines represent the difference of the absorption coefficients $\delta\alpha_{P_n}$ and $\delta\alpha_P$ for two frequencies f_k and f_i ; their values are shown respectively in Figs. 1 and 2 (points *a*). The values $\delta\alpha_{P_n}$ and $\delta\alpha_P$ were approximated by the method of least squares by straight lines (lines 1 in Figs. 1 and 2); the slopes of these straight lines characterize the dependence of the difference of absorption coefficients $\delta\alpha(f)$ on frequency. By parallel displacement of the straight lines $\delta\alpha(f)$ to the origin of coordinates (lines 2 in Figs. 1 and 2), the frequency dependences of the absorption coefficients themselves, $\alpha_{P_n}(f)$ and $\alpha_P(f)$, were obtained.

The equations of the averaging straight lines have the form: for the P_n wave, $\alpha_{P_n} = (1.9 \pm 0.12) \cdot 10^{-3} f \text{ km}^{-1}$; for the P wave, $\alpha_P = (2.8 \pm 0.27) \cdot 10^{-4} f \text{ km}^{-1}$.

Discussion of the results. Figure 3 shows the values of the absorption coefficients α_{P_n} , α_P , found by amplitude ^(2-6,9,10) and spectral methods. In the same figure, using the data of ⁽¹⁾, the values of the absorption coefficients of longitudinal waves are plotted for various crystalline and metamorphic rocks occurring in the Earth's crust, determined by amplitude methods in the frequency range from 1 to 50-60 Hz. As can be seen from consideration of this figure, straight line *I*, over a wide frequency range from 0.1 to 50-60 Hz, approximates rather well the corresponding experimental values of the absorption coefficients in rocks of the Earth's crust and upper mantle. Straight line *II* runs parallel to *I*, but approximately one order of magnitude below it, which is associated with the smaller values of the absorption coefficients in the lower mantle.

Fig. 3. Summary data on the frequency dependence of the absorption coefficient of longitudinal waves propagating in the Earth's crust and in the upper mantle (*I*) and in the lower mantle (*II*). Experimental values for the upper mantle: *a*—according to the data of the present work, *b*—according to ^(2,3,5), *v*—according to ^(9,10); *g*—in rocks of the Earth's crust: granites, gneisses, marbles, quartzites, crystalline schists, basalts, according to ^(1,11); for the lower mantle: *d*—according to the data of the present work, *e*—according to ^(4,6).

Thus, the frequency dependences of the experimental values α_{P_n} and α_P , found both by studying the character of the change in the ratios of the spectral components in the spectra of waves P_n and P with epicentral distance, and by amplitude methods, can, within a certain range of periods, be approximately approximated by the above-mentioned linear dependences; i.e., it may be assumed

that the absorption coefficients in the upper and lower mantle, respectively, depend linearly on frequency.

Table 1 gives the values of the absorption decrement v , found in the present work by spectral methods and determined from the character of the decrease of amplitudes with Δ according to the data of ^(2-6,9,12,13); in ^(2,3), for determining v , the same records were used as in the present work; the table also gives the corresponding values $Q = \pi/v$.

From comparison of the values of v for waves P_n , determined by different methods from records obtained on identical equipment, it is seen that these values are close; the values of Q are correspondingly close as well. In work ⁽⁵⁾, when higher-frequency equipment was used, smaller values of v and, correspondingly, larger values of Q were obtained for waves P_n . It should be emphasized that the values of v and Q , found from waves P_n , characterize the absorbing properties of a comparatively small layer of the mantle near its upper boundary.

When considering the values of the absorption coefficients and decrements v of P waves propagating in the mantle, it should be borne in mind that, in connection with the change of velocities in the mantle with depth, P waves, with increasing Δ , pass successively through ever deeper parts of it. Thus, for example, when observing P waves at $\Delta = 20^\circ$, the wave reaches depths of the order of 350 km, i.e., the path of the wave lies entirely in the upper mantle, the average velocity of P waves in which is about 8.5 km/sec. At $\Delta = 90^\circ$, the P wave penetrates to depths of the order of 2700 km, and the average velocity along its path is of the order of 10.5 km/sec. The absorbing properties of the mantle apparently decrease with increasing depth, as is indicated, in particular, by the different values of the absorption coefficients and decrements of absorption—

Table 1

Regions of the Earth	Wave type	Period, sec.	According to this work, v	According to this work, Q	According to other determinations, v	According to other determinations, Q
Earth's crust	$\bar{P}$	0.3			0.016	200 ⁽⁵⁾
Earth's crust	$\bar{P}$	0.1–1.0			0.017	185 ⁽¹²⁾
Earth's crust	P^*	0.5–0.8			0.011	286 ⁽³⁾
Earth's crust	S^*	1.5–1.8			0.012–0.014	260–224 ⁽³⁾

Regions of the Earth	Wave type	Period, sec.	According to this work, v	According to this work, Q	According to other determinations, v	According to other determinations, Q
Upper mantle (at the boundary M)	P_n	0.3	0.015	210	0.0055	570 ⁽⁵⁾
Upper mantle (at the boundary M)	P_n	0.6–0.8	0.015	210	0.012	260 ^(2,3)
Upper mantle (at the boundary M)	P_n	0.3–3.0	0.015	210	—	—
Upper mantle to a depth of about 600 km	sS_{cS}	25			0.017–0.02	185–151 ⁽¹³⁾
Upper mantle to a depth of about 600 km	P_a	8–12			0.012	260 ^(9,10)
Lower mantle	P	1.0	0.0029	1100		
Lower mantle	P	2.0	0.0029	1100	0.0013	2600 ^(4,6)

Regions of the Earth	Wave type	Period, sec.	According to this work, v	According to this work, Q	According to other determi- nations, v	According to other determi- nations, Q
to a depth of about 2700 km	P	4.0	0.0029	1100	0.0023	1300 ^(4,6)
to a depth of 2900 km	P	12.0	0.0029	1100	0.0080	400 ^(4,6)
to a depth of 2900 km	S_{cS}	25			0.0022	1430 ⁽¹³⁾

for the waves P_n , P_a , and P . Therefore the values found in the present work for the absorption coefficient for P waves are approximate.

The value of the decrement increases somewhat with depth, which is connected with the increase in velocity. This leads to a certain decrease of Q in the deeper parts of the mantle. However, taking into account what was said above about the dependence of α_P on depth, the values of the absorption decrement given in the table characterize rather the tendency of the decrement to increase with depth than its absolute values. To estimate the values of the absorption coefficients in definite depth intervals of the mantle, it is necessary to use jointly the spectra of waves of several types: P , PP , PcP , PKP , and others.

In this work, records of P_n and P waves excited by shallow sources of the expansion-center type were used; in their spectra the amplitudes of spectral components at frequencies below 0.3 Hz were relatively small. Therefore, for a more accurate estimate of the dependence of α_P on frequency in the frequency range from 0.2 to 0.05 Hz, records of strong earthquakes should be used, for which the maximum of the amplitude spectra lies in the range from 0.2–0.1 Hz, and the amplitudes of the spectral components at the above-mentioned frequencies have a significant magnitude.

Using spectral methods, one can, by the method described above, determine the values of the absorption coefficients of longitudinal and transverse waves and establish their dependence on frequency.

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