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Abstract

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GEOPHYSICS

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DETERMINATION OF THE VELOCITY SECTION OF THE UPPER MANTLE OF EUROPE

(Presented by Academician M. A. Sadovsky, 17 VII 1968)

In this work, models of velocity sections of S waves in the upper mantle of Europe are investigated by the method of trial and error. The method is based on the use of programs for solving direct problems ([1,2,8,15]) and, in general outline, consists of the following.

Proceeding from geophysical considerations, from the capabilities of programs for solving direct problems, and from the available machine time, we specify the domain in which we shall seek solutions (sections). In this domain we try sections, calculate for them theoretical regularities (travel-time curves, amplitude curves, dispersion curves), and compare them with observations. The solution of the problem is the set of sections for which the calculated regularities agree with the observations.

The available programs for solving direct problems make it possible to calculate travel-time curves and amplitude curves of any body wave in the ray approximation ([9]), and dispersion curves of Love waves ([4]) and Rayleigh waves ([7]) for a layered spherically symmetric Earth. The observed data were taken from published works.

The **group velocity of the fundamental harmonic of Love waves** for periods of 30–90 sec was taken from ([12]). The data were obtained from three earthquakes near the southern coast of Turkey, recorded at the station Uppsala (Sweden). The accuracy of the data in ([12]) is estimated as ±0.1 km/sec for all periods.

The **travel-time curve of the first arrivals of S waves** was specified from 10 to 35° with a step of 1°. In the range 10–26° the data of ([6,10]) were used, and in the range 27–35° ([11]). The standard errors in the range 10–29° were taken equal to ±10 sec, and in the range 30–35° to ±20 sec.

As a measure of the deviation of the calculated curves from the experimental ones, the mean-square σ^2 and maximum d_m discrepancies (normalized by the standard errors) were adopted. If σ^2 and d_m exceeded the specified limits (1.0 and 1.2, respectively), the section was rejected. The values of the limits were

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chosen broad enough so that, according to these criteria, only clearly unsuitable sections would be rejected. The algorithm for comparing travel-time curves is constructed so that it is not necessary to know which branch corresponds to each segment of the experimental travel-time curve. Sections having a shadow-zone extent greater than 3° were also rejected, since such a model does not explain many points of the experimental travel-time curve.

The **amplitude curves of S waves** were taken from ([3]). They were compared with the calculated ones visually.

Parameterization. Each mantle model is represented by a set of parameters —these are the positions of layer boundaries, values of velocities, densities, etc. at the boundaries (for details see ([2])). The values of velocities and densities inside the layers are interpolated linearly from their values at the boundaries. The parameterization includes specifying the following quantities: the number of layers in the models that we shall test; the limits within which the value of each parameter may vary from section to section; and the discretization steps for each variable parameter.

We proceeded from the assumption that among the possible models there must be models with a waveguide beginning deeper than the Mohorovičić discontinuity (the M boundary), and models having at least one boundary with a velocity varying under the waveguide. Hence the minimum number of layers in the upper mantle is four. The limits for the velocities were chosen so as to include (with some margin) all known sections of the upper mantle. We varied the shear-wave velocities at the first four layer boundaries b_1–b_4 (beginning with the M boundary).

Naturally, the upper part of the section must be specified in greater detail. Therefore, for the 2nd and 3rd boundaries between layers it was decided to vary not only the velocities on them, but also their depths H_2 and H_3. We also introduced restrictions on the distances between these depths, so as not to consider models with very thin layers. The minimum thickness of the first layer is 15 km, that of the second 30 km. Deeper than H_3, the section practically coincides with the Jeffreys section ([14]). As a result, we chose the parametrization of the upper mantle given in Table 1.

Table 1

Depth from the M boundary in km	Limits of variation of b, in km/sec
$H_1 = 0$	$4.3 \leqslant b_1 \leqslant 4.8$
$15 \leqslant H_2 \leqslant 65$	$4.2 \leqslant b_2 \leqslant \frac{0.4}{315} H_2 + 4.8^*$
$H_3 + 30 \leqslant H_3 \leqslant 215$	$4.2 \leqslant b_3 \leqslant \frac{0.4}{315} H_3 + 4.8^*$
$H_4 = 315$	$4.2 \leqslant b_4 \leqslant 5.2$
$H_5 = 565$	$b_5 = 5.65$
$H_6 = 735$	$b_6 = 6.08$

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Depth from the M boundary in km	Limits of variation of b, in km/sec
$H_7 = 935$	$b_7 = 6.33$

* This means that b_2 and b_3 are bounded above by the straight line joining the points $H = 0,\ b = 4.8$ and $H = 315,\ b = 5.2$ (see Fig. 2).

In the present work we did not specially investigate the structure of the crust; for this purpose it would have been necessary to choose the observations, region, etc., differently. However, the interpretation of the data used by us is undoubtedly affected by which crustal model we adopt. Therefore each mantle model was combined by us with 9 models of the earth' s crust: a mantle section was regarded as "good" if it satisfied the observations for at least one such model. In addition, in computing body waves for each variant, three source depths were tried.

The density distribution with depth was taken according to Bullen' s model A ([13]).

The **search of upper-mantle sections** was carried out by the "hedgehog" method ([2]). By the Monte Carlo method (random trials), in the space of the unknown parameters $b_1, b_2, b_3, b_4, H_2, H_3$, the nodes of a coordinate grid were searched; these nodes corresponded to discrete parameter values with discretization steps of 0.1 km/sec for b_1, b_2, 0.2 km/sec for b_3 and b_4; $H_2 = 15$ km, $H_3 = 20$ km. For each node, hodographs and the dispersion curve were calculated, and a comparison was made according to the criteria indicated above. After a "good" node had been found, the nodes adjacent to it were searched. For those nodes which also proved to be good, their neighboring nodes were searched, and so on, until all neighbors of the good nodes had been investigated. Then a new region of solutions was sought by the Monte Carlo method. We regarded as neighboring nodes those which differ from one another by 1 step in one or two coordinates.

The **history of the computation** is as follows. The first 204 nodes, searched by Monte Carlo, did not satisfy the experimental data; the 205th node proved to be good. The search by the "hedgehog" method yielded another 150 good nodes. In this process about 2500 nodes neighboring the good ones were searched. After this the machine returned to the search by the Monte Carlo method. Nodes 1066, 1094, 2209, 2235, 2370 proved to be good, but had already been found earlier by the "hedgehog" method. In all, 2590 nodes were searched by the Monte Carlo method, after which the search was stopped. In this case the probability that a group of 40 or more good nodes had been missed is less than 0.07.

Selection of sections from amplitude curves. For 151 upper-mantle sections whose hodograph and dispersion agree with observations, plots of the calculated amplitude curves A_T^* were constructed for different focal depths. They were compared visually with the experimental points from (3). As a result of

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Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

the comparison, 7 sections were found whose A_T^* curves satisfy the experimental data (Fig. 1).

Fig. 1. Example of A_T^* (solid line) agreeing with the observations from (3) (points)

Description of the solution. The obtained solutions occupy a small subregion in the space of variable parameters. The values of 3 parameters (b_1, b_2, b_3) are the same in all 7 sections: $b_1 = 4.5$, $b_2 = 4.5$, $b_3 = 4.6$ km/sec. However, as is seen from Fig. 2, H_2, H_3, b_4 vary from section to section by 1-2 steps, so that the solution contains sections with and without a waveguide. Our solutions differ greatly from the classical sections—

Fig. 2. Velocity sections of the upper mantle: 1 —found in the present work; 2 —Jeffreys [14]; 3 —Gutenberg [5]; 4 —Lehmann [6]; 5 —limits of the parametrization

zones of the upper mantle: Jeffreys [14], Gutenberg [5], Lehmann [6], none of which satisfies the selected body of data.

Thus, out of 35,000 possible sections allowed by our parameterization (Table 1), 7 solutions were found that agree satisfactorily with the selected set of observations. Nevertheless, substantial differences between some of them indicate that, on the basis of the selected data, it is impossible to carry out a geophysically unambiguous interpretation. The stability of the solutions with respect to the character of the parameterization remains uninvestigated (the introduction of additional boundaries into the section, reduction of the discretization step, etc.).

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REFERENCES

[1] I. Ya. Azbel, V. I. Keilis-Borok, T. B. Yanovskaya, *Computational Seismology*, vol. 2, "Nauka," 1966.
[2] V. P. Valyus, *Computational Seismology*, vol. 4, "Nauka," 1968.
[3] I. Vanek, P. Stoltsner, in: *The Upper Mantle*, Moscow, 1964.
[4] E. B. Bylkovich, A. L. Levshin, M. G. Neygauz, *Computational Seismology*, vol. 2, "Nauka," 1966.

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[5] B. Gutenberg, in: *The Earth' s Crust*, IL, 1957.
[6] I. Lehmann, in: *The Upper Mantle*, Moscow, 1964.
[7] M. G. Neygauz, G. V. Shkadinskaya, *Computational Seismology*, vol. 2, "Nauka," 1966.
[8] T. B. Yanovskaya, *Izvestiya of the Academy of Sciences of the USSR, Geophysical Series*, No. 8 (1963).
[9] T. B. Yanovskaya, *Problems of the Quantitative Study of Seismic Waves*, vol. 8, Leningrad, 1966.
[10] E. R. Arnold, H. Jeffreys, M. Shimshoni, *Geophys. J. Roy. Astr. Soc.*, 8, No. 4 (1963).
[11] M. Båth, *Travel Times of the Principal Earthquake Waves for Uppsala*, Uppsala, 1947.
[12] M. Båth, A. Vogel, *Geofisica pura e appl.*, 38, No. 4 (1957).
[13] K. E. Bullen, *An Introduction to the Theory of Seismology*, Cambridge, 1953.
[14] H. Jeffreys, *The Earth, Its Origin, History and Physical Constitution*, IL, 1960, p. 153.
[15] F. Press, S. Beihler, *J. Geophys. Res.*, 69, No. 14 (1964).

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