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Peculiarities of mantle waves from long-range profiles

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Abstract. Long-range seismic experiments carried out in different regions of the USSR show strong variations of the mantle wave velocities and attenuation. Relatively high mantle velocities, more than 8.2–8.3 km/s, are observed in the old platform areas. To exclude the crustal influence on the mantle waves and to separate the vertical and horizontal inhomogeneity effect the relations between the overlapping travel-time curves are analyzed. As a result, a mantle stratification with positive average velocity gradient in the strata is revealed up to depths of 200 km. Local inclusions with very high (more than 8.5 km/s) and relatively low (less 8.0 km/s) velocities are typical of the mantle.

Key words: Russian and Siberian Platforms – Long-range profiles – Mantle velocities

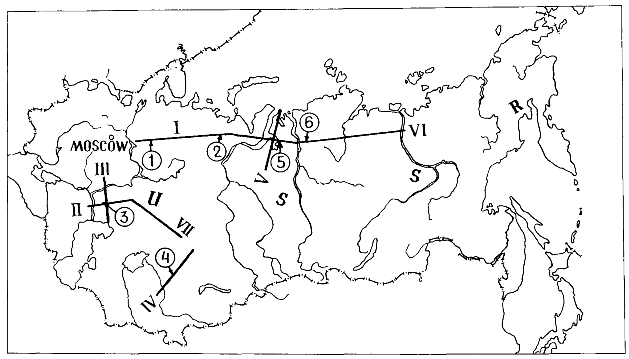

Fig. 1. Location of the long-range profiles I–VII used in the paper. Figures in circles indicate the areas for which the velocity models are given in Fig. 8

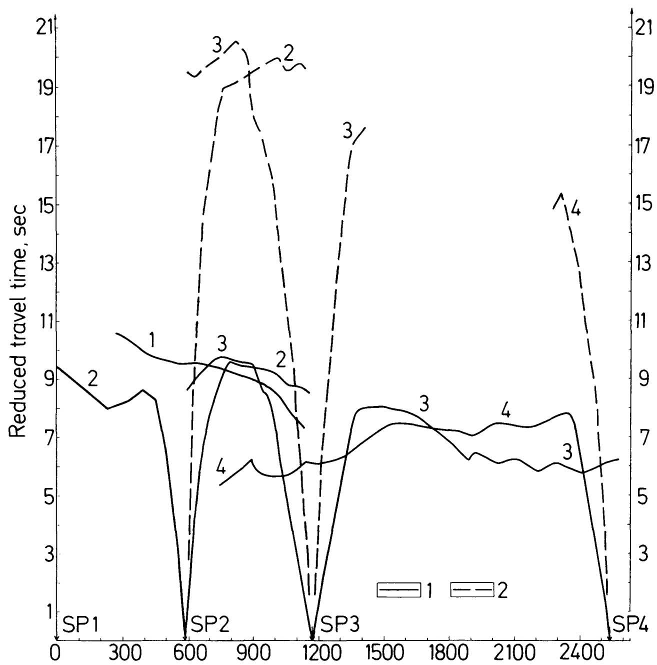

Fig. 2. Reduced travel-time curves of *P*- and *S*-waves for the profile VI. 1 = *P*-waves, 2 = *S*-waves

Seismic investigations of the Earth's crust and upper mantle by controlled source experiments have been carried out in the Soviet Union on several long-range profiles (Fig. 1). The reversed and overlapping system of observations with source-receiver distances of more than 1,500 km was used. The recording was performed with seismometers of 1.5 Hz natural frequency and "Taiga" seismic recorders (Chichinin et al., 1969) resulting in an overall frequency band of 1–9 Hz. Three displacement components were recorded at each station: one vertical and two horizontal (along the profile and perpendicular to it) which facilitated the correlation of different types of waves: longitudinal, shear and converted waves. The station interval varied between 5 and 15 km, the shotpoints were situated on average 500–800 km apart.

Preliminary results of the investigations were published by Burmakov et al. (1975), Yegorkin et al. (1977), Yegorkin (1980), Yegorkin and Pavlenkova (1981). In this paper some general features of the mantle refractions are described. Special attention is paid to those wave characteristics which are indicative of vertical and horizontal inhomogeneities of the upper mantle.

Examples of typical travel-time curves and record sections of the vertical components are presented in Figs. 2, 3 and 4. The refracted waves penetrating into the upper and lower parts of the crust and also into the mantle as the waves reflected from the intermediate crustal boundaries and *M*-discontinuity are reliably correlated. It was also possible to separate reflections and converted waves from upper mantle boundaries, but special computer analysis was needed.

The mantle refractions start to be recorded as first arrivals at epicentral distances of 150–200 km. Their apparent

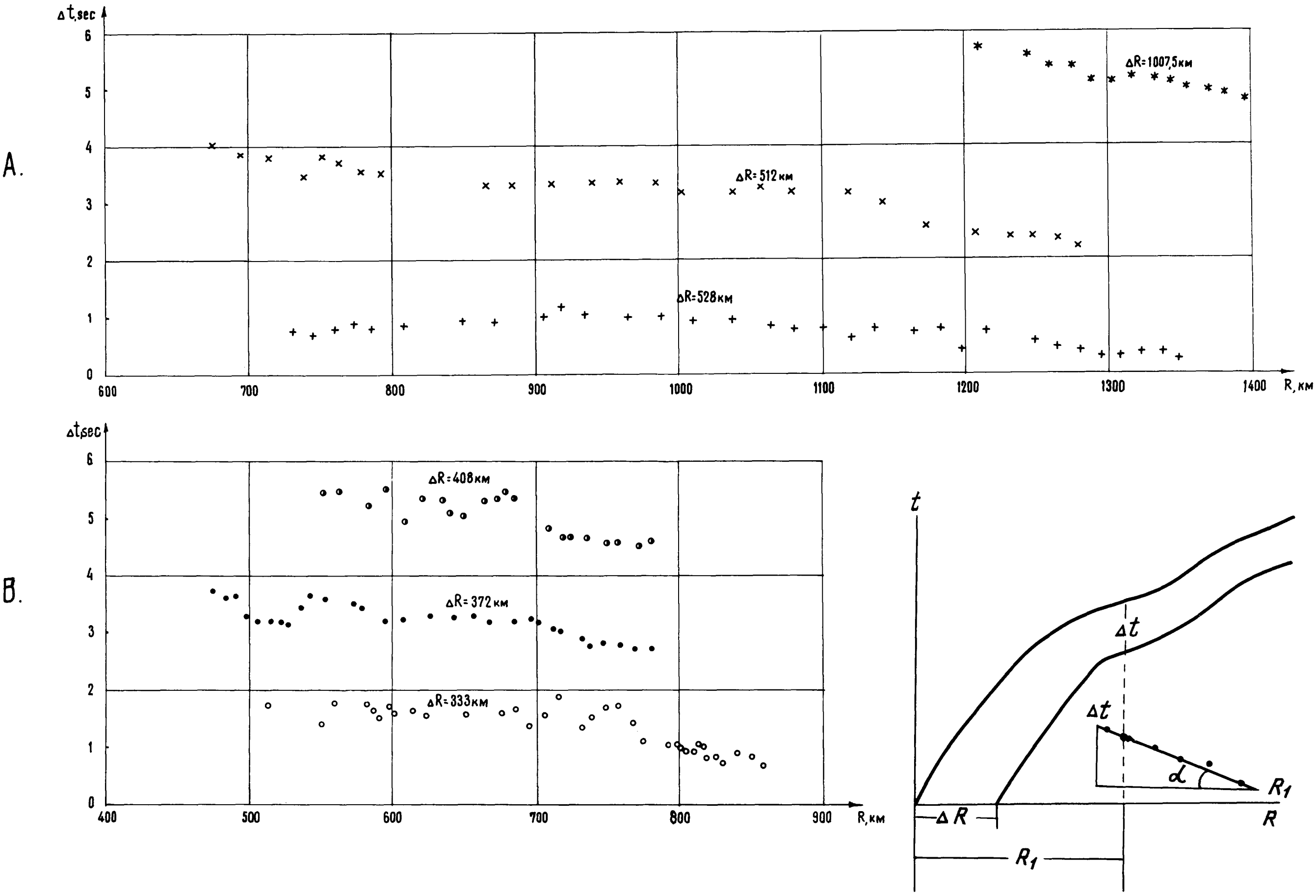

Fig. 5. The relative time differences (Δt) for pairs of the overlapping travel-time curves of the first arrivals for the profiles I, II and IV. ΔR – interval between two shotpoints of the overlapping profiles, R – distance to the farthest first shotpoint

velocities varied between 7.5 and 9.5 km/s which in many cases is influenced by the relief of the M-discontinuity and by the sedimentary variations. However, a common trend of a gradual increase in the apparent velocity with distance from the shotpoint is marked for all the profiles (Fig. 2).

To separate the effect of horizontal inhomogeneity of the crust and upper mantle from the velocity distribution with depth, special methods of travel-time analysis were used (Gamburzev et al., 1952). The comparison of the reversed travel-time curves gave the possibility to reveal high and low velocity blocks beneath the M-discontinuity. The vertical velocity gradient was derived from $\Delta t(R_1)$-curves, where Δt is the time difference between two overlapping travel-time curves of the mantle refractions, and R_1 the distance to the farthest shotpoint (Fig. 5). The Δt-curves are relatively free of the influence of the crustal thickness variations and the horizontal inhomogeneity of the mantle near the M-discontinuity. The curve form depends mainly on the velocity distribution with depth and on the wave type: Δt of the head waves refracted at the same boundary is constant and it decreases with R_1 for refractions if the velocity increases with the depth. The change of the first arrival apparent velocities that is due to the arrival of refractions from deeper mantle boundaries is established from Δt-curves by sharp changes of the curve inclination.

Examples of $\Delta t(R_1)$-curves for the long-range profiles I, II, IV are presented in Fig. 5. They show some regularities in the mantle velocity distribution. Usually Δt decreases

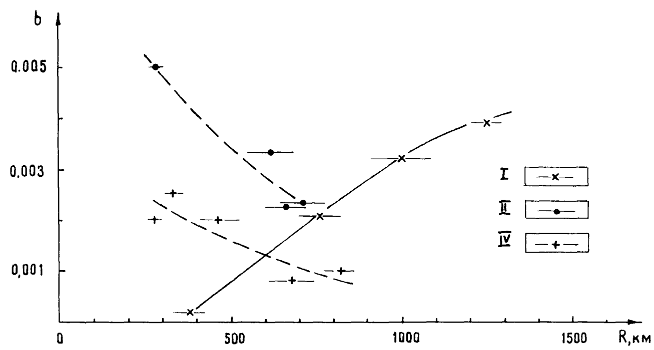

Fig. 6. Relation between coefficient "b", slope of the Δt-curve (see Fig. 5), and distance to the shotpoints for the profiles I, II, IV

with increasing distance which indicates a regular increase of the velocity with depth in all regions. The slope of the $\Delta t(R_1)$-curves may be used for the calculation of the vertical velocity gradient. Their average values varied between 0.002–0.006 s^{-1}. An analysis of the Δt-curves also gives the possibility to determine how the vertical velocity gradient changes with depth. For this, the slope of the Δt-curve (parameter "b") is useful (Averbuch, 1975). In Fig. 6 plots of the parameter "b" for the profiles I, II, IV are presented. It was measured from Δt-curves selected in the following way: the time differences were taken between the travel-time curves observed over ranges of about 100 km starting

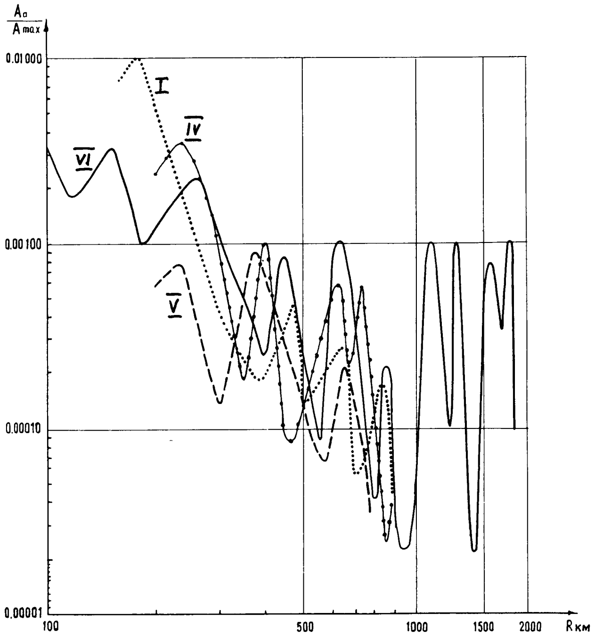

Fig. 7. Normalized amplitude curves of the mantle reflections for the profiles I, IV, V, VI

with observational distances of 200–300 km for all curves overlapping the same section of the profile. R is the distance between the middle of the observation interval and the shotpoints. The length of these sections is shown in Fig. 6 by the horizontal lines.

Figure 6 shows that the vertical velocity gradient in the upper mantle increases slightly with depth in the Russian Platform (profile I) because the parameter "b" increases with distance. In Kazakhstan (profile IV) and in the Precaspian Depression (profile II) the parameter "b" decreases with increasing R. That means that the vertical velocity gradient decreases with increasing depth in these areas.

These peculiarities characterize only some average trend of the change of the mantle velocity with depth. A detailed analysis of the $\Delta t(R_1)$-curves shows that the velocity distribution in the mantle is more complicated. It is not monotonic. For instance, the change of the slope of the $\Delta t(R_1)$-curve at distances of about 700 and 1110 km which is observed for all curves of Fig. 5 indicates a regular layering in the uppermost mantle. The case of $\Delta t(R_1)$ increasing with R is also observed (profile I, Fig. 5) which may be explained by the local low velocity layers.

Similar conclusions about heterogeneities of the upper mantle may be drawn on the basis of the dynamic parameters of the mantle refractions. Figure 7 presents the amplitudes of absolute displacement normalized to a maximum amplitude for every shotpoint. A rapid decrease of the amplitudes in the interval 100–300 km is observed. At greater epicentral distances the wave attenuation is on the average weaker. It is also possible to separate two branches of the amplitude curves with different slope in the distance intervals 300–800 and 1000–2000 km. Local minima of the amplitudes which may be referred to shadow zones or wave interference of first arrivals are typical for the data. These characteristics support the idea about regular stratification of the mantle and existence of separate layers with different velocities, velocity gradients and attenuations.

Besides the stratification, strong horizontal inhomogeneities of the upper mantle are revealed on the long-range profiles. Comparison of the reversed and overlapping travel-time curves of the first arrivals gave the possibility to establish the velocity variation near M-discontinuity. They are usually very high in the old platform area, more than 8.3 km/s and relatively low in young platform areas (Yegorkin, 1980; Yegorkin and Pavlenkova, 1981). The velocity models are also different for platforms of the same age (Fig. 8).

One of the more surprising features of the mantle is the existence of very high velocities in its uppermost part. Velocities of 8.5–8.6 km/s were established beneath M-discontinuity in the Precaspian Depression (Fig. 9) and in the Siberian Platform. These features were observed in many other regions, in continents (Ansorge et al., 1979; Fuchs, 1979) and in oceans as well (Steinmetz et al., 1977;

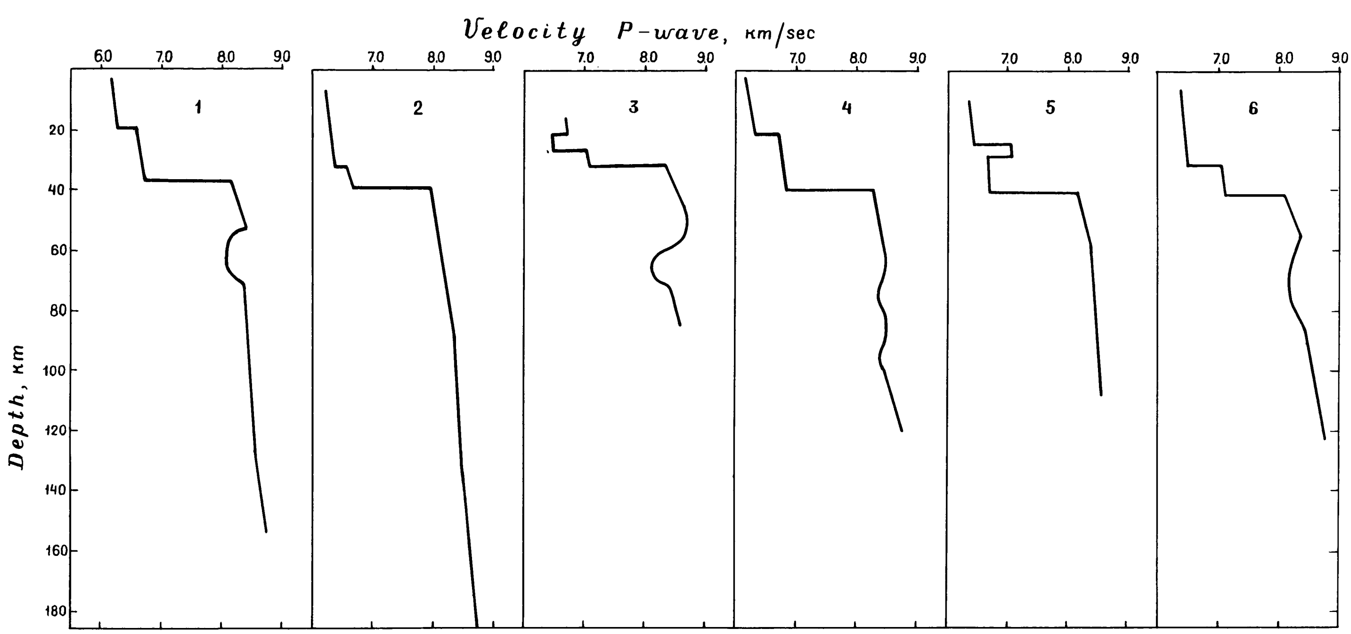

Fig. 8. Velocity models of the mantle for the areas, indicated in Fig. 1

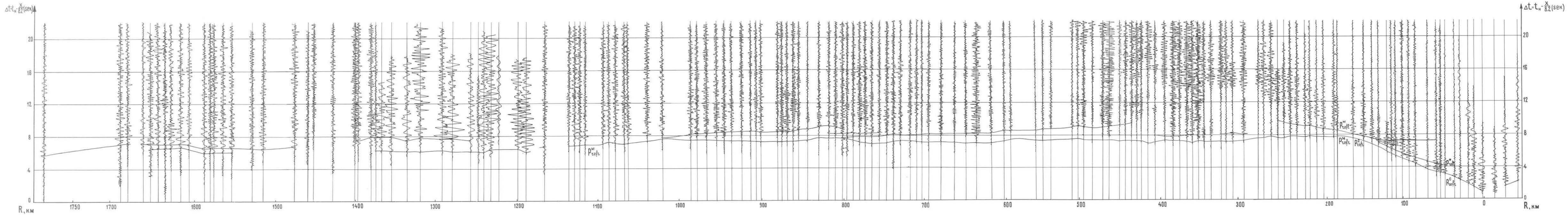

Fig. 3. Record section of the vertical components for the eastern part of the profile VI, shotpoint 4

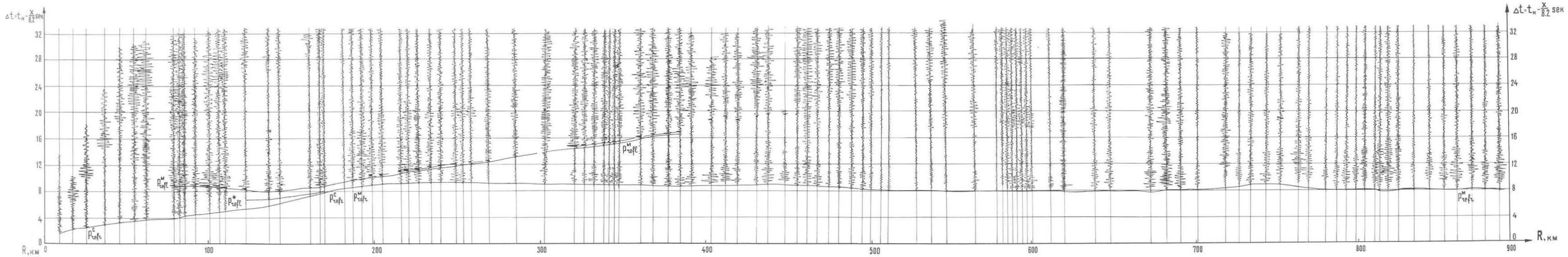

Fig. 4. Record section of the vertical components for the profile IV

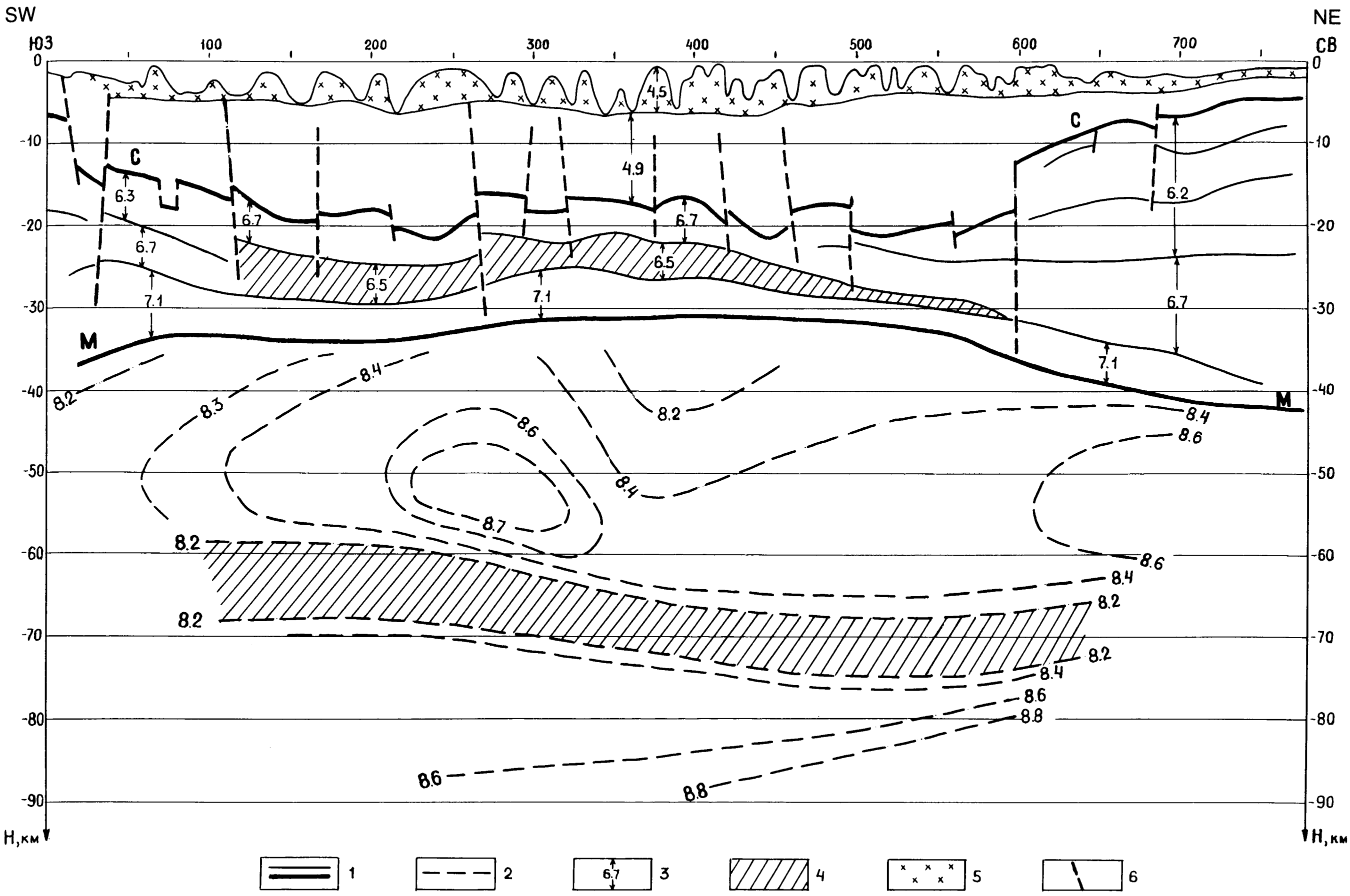

Fig. 9. Seismic cross-section along the profile II, crossing the Precaspian Depression: 1 – Seismic boundaries (*C*-basement, *M*-Moho), 2 – velocity isoline, 3 – layer velocity, 4 – low velocity zones, 5 – salt domes, 6 – fault.

Shimamura et al., 1976). Comparison of the crossed long-range profiles in Siberia proved the reality of these high velocities in different directions of the wave propagation. It is necessary to emphasize that their reliability is based upon the dense observation system with the reversed and overlapping profiles and by using the first arrivals. The method of mathematical modelling (Yegorkin et al., 1977; Pavlenkova and Pšenčik, 1977) was applied to construct the cross-sections. The dynamic characteristics of the waves were also used in the interpretation in a form of qualitative comparison of the experimental amplitude curves of the waves with the calculated density of the rays for two-dimensional models. The accuracy of the velocity determination is 0.1 km/s in the 100–150 km interval of the profile.

Another characteristic of the mantle models is the existence of low velocity layers at depths of 55–80 km. They are usually more pronounced in the old platform regions. For instance, Fig. 8 gives the one-dimensional models for Moscow Syncline (1) and Precaspian Depression (3) of the old East-European Platform, Central Kazakhstan Folding (4) and East-Siberian Platform (6), that belong also to the oldest structures of Eurasia, and for the younger tectonic elements – Predural Forland (2) and West-Siberian Platform (5). The latter have no velocity inversions in the mantle because the average velocities in the upper 50 km beneath the *M*-discontinuity are lower in these areas than in the old platforms. That means the velocity in the inversion zones beneath the old platforms is a rather more normal mantle velocity than a reduced one.

Thus, the data presented characterize the upper mantle as a medium with strong horizontal and vertical velocity heterogeneities, including high and low velocity layers and bodies. A regular large-scale layering of the mantle with increasing velocity in the layers is also observed. The conclusions were made considering only first arrivals. If reflections and converted waves are taken into account, the mantle appears much more complicated (Yegorkin, 1980).

References

Ansorge, J., Bonjer, K.-P., Emter, D.: Structure of the upper-most mantle from long-range seismic observations in southern Germany and the Rhinegraben area. Tectonophysics **56**, 31–48, 1979

Averbuch, A.G.: Interpretation of seismic refraction data. Moscow: Nedra 1975

Burmakov, Y.A., Yegorkin, A.V., Popov, E.A., Ryaboy, V.Z.: Upper mantle structure of the north-eastern regions of the European Platform from seismic data. Dokl. Akad. Nauk SSSR **224**, 84–87, 1975

Chichinin, I.S., Yegorov, G.V., Yemelianov, A.V., Bochanov, A.J.: Portable telemonitored seismic equipment "Taiga". In: Methods of seismic research, pp. 95–119. Moscow: Nauka 1969

Fuchs, K.: Structure, physical properties and lateral heterogeneities of the subcrustal lithosphere from long-range deep seismic sounding observations on continents. Tectonophysics **56**, 1–5, 1979

Gamburzev, G.A., Riznichenko, J.V., Berson, I.S. et al.: Correlation method of refracted waves, AN SSSR, Moscow, 90–140, 1952

Pavlenkova, N.I., Pšenčik, I.: Mathematical modelling as a method of solution of two-dimensional seismic problem, Publ. Inst. Geophys. Pol. Acad. Sc. **A-4** (115), 267–275, 1977

Steinmetz, L., Whitmarsh, R.B., Moreira, V.S.: Upper mantle structure beneath the Mid-Atlantic Ridge north of the Azores based on observations of compressional waves. Geophys. J. R. Astron. Soc. **50**, 353–380, 1977

Shimamura, H., Asada, T.A.: Apparent velocity measurements on an oceanic lithosphere. Phys. Earth Planet. Int. **13**, 15–22, 1976

Yegorkin, A.V.: General features of mantle structure. In: Seismic models of the lithosphere for the major geostructures on the territory of the USSR, pp. 161–170. Moscow: Nauka 1980

Yegorkin, A.V., Pavlenkova, N.I.: Studies of mantle structure of USSR territory on long-range seismic profiles. Phys. Earth Planet. Int. **25**, 12–26, 1981

Yegorkin, A.V., Ryaboy, V.Z., Starobinets, L.N., Druzinin, V.S.: Construction of horizontal heterogeneous velocity model of the upper mantle from DSS data. Izv. AN SSSR, Fizika Zemli **7**, 1977

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