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**Abstract**

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**GEOPHYSICS**

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# STRUCTURE OF THE EARTH' S CRUST ACCORDING TO REGIONAL SEISMIC WORK IN THE SOUTHEAST OF THE RUSSIAN PLATFORM

The article examines the results of interpreting hodographs of waves recorded at shot-instrument distances exceeding the critical distances during regional seismic investigations in the southeastern regions of the Russian Platform, carried out by the All-Union Scientific Research Institute of Geophysical Prospecting Methods in 1956-1959. The tasks and methodological principles of regional seismic investigations along reference profiles are set forth in special articles ([2,3]).

A characteristic feature of the seismograms obtained is the presence on them of groups of waves possessing similar kinematic and dynamic features (an analogous phenomenon was also observed in other regions during deep seismic sounding work ([3,4])). The first wave of a group, usually having the greatest length of the tracking zone and the most stable dynamic characteristics, is considered to be a single longitudinal wave. In all, up to 7 groups of waves are distinguished (Fig. 1; the initial waves of the groups are denoted by the symbols $P_1^0$, $P_2^0$, $P_1^*$, $P_2^*$, $P_1^{\text{pr}}$, $P_1^{\text{otr}}$, $P_2$), the first of which is associated in its origin with the surface of the crystalline basement. The waves $P_1^*$, $P_1^{\text{pr}}$, $P_1^{\text{otr}}$ were probably formed at boundaries close to the Conrad surface (the basalt surface) and the Mohorovičić surface. The remaining waves correspond to certain intermediate boundaries.

The first waves of each of the noted groups are in most cases traced over a certain interval (20-100 km) in the region of first arrivals (in some cases as visible first arrivals). The wave $P_2^0$ is traced in first arrivals at distances of 95-155 km; $P_1^*$, 115-175 km; $P_2^*$, 145-210 km; and $P_1^{\text{pr}}$, 155-240 km. In most cases the available material does not make it possible to trace reliably the waves of any group after their interference with a later wave.

Dominant in intensity over the greater part of the seismograms are the waves of the groups $P_1$, $P_1^{\text{otr}}$, $P_2$. The ratio of the intensities of the waves $P_2^0$, $P_1^*$, $P_2^*$ changes with distance from the source of oscillation: closer to the shot point the intensity is somewhat greater for the wave $P_2^0$; then waves formed at deeper boundaries begin to predominate. The value of the effective attenuation

Fig. 1. Schematic hodographs along Profile II.

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coefficient is smallest for waves formed at the deepest boundaries (for the wave $P_1$, on the order of $0.7 \cdot 10^{-5}$ $m^{-1}$; for the wave $P_1^0$, $4.0 \cdot 10^{-5}$ $m^{-1}$). The frequencies of all recorded waves are approximately the same and lie within the range 11-16 Hz.

To determine the nature of the waves recorded at overcritical distances, an analysis was used of the totality of dynamic and kinematic criteria (the character of the change with distance from the shot point of the apparent velocities measured from the hodographs of the different waves; the parallelism of overtaking hodographs; the general character of the observed wave pattern; the presence on the seismograms of waves of different types related to a single boundary; entry into the region of first arrivals, etc.). On the basis of this analysis the following conclusions were drawn: near the region of critical—

from a seismic station, supercritical reflections and head waves are recorded together. With increasing distance from the source of oscillations, the intensity of the supercritical reflections formed at seismic boundaries lying above the Mohorovičić surface becomes so small that they are difficult to distinguish against the background of other, sufficiently strong oscillations, and at

**Fig. 1.** Schematic hodographs along Profile II. $P_0$—head waves formed at the surface of the crystalline basement; $P_2^0$—head waves and precritical reflections formed at the first refracting boundary within the crystalline sequence; $P_1^*$—waves formed at the surface of the "basalt"layer; $P_2^*$—waves formed at a refracting boundary located within the "basalt" ; $P_1$—waves formed at the Mohorovičić surface; $P_1^{otr}$—waves reflected from the Mohorovičić surface at an angle greater than the critical angle; $P_2$—waves associated with a seismic boundary located below the Mohorovičić surface; cross—the initial point of the head wave.

these distances only head waves are traced (it is possible that weakly refracted waves were also assigned to the head waves, since by kinematic criteria they are difficult to distinguish from head waves). For waves formed at the Mohorovičić boundary, a somewhat different picture is observed. In this case there are both head waves and supercritical reflections, and, according to the available material, as a rule the supercritical reflections predominate in intensity.

Construction of sections and determination of boundary velocities from head waves were carried out by the "time-field" method. The value of $V_{gr}$ for waves $P_1^0$ is $6.1 \pm 0.4$ km/sec; for $P_2^0$, $6.6 \pm 0.2$ km/sec; for $P_1$, $7.2 \pm 0.3$ km/sec; for $P_2^*$, $7.6 \pm 0.3$ km/sec; and for $P_1^{pr}$, $8.5 \pm 0.3$ km/sec. The mean depths to the constructed discontinuity boundaries for these waves are, respectively, 5; 10; 20; 30; and 38-40 km. The relief of the boundaries lying above the Mohorovičić surface, averaged with the same degree of accuracy, in general repeats the pattern observed on the surface of the crystalline basement. A

Fig. 2. Various variants of the structure of the earth' s crust within the southeast of the Russian Platform: A—according to A. V. Egorkin; —according to I. V. Pomerantseva, E. D. Tagai, and M. V. Margoteva; —graph of average velocities

Figure 2: Fig. 2. Various variants of the structure of the earth's crust within the southeast of the Russian Platform: A—according to A. V. Egorkin; —according to I. V. Pomerantseva, E. D. Tagai, and M. V. Margoteva; —graph of average velocities

general subsidence of all boundaries toward the Peri-Caspian depression is noted. No changes in the character of the behavior of deep boundaries are observed on approaching the Cis-Urals.

The velocity section of the Earth' s crust is characterized by boundary, effective, and layer velocities obtained as a result of processing the hodographs of reflected and head waves. The values of effective velocities for

were determined from reflected waves by the "theoretical hodograph" method, and from head waves by the method of S. V. Chibisov, using the points of intersection of hodographs and initial points. The statistical processing that was carried out on a considerable volume of material made it possible to obtain an accuracy in the determinations of $V_{\text{eff}}$ on the order of 4-5%*. From reflected-wave data the following values of effective velocities were obtained: down to the first discontinuity boundary below the basement surface, 5.15-5.2 km/sec; down to the second, 5.5 km/sec; down to the third, 5.9 km/sec; down to the Mohorovičić discontinuity, 6.15-6.25 km/sec (Fig. 2 ). Boundary velocities determined from head waves usually exceed the layer velocities determined from reflections by 200-400 m/sec. On the basis of the currently existing ideas about the propagation of seismic waves in layered media, a variant of the velocity section of the earth' s crust, shown in Fig. 2 A, may be proposed to explain this phenomenon. This variant (compiled by A. V. Egorkin) assumes the existence, within the earth' s crust, of relatively thin layers with elevated values of the velocities of propagation of elastic waves.

**Fig. 2.** Various variants of the structure of the earth' s crust within the southeast of the Russian Platform: **A**—according to A. V. Egorkin; —according to I. V. Pomerantseva, E. D. Tagai, and M. V. Margoteva; —graph of average velocities.

Possible confirmation of the presence of thin layers may be provided by: reflecting surfaces of discontinuity boundaries located 2-4 km deeper than the refracting boundaries; the existence of different types of waves, whose origin may be explained by the presence in the earth' s crust of layers with reduced velocities; the discrepancy between the values of seismic-wave propagation velocities obtained as a result of processing records of earthquakes and surface explosions, etc.

On this basis, the following velocity section of the earth's crust may be proposed: the upper part of the crust consists of a layer with an average layer velocity of about 6.0 km/sec, within which, at a depth of 12-13 km, there is a so-called thin layer ($h$ = 1-3 km) with $V_{\mathrm{pl}} = 6.6$ km/sec; from a depth of about 20 km down to the Mohorovičić discontinuity, a layer is distinguished with an average layer velocity of about 7.1 km/sec, within which, at a depth of 31-33 km, a thin layer ($h$ = 1-3 km) with $V_{\mathrm{pl}} = 7.6$ km/sec is distinguished. Below the Mohorovičić discontinuity, in a layer about 10 km thick, $V_{\mathrm{pl}} = 8.15$ km/sec. The surface along which the velocity of propagation of head waves is 9.15 km/sec is possibly the surface of a thin layer located in the mantle.

The recording of head and reflected waves from a number of surfaces makes it possible to suppose that the change in velocity near these boundaries occurs abruptly (at any rate, there is a sharp increase in velocity within a layer of small thickness).

It is quite probable that in individual layers there is some positive, and possibly also negative, gradient of velocity change with depth.

* The processing of reflected waves and the determination of average velocities by the method of S. V. Chibisov, using deep seismic sounding materials, were first carried out by E. D. Tagai.

It should be noted that quantitative data on the thicknesses of thin layers and on the velocities of propagation of elastic vibrations in rocks lying at depths of 12-20 km and 33-39 km cannot be determined with the necessary accuracy and give only a qualitative character of the section. For a more definite solution of this question, further accumulation of material is necessary.

Experimental materials obtained recently ([5]) show that the observed discrepancy between the values of $V_{\mathrm{gr}}$ and $V_{\mathrm{pl}}$ may be explained not only by the presence of layers with increased values of bed velocities, but also either by a phenomenon similar to the anisotropy of sedimentary deposits (as a result of the existence of differences between horizontal and vertical stresses within the Earth ([1])), or, which is most probable, by the penetration of head waves in the presence of a gradient-layered medium. Taking these considerations into account, as well as new views on the nature of deep waves, a second possible variant of the structure of the Earth' s crust has been compiled (I. V. Pomerantseva, E. D. Tagai, and M. V. Margot' eva; see Fig. 2B).

In this case, the entire thickness of the Earth' s crust is represented as consisting of three complexes: 1) the sedimentary sequence—a layered medium with velocities of propagation of elastic waves varying depending on the lithological properties of the rocks and the depth of their occurrence; 2) the "granite" sequence, representing a 2- or 3-layer medium with constant or slightly increasing velocities of propagation of elastic waves; 3) the "basalt" sequence, considered as a gradient medium with a continuous law of increase of velocity with depth.

The presence of intermediate boundaries in the "granite" sequence may be indicated by: the ubiquitous tracing of head waves or weakly refracted waves $P_2^0$; the presence of waves reflected up to the critical point, seismic boundaries along which coincide with sections constructed from refracted waves. The assumption of the existence of a homogeneous medium with a constant increase of velocity with depth below the surface of the "basalt" layer was made on the basis of such factors as the agreement between the ratios of the observed dynamic curves $A^*_{P_1}/A^{0\mathrm{tr}}_{P_1}$ and the theoretical ones for a section where a gradient medium is observed below the surface of the basalt layer ([5]).

Recently, velocity sections of the Earth' s crust of the Russian Platform have appeared in the foreign literature ([6], [7]), obtained from preliminary data of the works described in the present article. It should be noted that the section given by Wilson ([6]) is one of the preliminary variants of a section of the first type, while Woollard' s data ([7]) do not correspond to reality.

To compile a more accurate representation of the velocity section of the Earth' s crust, it is necessary to continue deep seismic investigations, devoting primary attention to the question of obtaining clear deep reflections at precritical distances*, as well as to a more thorough interpretation of the nature of the waves recorded at large distances from the shot point.

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* In 1959, special experimental work was organized by the VNIIgeofizika Institute to clarify the possibility of recording deep reflections near the source of vibrations.

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