

# Surface Wave Tomography of the Kola Peninsula and Adjacent Territories: Data on Dispersion of Group Velocities of Rayleigh and Love Waves

A. I. Filippova<sup>a,b,\*</sup> and O. A. Solovey<sup>c</sup>

Presented by Academician V.V. Adushkin January 31, 2022

Received January 31, 2022; revised February 24, 2022; accepted February 25, 2022

**Abstract**—The deep structure of the crust and the upper mantle of the Kola Peninsula and adjacent territories is studied using representative data on the dispersion of group velocities of surface waves in the period range of 10–250 s. The distributions of group velocities of Rayleigh and Love waves with their estimated horizontal resolution are calculated by surface wave tomography. The velocity sections of SV- and SH-waves to a depth of 500 km are calculated from the maps for the western and eastern parts of the Kola Peninsula. The results of this study are characterized by higher horizontal resolution relative to the current surface wave models and allow tracing the main peculiarities of the structure of the crust and the upper mantle of the study territory. Our results indicate possible differences in the structure of the crust and the value of radial anisotropy of the upper mantle for the western and eastern parts of the Kola Peninsula.

**Keywords:** Rayleigh and Love waves, group velocities, tomography, Kola Peninsula

**DOI:** 10.1134/S1028334X2206006X

At present, the deep structure of the Kola Peninsula has been studied on the basis of data on body ([1]) and surface [2–5] waves in relatively large-scale detail in contrast to the western part of the Baltic Shield [6]. Thus, the main task of this work is study of the deep structure of the crust and the upper mantle of the Kola Peninsula and adjacent territories (60°–80° N, 15°–54° E) from the dispersion of group velocities of Rayleigh and Love waves.

The primary data included the records of surface waves from remote earthquakes on broadband stations of international seismic networks. The total amount of stations was 144 and 128 for Rayleigh and Love waves, respectively. In total, 45 earthquakes ( $M_w > 5.6$ , 2000–2021) that occurred within the considered region were processed. The range of distances from the epicenters to the registering stations was 2000–10000 km. In

most cases, this allowed us to distinguish the fundamental mode of surface waves at periods  $T$  of 10–250 s.

The dispersion curves of group velocities were calculated along epicenter–station paths using frequency–time analysis [7]. In total, 1194 and 743 dispersion curves of Rayleigh and Love waves, respectively, were calculated. This sampling was supplemented by data of previous studies of the Arctic deep structure [2]. As a result, the total amount of seismic paths was 2751 and 2014 for Rayleigh and Love waves, respectively.

The calculation errors of dispersion curves were estimated by their mean square deviations (MSDs) calculated for curves along close paths [2]. As a result, the minimum MSDs (0.02–0.03 km/s) are confined to the range of periods of 20–200 s and 30–100 s for the Rayleigh and Love waves, respectively, and are slightly higher for other periods. At small periods, a large scattering in the values of group velocities can be caused by both the calculation errors and the high degree of heterogeneity of the crust.

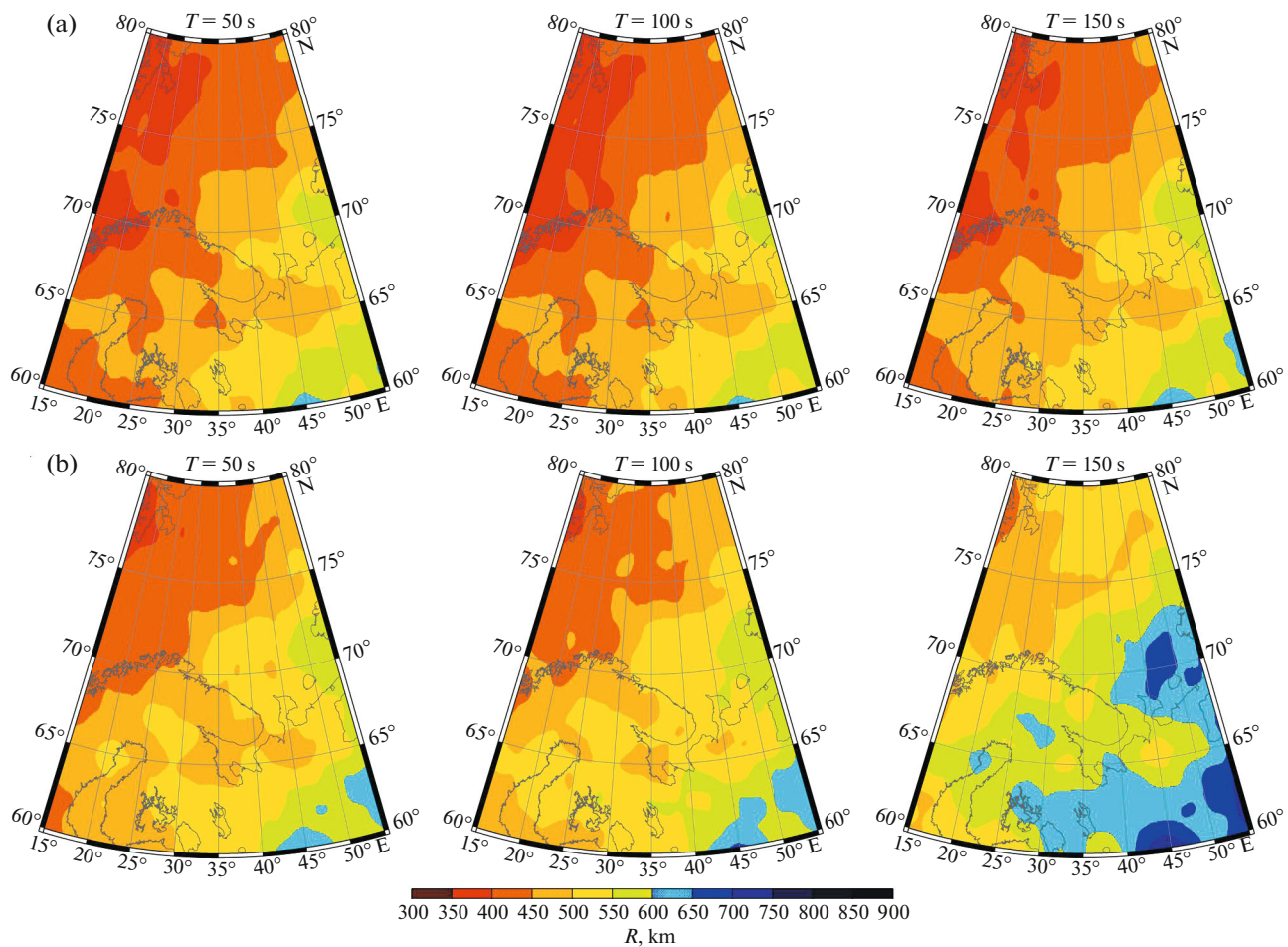
The distributions of the group velocities of surface waves were calculated using 2-D tomography for the case of a spherical surface [8]. Their horizontal resolution was estimated by calculation of the effective radius of averaging [8]. The best resolution was achieved for the Kola Peninsula and almost the entire

<sup>a</sup> Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Russian Academy of Sciences, Troitsk, Moscow, 108840 Russia

<sup>b</sup> Sadovskii Institute of Geosphere Dynamics, Russian Academy of Sciences, Moscow, 119334 Russia

<sup>c</sup> Institute of the Earth's Crust, Siberian Branch, Russian Academy of Sciences, Irkutsk, 664033 Russia

\*e-mail: aleirk@mail.ru



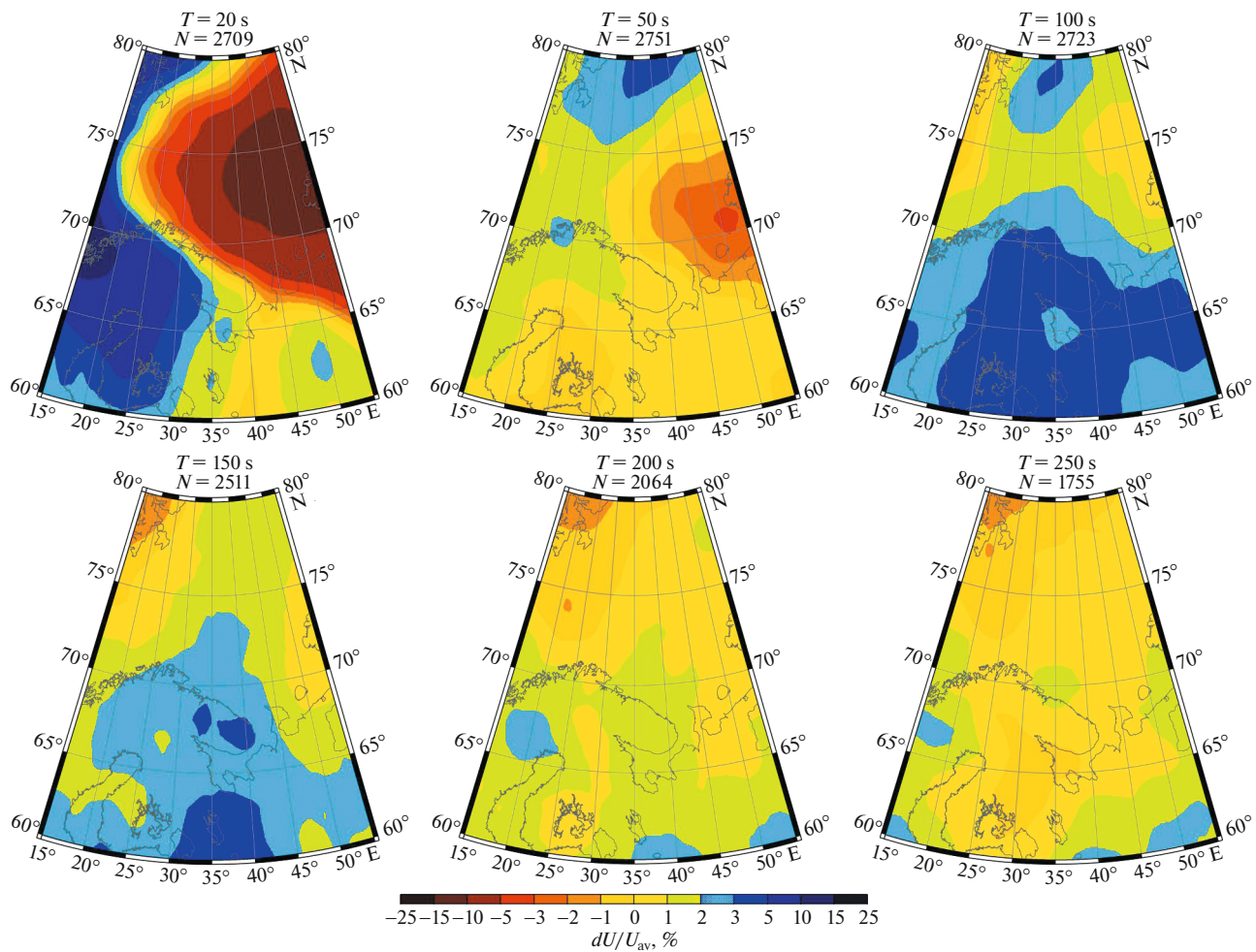
**Fig. 1.** Effective averaging radius ( $R$ , km) for (a) Rayleigh and (b) Love waves. Each map shows the corresponding period ( $T$ , s).

basin of the Barents Sea (Fig. 1). The effective radius of averaging for this territory is 350–450 km ( $T = 15$ –150 s) and 400–500 km ( $T = 20$ –100 s) for Rayleigh and Love waves, respectively. At shorter and longer periods, the resolution regularly decreases, which is related to using a lower amount of seismic paths (Figs. 2, 3). Our resolution is higher in comparison with the current surface wave models for the entire Arctic [2–5]. At periods of 20–40 s, our results are characterized by a resolution similar to the BARMOD model [9] and exceed it with increasing period due to the use of a larger (almost two times) amount of seismic tracks.

The analysis of the distributions of variations in the group velocities of surface waves at individual periods (Figs. 2, 3) allows the following conclusions on the deep structure of the considered territory. Taking into account the sensitivity of group velocities of Rayleigh and Love waves to the velocity structure of the medium, the maps at a period of 20 s should reflect the variations in the thickness of sedimentary rocks [8]. The most striking correlations between the velocity anomalies and the thickness of sediments are typical

for Rayleigh waves ( $T = 20$  s, Fig. 2). The minimums of the group velocities are observed in the eastern part of the basin of the Barents Sea, where, according to the EUNaseis model, the thickness of sediments reaches 12–18 km [10]. The velocities of Rayleigh waves are lower in its western part with the thickness of sediments of 4–8 km. Most of the Baltic Shield is characterized by high velocities of surface waves, which is in agreement with the almost complete absence of a sedimentary layer for this territory. In the eastern part of the Kola Peninsula, the velocities of surface waves decrease slightly, which can be related to the presence of a thin (up to 2 km) sedimentary layer [10].

For Rayleigh waves at a period of 50 s, this distribution reflects the main features of variations in the Moho depth, which decreases from 35–40 km beneath the eastern part of the basin of the Barents Sea to 30–35 km beneath the western part [10] accompanied by the increase in group velocities (Fig. 2). For a continent, the minimum of the velocities in the area of 27° E and 62° N corresponds to the area with a maximum (up to 56 km) thickness of the crust below the Baltic Shield. The maps for the higher oscillation peri-



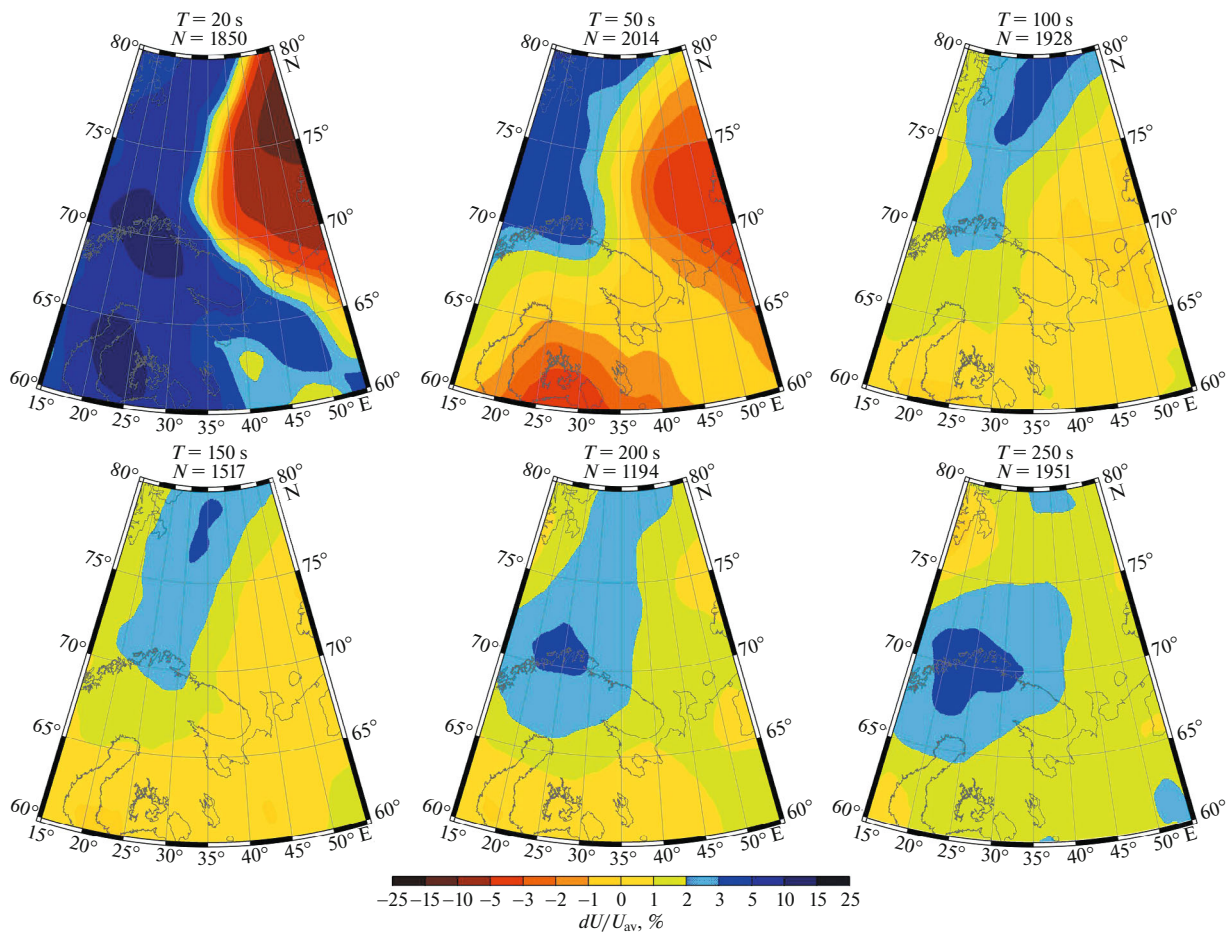
**Fig. 2.** Variations in the group velocities of Rayleigh waves relative to the average values ( $\delta U/U_{av}$ , %). The average values of the group velocities are 2.96, 3.78, 3.85, 3.77, 3.70, and 3.72 km/s for the periods of 20, 50, 100, 150, 200, and 250 s, respectively. Here and in Fig. 3, each map shows the corresponding period ( $T$ , s) and the amount of paths used ( $N$ ).

ods (up to 150 s) reflect the distribution of horizontal heterogeneities to a depth of  $\sim 250$  km. In this range of periods, the entire Baltic Shield is characterized by maximum velocities of Rayleigh waves, which can be caused by the presence of a thick high-speed lithosphere (the velocities slightly increase to the east). The lower velocities of surface waves at these and longer periods are observed below the Svalbard, which is in agreement with the available data on the deep structure of the mantle below the archipelago [3, 5, 9]. For periods of  $> 150$  s, where the variations in group velocities of surface waves do not exceed 3%, the character of dispersion of surface waves is affected by the structure of the upper mantle at depths of  $> 250$  km. Thus, the mantle in this depth range becomes less differentiated by the velocities relative to the overlying layers.

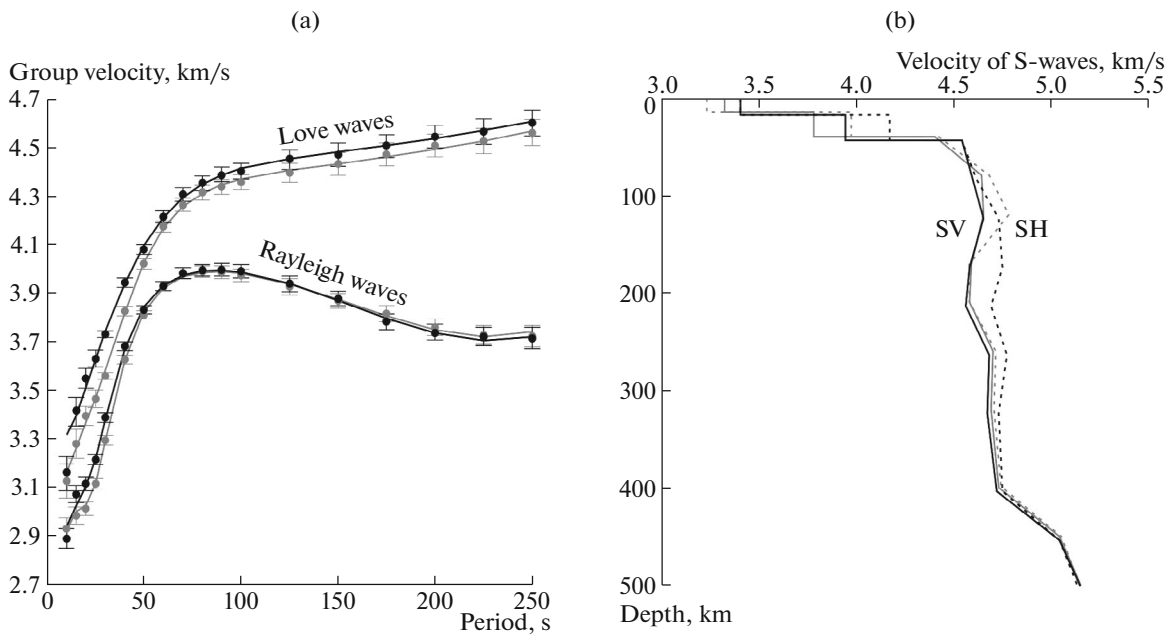
For detailed study of the deep structure of the Kola Peninsula on the basis of the obtained maps (Figs. 2, 3), we determined the local dispersion curves in the western ( $68^\circ$  N,  $30^\circ$  E) and eastern ( $67^\circ$  N,  $37^\circ$  E) parts of

the peninsula (Fig. 4a), and their inversion into velocity sections of SV- (from Rayleigh waves) and SH- (from Love waves) waves was conducted to a depth of 500 km (Fig. 4b). The calculations were conducted using joint gradients for the model of the medium with two crustal layers with constant velocities of S-waves and 11 mantle layers with linear variation of velocity with depth on the halfspace similarly to [2, 5].

It was found that the thickness of the crust for the western and eastern parts of the peninsula is 43 and  $\sim 36$  km, respectively. The velocity sections of SV-waves differ from each other to a depth of  $\sim 100$  km and become almost identical deeper (Fig. 4b), which is also reflected in the similarity of the group velocities of Rayleigh waves at periods of  $> 50$  s (Figs. 2, 4a). The differences in the velocity sections of SH-waves for the considered regions are observed to a depth of  $\sim 300$  km (Fig. 3b), which is also reflected in the differences in the group velocities of Love waves (Figs. 2, 4a). The difference between velocities of SV- and SH-waves,



**Fig. 3.** Variations in the group velocities of Love waves relative to the average values ( $\delta U/U_{av}$ , %). The average values of the group velocities are 3.22, 4.04, 4.34, 4.40, 4.44, and 4.49 km/s for the periods of 20, 50, 100, 150, 200, and 250 s, respectively.



**Fig. 4.** (a) Local dispersion curves of Rayleigh and Love waves (circles) with the errors of their determination and dispersion curves corresponding to inverted velocity sections (solid lines). Black and gray mark curves for the western and eastern parts of the Kola Peninsula, respectively. (b) Velocity sections of SV- (solid lines) and SH- (dotted lines) waves.

which characterizes the radial anisotropy of the mantle, is of greatest interest [8]. For example, the upper mantle in the area of 68° N and 30° E is anisotropic in the range of depths of 100–300 km in contrast to the narrower range of 70–160 km for the area of 67° N and 37° E (Fig. 4b). Thus, our results indicate a possible difference in the western and eastern parts of the Kola Peninsula both in the structure of the crust (as was previously indicated in [1]) and in the value of the radial anisotropy in the upper mantle.

#### FUNDING

This work was supported by the Russian Science Foundation, project no. 21-17-00161.

#### CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

#### REFERENCES

1. V. V. Adushkin, A. G. Goev, I. A. Sanina, and A. V. Fedorov, *Dokl. Earth Sci.* **501** (2), 1049–1052 (2021).
2. A. I. Seredkina, *Izv., Phys. Solid Earth* **55** (3), 439–451 (2019).  
<https://doi.org/10.1134/S106935131903008X>
3. S. Lebedev, A. J. Schaeffer, J. Fulla, et al., in *Circum-Arctic Lithosphere Evolution* (UK Geol. Soc., London, 2017), Vol. 460, pp. 419–440.
4. A. L. Levshin, M. H. Ritzwoller, M. P. Barmin, et al., *Phys. Earth Planet. Inter.* **123**, 185–204 (2001).
5. A. Seredkina, *Phys. Earth Planet. Inter.* **290**, 76–86 (2019). <https://doi.org/10.1016/j.pepi.2019.03.007>
6. H. A. Pedersen, E. Debayle, V. Maupin, et al., *Earth Planet Sci. Lett.* **383**, 164–172 (2013).  
<https://doi.org/10.1016/j.epsl.2013.09.024>
7. A. L. Levshin, T. B. Yanovskaya, A. V. Lander, et al., *Surface Seismic Waves in the Horizontal-Inhomogeneous Earth* (Nauka, Moscow, 1986) [in Russian].
8. T. B. Yanovskaya, *Surface-Wave Tomography for Seismic Researches* (Nauka, St. Petersburg, 2015) [in Russian].
9. A. L. Levshin, J. Schweitzer, C. Weidle, et al., *Geophys. J. Int.* **170**, 441–459 (2007).  
<https://doi.org/10.1111/j.1365-246X.2006.03285.x>
10. I. M. Artemieva and H. Thybo, *Tectonophysics* **609**, 97–153 (2013).  
<https://doi.org/10.1016/j.tecto.2013.08.004>

*Translated by I. Melekestseva*