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GEOPHYSICS

Structure of the Earth's Crust of the Continental Margin of the Laptev Sea and the Adjacent Part of the Eurasian Basin

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Abstract—A 3D model of the Earth's crust for the continental margin of the Laptev Sea and the adjacent part of the Eurasian Basin was developed using the latest seismic and gravity data. The thickness of the consolidated part of the Earth's crust in the study area is estimated at 7–11 km, which corresponds to a highly extended continental or oceanic crust. The formation of the basement and sedimentation in this area most likely began in the Late Jurassic. The southeastern part of the Eurasian Basin is separated from the rest of the basin by a dextral shear zone, the displacement along which during the Paleogene was more than 100 km.

Keywords: Laptev Sea, Eurasian Basin, geophysical modeling, Earth's crust, tectonics

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After the completion of the first stage of aeromagnetic surveys within the Eurasian Basin and the subsequent discovery of a system of linear magnetic anomalies characteristic of the ocean floor, this basin has been considered a classical oceanic basin [1, 2]. As a result, a spreading scheme has been developed, according to which the Eurasian Basin opened during the Cenozoic [3]. However, a number of bathymetric, seismic, gravitational, and magnetic characteristics of the Eurasian Basin floor obtained in the recent years contradict the hypothesis of single-stage formation of the basin [4, 5]. Based on seismic investigations [6–8], the strata of deposits, presumably of Mesozoic age, are traced to the southeastern part of the basin. According to these data, the task of determining the formation history and the pattern of the crustal structure of the southeastern part of the Eurasian Basin is relevant.

In the years 2018–2021, the study area was the target of a number of new seismic works, which allowed researchers to make new calculations and update the previously developed 3D crustal density model of the region [9]. Figure 1 shows the scheme of the geophysical knowledge of the region based on single-channel seismic reflection and multi-channel common-depth-point seismic reflection data. This scheme indicates the profiles used for updating the previous model.

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New seismic data were used to prepare an initial crustal density model of the region, subsequent calculations, and iterative fitting of the model by gravity modeling using the Grav3D software, and, then, to detail by inversion using a priori constraints with the Oasis Montaj software. Based on the model results, schematic maps and sections characterizing the Earth's crustal structure were obtained.

Due to the absence of prospect drilling in the study area, the age of the distinguished sedimentary strata is still debatable. As a result, it leads to uncertainty in the development of a model of the tectonic evolution of the region. Most studies show that the sedimentary cover in the region is subdivided into three strata, separated by the RU (23 Ma) and pCU (65 Ma) horizons.

The nature and age of the reflecting RU horizon in the lower part of the upper strata is least disputed. The unconformity seems to correspond to the largest Early Miocene erosional hiatus recorded by wells in the Lomonosov Ridge. By the Late Oligocene/Early Miocene (23 Ma ago), the re-orientation of the Arctic plates occurred, accompanied by the gradual opening of the Fram Strait and widespread sea-level regression. The 22.5 Ma milestone is given in work [10], where the history of the formation of the Norwegian–Greenland Basin is described in detail. Since that time, the opening of the Norwegian–Greenland Basin occurred with the spreading center moving to the Kolbeinsei Ridge.

The age of the pCU horizon, which separates the middle and lower strata in the region, is defined as 65 Ma. A number of seismic sections also show an unconformity, which was formed most likely in the Eocene. The age of this horizon (about 54.9–

Fig. 1. Scheme of single-channel seismic reflection and multi-channel common-depth-point seismic reflection data used for the development of the 3D density model of the Earth's crust. The profiles used in updating the model are shown in blue. The dotted rectangle outlines the area of the calculated 3D Earth crust model, and A–A' is the line of the 3D model section shown in Fig. 2.

48.9 Ma) coincides with the Early–Middle Eocene thermal maximum, which was accompanied by subtropical conditions of sedimentation with abundant freshwater *Azolla* ferns. A hiatus in sedimentation on the islands of the Laptev Sea occurred at the same time (65–55 Ma) [4].

Recently, there has been uniformity in determining the time of the onset of sedimentation in the region, which is shown in the sections as the surface of the consolidated basement (B). The age of this horizon was estimated at 125 Ma [7].

When developing the model, the objectivity of determining the average density of the selected three sedimentary strata has been checked. The verification was based on the known velocity–density ratios in the clastic sedimentary strata [11, 12]. The upper stratum, located in a depth range from 0 to 3.3 km, is characterized by average seismic wave velocities of about 2.5 km/s, which corresponds to rocks with a density of about 2.10 g/cm^3. The average seismic wave velocity in the middle stratum (from 1.4 to 6 km) is about 3.35 km/s, which corresponds to rocks with a density

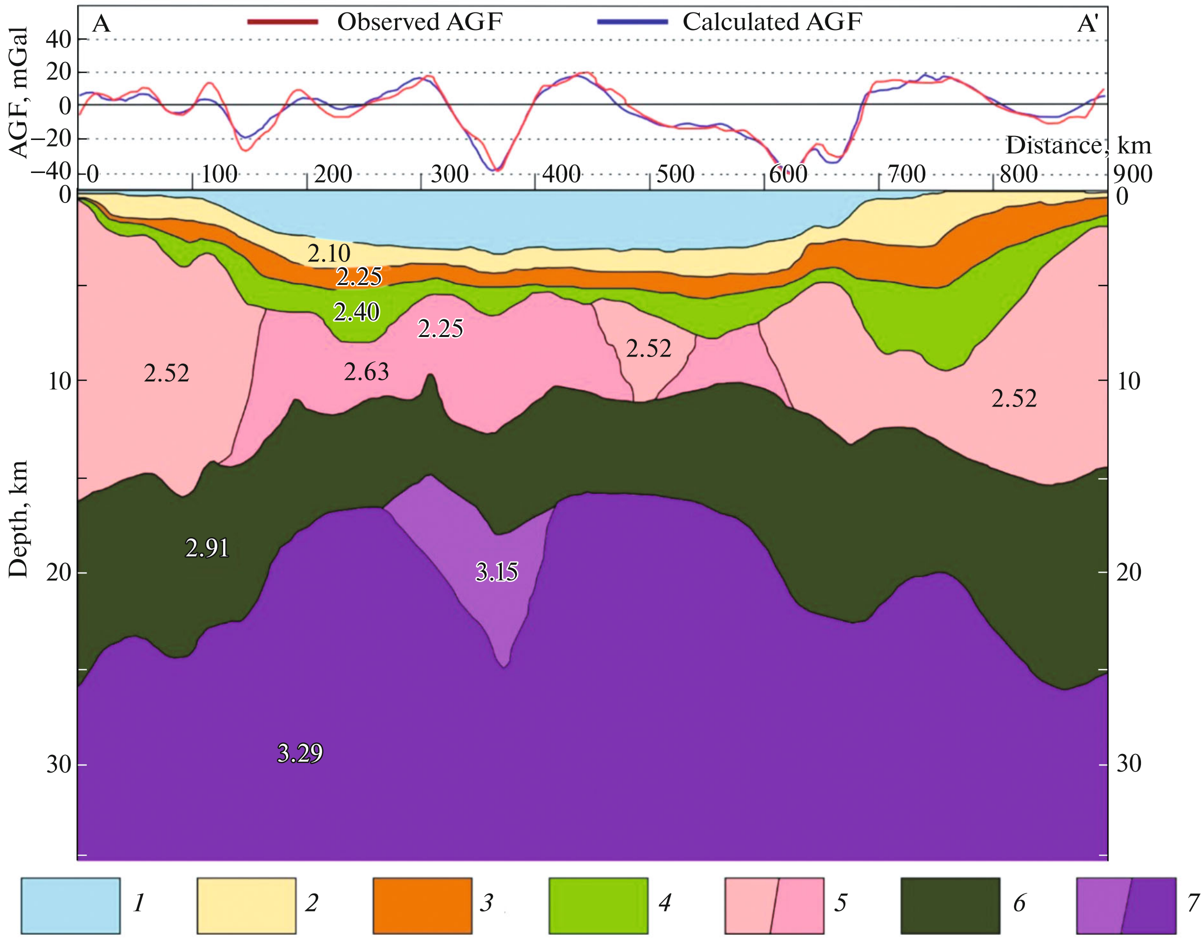

Fig. 2. The section along the A–A' profile of the 3D model of the Earth's crust in the northern part of the Laptev Sea (see the position of the section in Fig. 1). (*1*) Sea water; (*2*) upper sedimentary strata; (*3*) middle sedimentary strata; (*4*) lower sedimentary strata; (*5*) upper crustal metasedimentary and crystalline rocks; (*6*) lower crust; (*7*) mantle, including the decompaction zone below the area of active rifting.

of about 2.25 g/cm^3; in the lower stratum (from 1.6 to 10.5 km), it is about 4.1 km/s, which corresponds to rocks with a density of 2.40 g/cm^3.

The crustal section along the A–A' profile (Fig. 1), obtained based on the computational 3D model, is shown in Fig. 2.

The consolidated basement along the margins of the region under consideration of the Eurasian Basin is represented, presumably, by Mesozoic folded strata with an average density of 2.52 g/cm^3. It is assumed that the sedimentary strata in the deep part of the Eurasian Basin overlie the crystalline basement with a density of 2.63 g/cm^3. According to calculations, the density of the lower crust and mantle is 2.91 and 3.29 g/cm^3, respectively, except for the wedge-shaped decompaction zone in the modern seismically active rift zone with a fitted density of 3.15 g/cm^3.

The data on the thickness of the consolidated part of the Earth's crust in the conjunction zone of the southeastern part of the Eurasian Basin and the Laptev shelf zone are extremely important for the zoning of the region (Fig. 3). The thickness map of the consolidated part of the Earth's crust is the basis for the tectonic scheme given below.

The separation of the blocks I (part of the New Siberian–Chukotka fold region on the Precambrian basement), II (the Proterozoic Taimyr–Severnaya Zemlya folded region), and III (areas of Mesozoic dislocations of the Precambrian basement, margins of the Siberian Platform) corresponds to the classification accepted by most geologists. The classification of the crustal structures in the central part of the Laptev Sea is more complicated. Regarding the southern part of this region (IV), one can suggest that, in terms of the crustal thickness here of more than 15 km, this area corresponds to a moderately extended continental crust [13]. As for the northern region (V), where the thickness of the consolidated crust is 7–11 km, it may include both the highly extended continental crustal areas and the Mesozoic oceanic crust overlapped by a thick sedimentary cover.

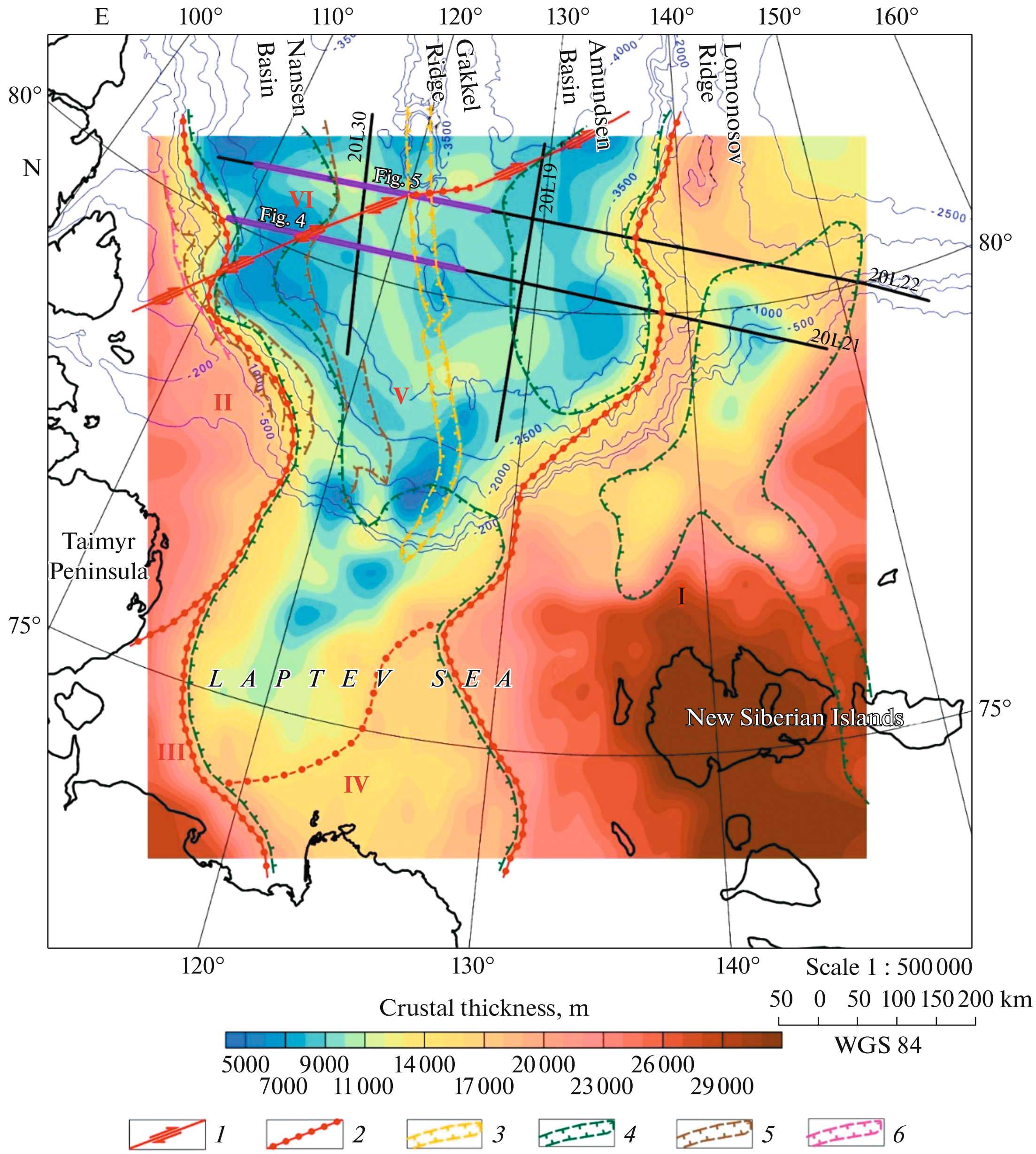

Fig. 3. Zoning of the Earth's crust in the conjunction zone of the southeastern block of the Eurasian basin and the Laptev Sea shelf zone. The thickness of the consolidated part of the Earth's crust is given according to 3D density modeling data. (*1*) Shear zone at the boundary between different-type blocks of the Earth's crust; (*2*) boundaries of different-type blocks of the Earth's crust; (*3*) seismic active zone of modern rifting; (*4*) boundaries of Jurassic–Cretaceous sedimentation areas; (*5*) outlines of areas of Paleogene sedimentation in the Nansen Basin; (*6*) outlines of the Neogene sedimentation area in the Nansen Basin. I, Chukotka folded area on the Precambrian basement; II, Late Proterozoic Taimyr–Novaya Zemlya folded area; III, the area of Mesozoic dislocations of the Precambrian basement; IV, Verkhoyansk folded area; V, the extended continental crust and areas of the Mesozoic oceanic crust; VI, oceanic crust.

Of particular interest is area VI, located in the northern part of the study region. The outlines of this area are rather confidently identified on the basis of analysis of the magnetic and gravity anomalies [4]. However, only the seismic works in 2020 provided evidence of the shear origin of the boundary separating the oceanic crust of area VI from the rest of the area. Apparently, this shear zone separates completely heterogeneous crustal blocks formed in different epochs.

Figure 4 shows a fragment of seismic profile 20L21 (see the position of the profile in Fig. 3). The contact (shear) zone of crustal blocks of different types in the Nansen Basin is marked on the section by a red oval.

The most likely position of the RU, E (Early Eocene), and pCU horizons is shown in the left part of

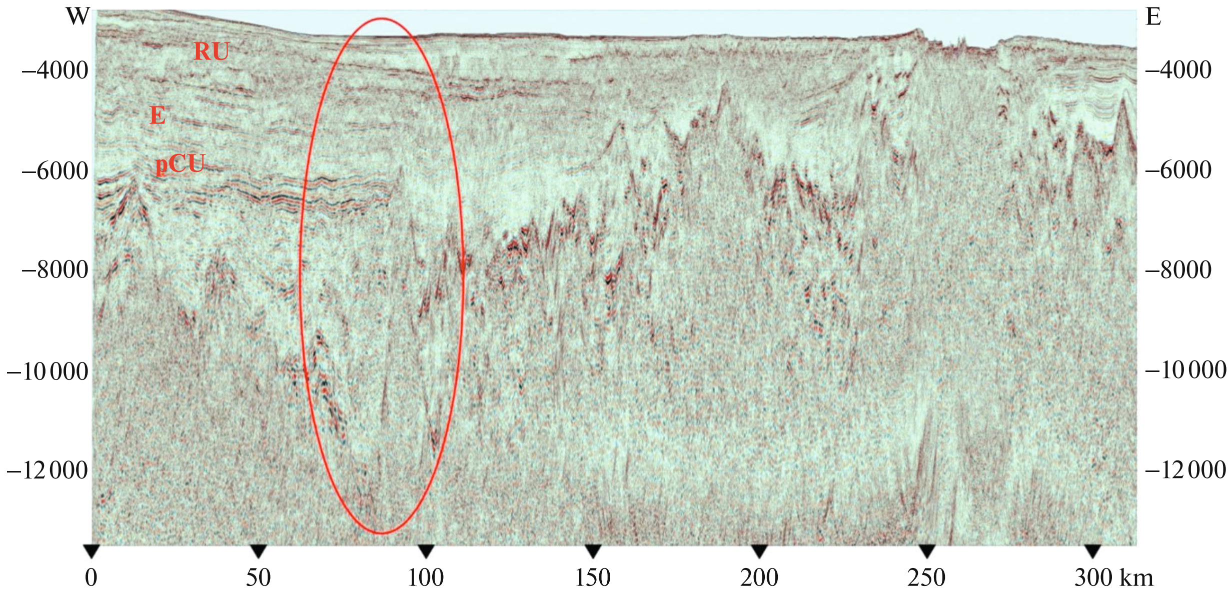

Fig. 4. A fragment of the profile 20L21, crossing the contact zone (shear zone) between crustal blocks of different types in the Nansen Basin. See the position of the section in Fig. 3.

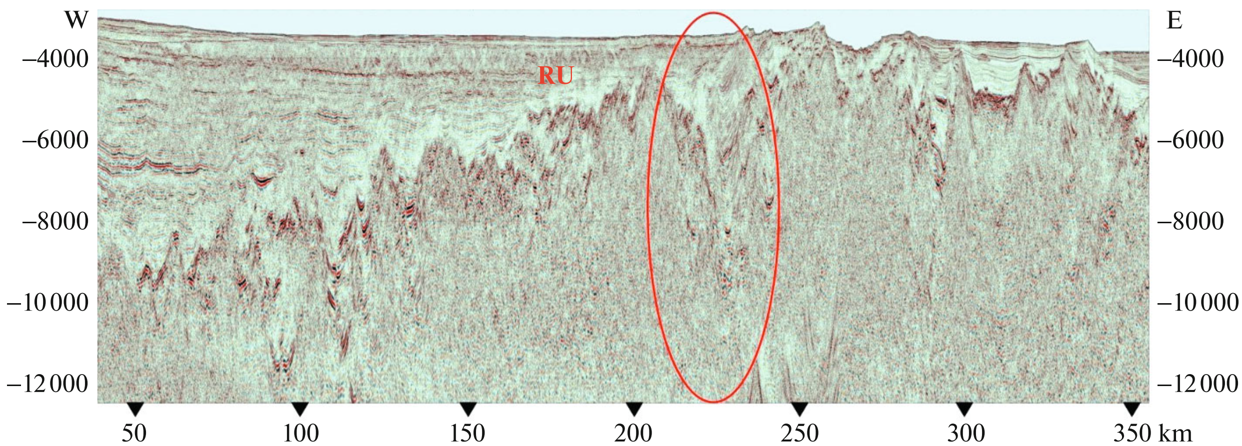

Fig. 5. A fragment of the profile 20L22, crossing the contact zone (shear zone) between crustal blocks of different types in the Nansen Basin, near the rift zone in the continuation of Gakkel Ridge. See the position of the section in Fig. 3.

the section. At the intersection of the proposed fault zone, the character of the seismic section is completely changed, which can be explained by the presence of a large-amplitude shear. As seen in Fig. 3, the outlines of the Mesozoic basin are displaced by 90 and 130 km along the dextral shear zone; those of the Paleogene basin, by 60 and 70 km. The termination of movements in this zone in Paleogene confirms the hypothesis of the geodynamic reason for this rearrangement [14].

Neogene sedimentary strata overlap the shear zone without significant disturbances. Consequently, one can assume that the shear zone became nonexistent in the Oligocene.

In the 20L22 profile, the intersection of the contact (shear) zone of crustal blocks of different types in the Nansen Basin is located near the rift zone in continuation of Gakkel Ridge (Fig. 5).

Since the thickness of the sedimentary cover in the contact zone between two blocks in the 20L22 profile is low, the comparison of sections on both sides of the contact zone is not as significant as in the previous profile. Nevertheless, the presence of a deeply penetrating disjunctive zone at the supposed contact is unquestionable.

Thus, the analysis of the developed 3D crustal model in the conjunction zone of the southern block of the Eurasian Basin and the Laptev Sea shelf zone indicates a fundamental difference in the geological structure of the Cis-Laptev part of the Eurasian Basin from the rest of its area. The formation of the basement and sedimentation in the region including the northwestern part of the Laptev Sea and the southeastern part of the Eurasian Basin most likely started in the Late Jurassic. Here, the basement itself is either part of the Late Jurassic ocean (the incompletely closed South Anyui basin) or the continental margin area extended in the Late Jurassic. The southeastern part of the Eurasian Basin is separated from the rest of the basin by the dextral shear zone, the displacement along which by the end of the Paleogene was more than 100 km.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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