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GEODYNAMICS

Neotectonic Dislocations on the Barents Sea Shelf and Their Origin on the Basis of Morphometry of the Seafloor Relief, Seismic Survey, and the Deep Structure of the Mantle

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Abstract—A comprehensive analysis of the morphometric attribute “general curvature” for the Barents Sea bathymetry and reports on the seismic and seismoacoustic data on tectonic dislocations in a wave field, the fault network of the sedimentary cover, and seismotomographic data on the heterogeneous deep pattern of the distribution of seismic wave velocities in the upper mantle are provided. The analysis showed that mobile blocks of the upper mantle, exhibiting heterogeneous rheological properties, are associated with the consolidated part of the Earth’s crust fault network of deep-seated origin. The fault network emerges on the seafloor and, becoming a relief-forming factor, forms specific domains with different textures displayed in the morphometric attribute “general curvature.”

Keywords: morphometry, neotectonics, Barents Sea, seismic sections, fault network, deep structure

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The geodynamics makes an impact in the northwestern framework of Eurasia on the Arctic shelves of Russia. It is manifested in seismicity and neotectonic dislocations of the sedimentary section, especially its upper part, and in many other factors [1–3]. The most recent and modern tectonic displacements of the seafloor in the deep framework of the Barents shelf can be reliably detected on the basis of the seismic survey data and, especially, by high-frequency seismoacoustic profiling with a vertical resolution of less than 1 m. In the deep parts of the water area, the density of this type of geophysical observations is low. In the process of the identification of faults on the sections, significant spaces between them remain unrepresented by data; thus, tracing dislocations in these zones is problematic.

Modern digital elevation models (DEM) of the Arctic seafloor on the International Bathymetric Chart of the Arctic Ocean (IBCAO) [4] of medium scale (1 : 250 000 and smaller) do not contain these spaces. This feature makes it possible to trace faults on the basis of the morphometric characteristics of the relief. This approach gives reliable results only together with seismic data, confirming the relationship between the morphometric anomalies with dislocations. The density of seismic data and of the results of their interpretation for the Barents Sea shelf is quite large. On this basis, we compared them with the relief through morphometrical analysis for the Russian part of the water area. This makes it possible to validate the application of this approach to studying neotectonics in water areas that have been poorly studied by seismic surveys.

Most lineaments in the relief are surface manifestations of near-surface and deep faults and structural formations of different origins, sizes, ages, and depths. At present, there are a limited number of works related to the morphometric analysis of the landforms, which are typical of tectonic structures and processes [5–8]. Single works are devoted to the identification of the tectonic structures in the seafloor relief with the use of morphometry [9, 10].

We used the actual DEM IBCAO [4] on a 200-m grid. The morphological attributes of faults are linear structures and structural differences in relief on the neighboring domains bounded by the fault network. The most likely fault structures, identified from the morphometric attributes of the seafloor relief, are compared with the faults confirmed by direct seismic

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observations. Figure 1 demonstrates the General Curvature map calculated in the SAGA software [11] using the DEM IBCAO, smoothed in a 5-km moving window. The need for smoothing arises because this DEM is a combination of ordinary measurements, the data of navigation maps, and altimetry with individual fragments of the detailed multibeam bathymetry. This creates artifacts on a map with spatially inhomogeneous accuracy of data, which must be excluded from the interpretation. Figure 1 also demonstrates the fault networks on the basis of the data with a scale of 1 : 5000000 [12] and from data of the T-37-40 sheet of a geological map with a scale of 1 : 1000000 [13] with differentiation by the kinematic type, constructed from 2D seismic data.

The analysis of various attributes, which were processed in the SAGA software, showed that, in comparison with faults, the variant of calculation with the greatest contrast is the general curvature, which is a combination of the second derivatives of the topography for both spatial coordinates.

Comparison of the general curvature with fault network reliably established from the seismic data and shown on the published maps (Fig. 1) demonstrates that the latter delimits the seafloor into domains with different patterns of the attributes. Domains with an intense chaotic texture are observed; most of them are concentrated in the zones between the northwest-striking left lateral strike–slip faults, from the central part of the Barents Sea to the head of the St. Anna Trough in the northeast. Domains with a lighter texture are manifested to a lesser degree. The intersection of the strike–slip fault and chaotic domains is shown in a section in Fig. 2. This section contains two negative flower structures, the near-surface fault paragenesis of which emerges onto the seafloor surface. The main strike–slip rupture runs deeper than the Triassic reflecting horizon $A_3(T_3)$. In the central part of the section, multiple dislocations are visible in the upper 800–900 ms between the two strike–slip structures. These dislocations not only emerge to the surface, but also form small positive landforms on the seafloor with an amplitude of 10 to 25 m. This points to the modern age of the dislocations, which displace the Mesozoic sedimentary complexes in the transtensional mode and play a relief-forming role. The secondary dislocations may be manifested in the entire chaotic domain between long strike–slip faults (Fig. 1). Deposits of seafloor flows, adapted to the fault network, may enhance their relief-forming effect.

The attribute of curvature on the northern framework of the shelf clearly shows the sides of the troughs reaching onto the shelf edge. In the Norwegian part of the Barents Sea, the domains with a chaotic texture of the feature with linear elements (Fig. 1) are oriented northeastward and correspond to the known system of troughs in this part of the shelf. In the northern Russian part, these elements are confirmed by the fault network plotted on medium-scale maps (Fig. 1). In the southern Russian part of the shelf, domains with different textures are also observed. In addition, the map [13] indicates a fault network oriented northwestward similar to that in the northern part of the water area. Some of the faults shown on the map do not run continuously through the southern part of the Barents Sea. Nevertheless, the deep sections (Fig. 3) and high-frequency profiles (Fig. 4) indicate tectonic dislocations that emerged on the seafloor surface on an assumed line of the fault continuation toward the southwestern edge of Novaya Zemlya. We highlight that the high-frequency section (Fig. 4) in the vicinity of the fault displays an increase in the intensity of the reflector located at a depth of ~6 meters below the seafloor, which probably indicates the accumulation of free gas that enters along this fault. The increase in intensity may also have resulted from mechanical destruction of the subhorizontal boundary at a depth of 363 ms in the fault zone, which, most likely, has a permafrost origin and serves as a fluid reservoir-seal rock.

A system of northwest-oriented faults with obvious signs of neotectonic activity covers the entire water area of the Barents Sea. According to [14, 15], the scheme of the Devonian–Triassic rift system and its Jurassic–Cretaceous activation have a system of transform displacements, the spatial orientation of which coincides with the faults highlighted in the maps [12, 13]. This indicates the genetic connection of the areas of modern neotectonics with the Paleozoic and Mesozoic structural heterogeneities, but raises a question about the geodynamic effect on the plate with the block structure at the present time.

According to [3], the geodynamically active framework of the Barents Sea shelf (Knipovich and Gakkel ridges) with a time-varying seismic cycle forms deformation waves that affect the shelf propagating from two mutually perpendicular divergent zones. In addition, based on the postulate that one of the “engines” of the plate tectonics is “ridge push,” two pressure sources are superimposed on the shelf. They can affect the intraplate dynamics by activating the fault system located at an angle of ~45° in both directions of the propagation of deformation waves.

Another geodynamic factor is the presence of the anomalously hot mantle beneath the Spitsbergen Archipelago including its vicinity. This is confirmed by the rift-related heat flux measured in the Orli Trough during the 25th cruise of the R/V *Akademik Nikolai Strakhov* [16]. The shape of the iso-surface of seismic velocities of 8.3 km/s in Fig. 5a illustrates that the northwestern part of the Svalbard plate up to depths of 250 km has a cavity oriented northeastwards with reduced velocities. On the southwestern framework of the Franz Josef Land archipelago (Fig. 5b), a dense network of faults oriented northeastward is manifested on the surface of this cavity. According to

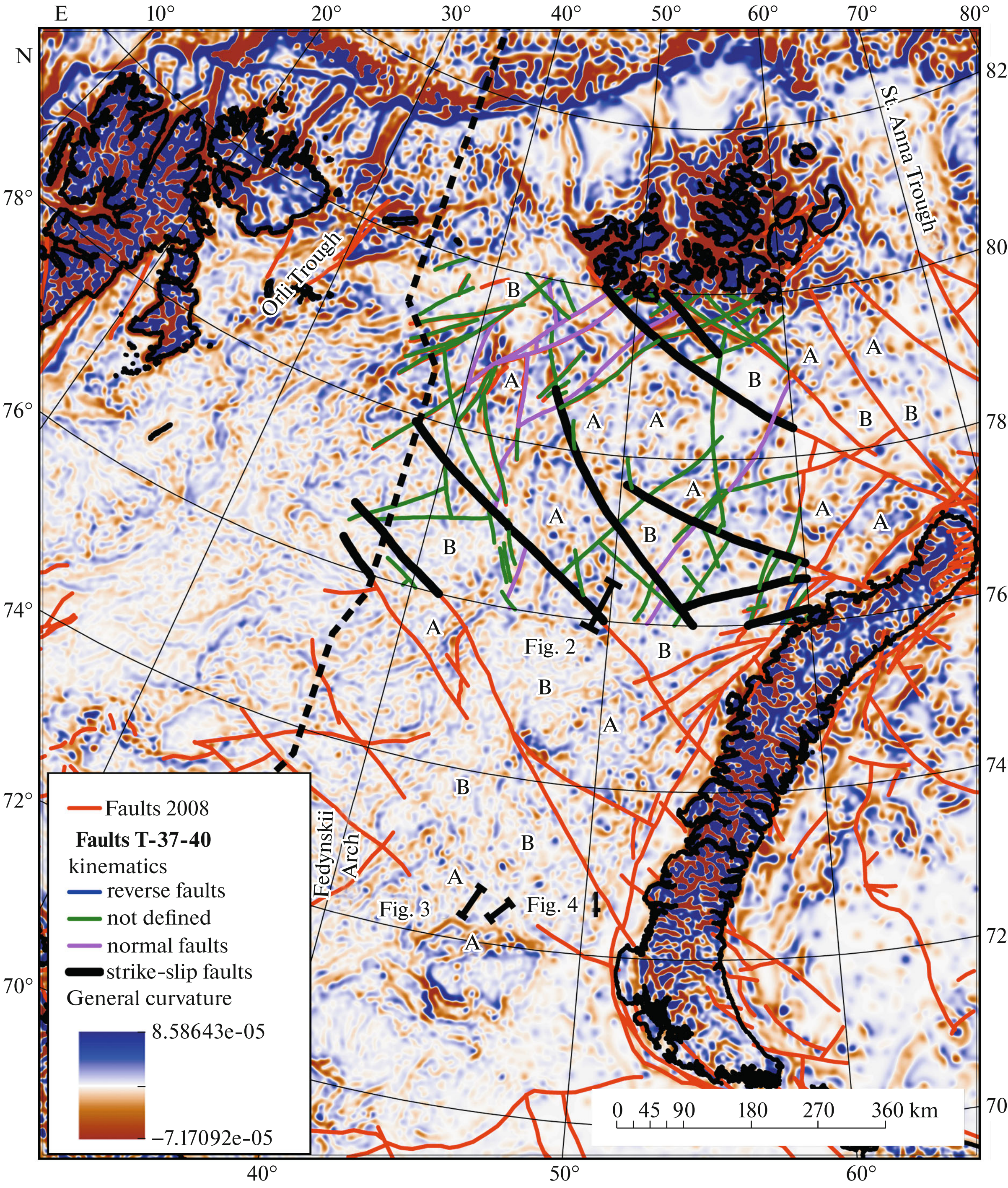

Fig. 1. The map of the morphometric attribute "general curvature" of the Barents Sea, calculated from IBCAO [4] data in the SAGA software [11], the fault networks on a scale of 1 : 5 000 000 according to [12] and on a scale of 1 : 1 000 000 according to sheet T-37-40 [13] with classification by the kinematic type. Letters show the domains in the attribute field: A, with a chaotic texture; B, with a lightened texture. The numbers give the positions of the seismic sections in the corresponding figures.

the interpretation of the 4-AR reference section [17], these faults also emerge on the seafloor surface. This indicates that the dynamics of the plate with a block structure, besides the standard factors of plate tectonics, is affected by the relatively more heated and mobile mantle, which additionally has an impact on the developed fault network, and is manifested by the Quaternary volcanism on Spitsbergen as well [18]. The iso-surface (Fig. 5a) has small depressions oriented northwestward and a distinct branch of the low-veloc-

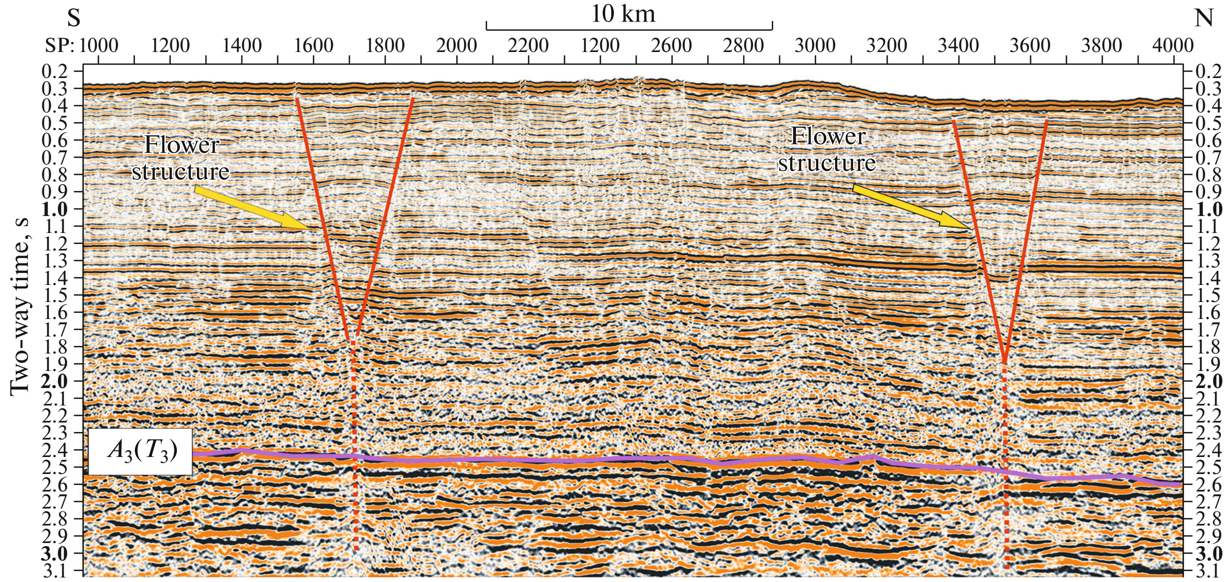

Fig. 2. Fragment of the CDP TF102 section in the northern part of the Barents Sea, crossing the zone of the northwesterly oriented strike–slip dislocations. The solid red lines show the fault paragenesis of the negative flower structures emerging on the seafloor surface. The dotted red lines show the main strike–slip dislocations. The position of the fragment is shown in Fig. 1.

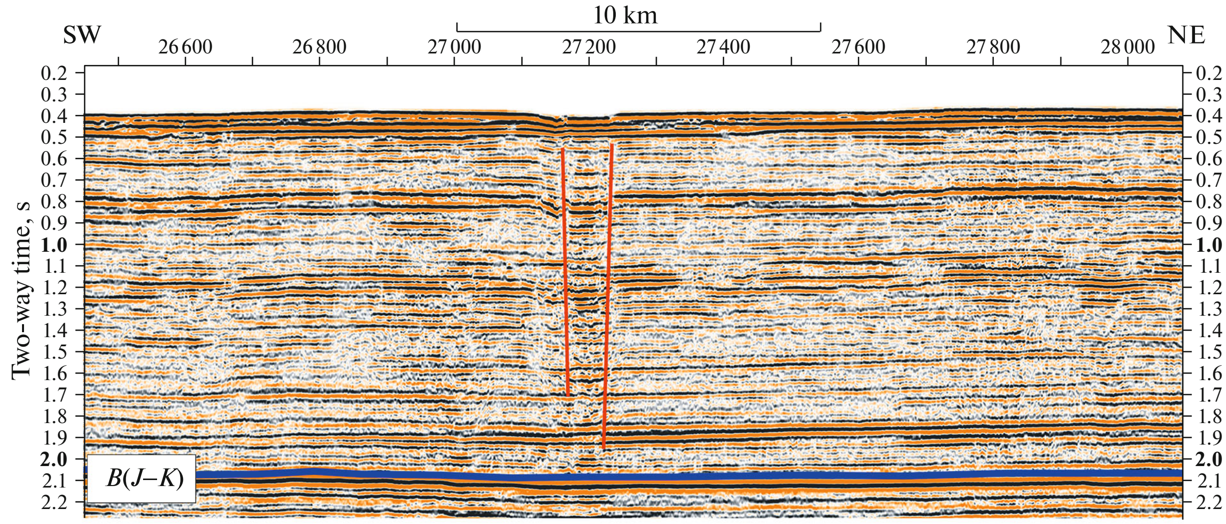

Fig. 3. Fragment of CDP KS103 section in the southern part of the Barents Sea according to [19], crossing the zone of the supposed northwest-oriented dislocations. The solid red lines show the faults emerging on the seafloor surface. The position of the fragment is shown in Fig. 1.

ity cavity to the Kola Peninsula under a high-velocity "canopy" at a depth of ~75 km under the Fedynskii Arch.

Comparison of the fault network with the velocity slice of the mantle at a depth of 50 km (Fig. 5b) shows that the neotectonical dislocations quite clearly divide the velocity heterogeneities into segments in both the northwesterly and northeasterly directions. This points to the mobility of the plate blocks down up to the deep zones, resulting in neotectonic deformations on the surface. The question of the mechanism of the tangential impact on the plate blocks, which create displacements at angles of ~45° to the geodynamically active zones surrounding the Barents Sea, remains open due to the strike–slip kinematics of many faults.

Therefore, the analysis of the deep structure of the mantle in terms of the velocities, fault network, and morphometry of the seafloor relief of the Barents Sea

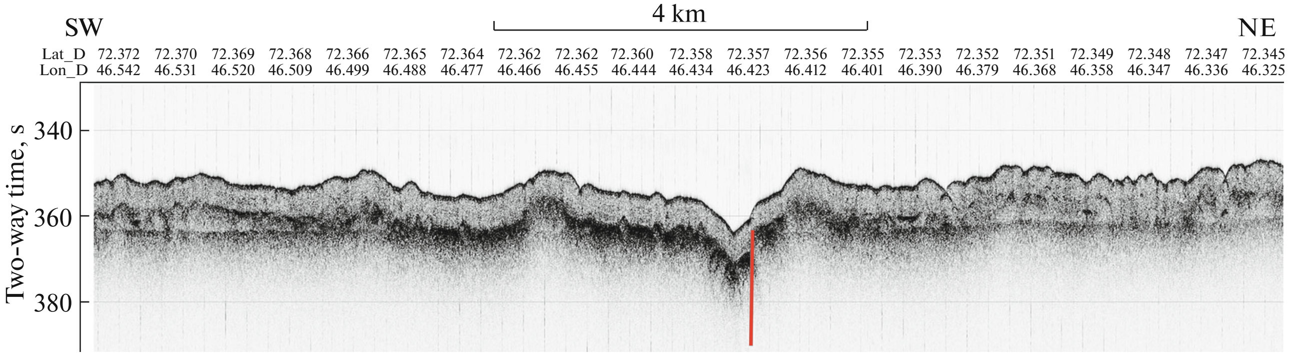

Fig. 4. Fragment of the ANS_to_W44 section, obtained by a high-frequency profiler during the 41st cruise of R/V *Akademik Nikolai Strakhov* in the southern part of the Barents Sea, crossing the zone of the supposed northwesterly oriented dislocations. The solid red line shows the fault extending to the seafloor surface. The position of the fragment is shown in Fig. 1.

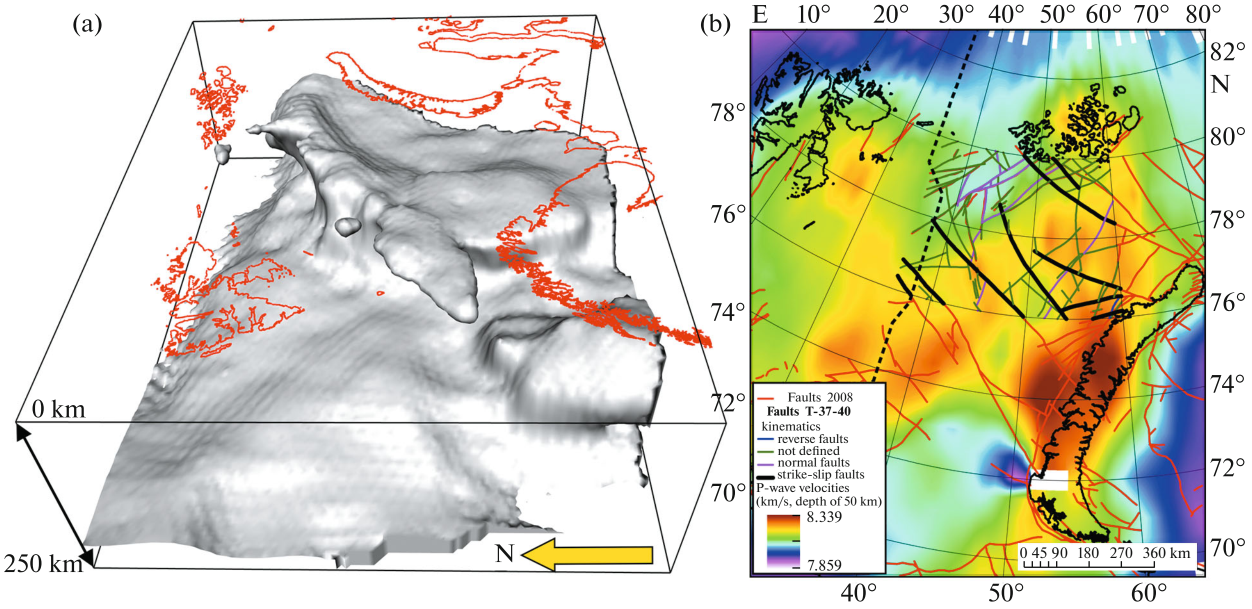

Fig. 5. The deep structure of the Barents Sea based on the seismotomographic data [20]. (a) 3D block-diagram of the P-wave velocity iso-surface with 8.3 km/s in at depths from 250 km to the surface. (b) Map of the P-wave velocity distribution at a depth of 50 km, the fault networks on a scale of 1 : 5000000 [12] and on a scale of 1 : 1000000 according to the T-37-40 sheet [13] with classification by kinematic type.

has shown the relationship between the rheologically heterogeneous and mobile blocks in the upper mantle and the consolidated part of the Earth' crust with the deep fault network. The fault network emerges on the seafloor surface as a relief forming factor; it forms the specific domains with different textures displayed in the morphometric attribute "general curvature." The casual relationship of the tectonic processes from the deep lithosphere to the surface is confirmed.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. R. B. Krapivner, Geotectonics **41** (2), 149–163 (2007).
2. E. E. Musatov, Ross. Zh. Nauk Zemle **1** (2), 157–183 (1998).
3. G. N. Antonovskaya, I. M. Basakina, N. V. Vaganova, et al., Seismol. Res. Lett. **92**, 2876–2890 (2021). https://doi.org/10.1785/0220210024
4. M. Jakobsson, L. A. Mayer, C. Bringensparr, et al., Nat. Sci. Data **7** (176) (2020). https://doi.org/10.1038/s41597-020-0520-9
5. I. V. Florinsky, Geomorphology **16** (2), 103–119 (1996).
6. G. Jordan, Earth Surf. Processes Landforms **28** (8), 807–822 (2003). https://doi.org/10.1002/esp.469
7. G. Jordan, B. M. L. Meijninger, D. J. Hinsbergen, et al., Int. J. Appl. Earth Observ. Geoinf. **7** (3), 163–182 (2005). https://doi.org/10.1016/j.jag.2005.03.003
8. M. F. Ramli, N. Yusof, M. K. Yusoff, et al., Bull. Eng. Geol. Environ. **69** (2), 215–233 (2010).
9. E. Kokinou and C. Panagiotakis, Remote Sens. **12** (10), 1538 (2015). https://doi.org/10.3390/rs12101538
10. C. Panagiotakis and E. Kokinou, IEEE J. Select. Top. Appl. Earth Observ. Remote Sens. **8** (1), 3–11 (2015).
11. O. Conrad, B. Bechtel, M. Bock, et al., Geosci. Model Dev. **8** (7), 1991–2007 (2015).
12. J. C. Harrison, M. R. St-Onge, O. V. Petrov, et al., *Geological Map of the Arctic, 1:5000000* (Geol. Surv. Canada, 2008), Open File Report No. 5816.
13. *The 1 : 1000000 State Geological Map of the Russian Federation, New Ser., Map of Pre-Quaternary Formations T-37-40, Sheet No. 1,* Ed. by B. G. Lopatin (Mar. Arctic Geol. Exped., Polar Marine Geosurvey Expedition, VNIIOkeangeologiya, 2004).
14. A. N. Vinogradov, M. L. Verba, V. V. Verba, et al., in *Lithosphere Structure of the Russian Part of Barents Region,* Ed. by N. V. Sharova, F. P. Mitrofanova, M. L. Verby, and K. Gillena (Karelian Res. Centre Russ. Acad. Sci., Petrozavodsk, 2005), pp. 16–39 [in Russian].
15. E. V. Shipilov, Geotectonics **38** (5), 344–366 (2004).
16. M. D. Khutorskoi, Yu. G. Leonov, A. V. Ermakov, et al., Dokl. Earth Sci. **424** (1), 29–36 (2009).
17. K. F. Startseva, A. M. Nikishin, N. A. Malyshev, et al., Geotectonics **51** (4), 383–398 (2017).
18. A. N. Sirotkin and V. V. Sharin, Geomorfologiya, No. 1, 95–106 (2000).
19. G. S. Kazanin, S. P. Pavlov, V. V. Shlykova, et al., in *Continental Boundaries of Eurasia: Geology and Geoecology* (GEOS, Moscow, 2011), Iss. 3, pp. 59–81 [in Russian].
20. H. Bungum, O. Ritzmann, N. Maercklin, et al., EOS **86** (16), 1–3 (2005).

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