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GEOLOGY

Paleogeographic Settings and Tectonic Deformations of the Barents Sea Continental Margin in the Cenozoic

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The Barents Sea continental margin (hereafter, Barents margin) differs from other passive margins by the most extensive shelf, the giant thickness of sedimentary rocks in basins and troughs, and its unique tectonic position. The outer, almost rectangular promontory of the Barents margin juts out into its deepwater western and northern framing (Fig. 1), identified as the Norwegian–Greenland and Eurasia basins, respectively. In this regard, the continental margin is affected by two, mutually perpendicular spreading zones (Knipovich and Gakkel ridges).

The evolution of oceanic basins proceeded in the course of continuous tectonic and geodynamic interaction with the framing continental margins. In our case, this was expressed, first of all, in the separation and evolution of the Barents Sea shelf platform as an area of neotectonic transformations during the opening of young oceanic basins. Its structures were transformed against the background of breakup and block-shaped disintegration (destruction and fractalization) of the continental crust. This is indicated by Cenozoic volcanism in the Spitsbergen and Novaya Zemlya segments, development of tectonomorphic trenches (grabens), anomalous geophysical properties of the present-day Earth's crust (including thermal and seismic activity), and specific deformations of the sedimentary cover.

All the aforementioned allow us to make a judgement about the contribution of the Cenozoic ocean formation to the modern tectonics and architecture of the Barents margin.

The initial breakup of the joint continental lithosphere located between the Barents margin, on the one hand, and Greenland and Lomonosov protoridge, on the other, most likely occurred in the region of the future divergence of plates during the Late Cretaceous–Early Paleocene. This is indicated by marine drilling and seismic profiling data suggesting that geological history of the Barents margin included a very important erosion and denudation phase related to the regional uplift before the rift stage. The amount of the material removed from only the inner shelf during the Cenozoic is estimated at 1.5–2.0 km [1, 2]. In the peripheral zones adjoining the intercontinental rift systems in the Late Cretaceous–Early Paleogene, the amount of eroded material increases to 3 km or more. However, up to one-half of the material was eroded by glacial processes.

The main tectonic transformations of that time also concentrated on the periphery of the Barents margin. The active differential movements in the near-oceanic zone transformed Svalbard, Franz Josef Land, and Severnaya Zemlya into arch–block rises divided by marginal graben-like trenches. As oceanic basins expanded, the aforementioned rises continued to grow up, and afterwards were covered by glaciers. The neotectonic Medvezhii, Franz-Victoria, Svyataya Anna, Voronin, and other grabens (trenches) expressed in the bottom topography as deep incisions reworked by glaciers served as pathways for intense transport of eroded materials into oceanic basins and formation of rather thick fans until the early Pliocene.

The insignificant Late Cretaceous and Paleogene sedimentation in the Barents Sea was confined to the near-latitudinal and coastal belt, including the Tromsö, Hammerfest, Nordkapp, and South Barents basins. This discontinuous belt of neotectonic subsidence reflects the natural response of the rear zone of the West Arctic margin to the emergence of its northwestern and northern peripheries (Spitsbergen, Franz Josef Land, and the adjacent shelf), owing to expansion of the Norwegian–Greenland and Eurasia basins and the impact of new portions of oceanic lithospheric masses on the diverging continental plates. In the Barents Sea, this

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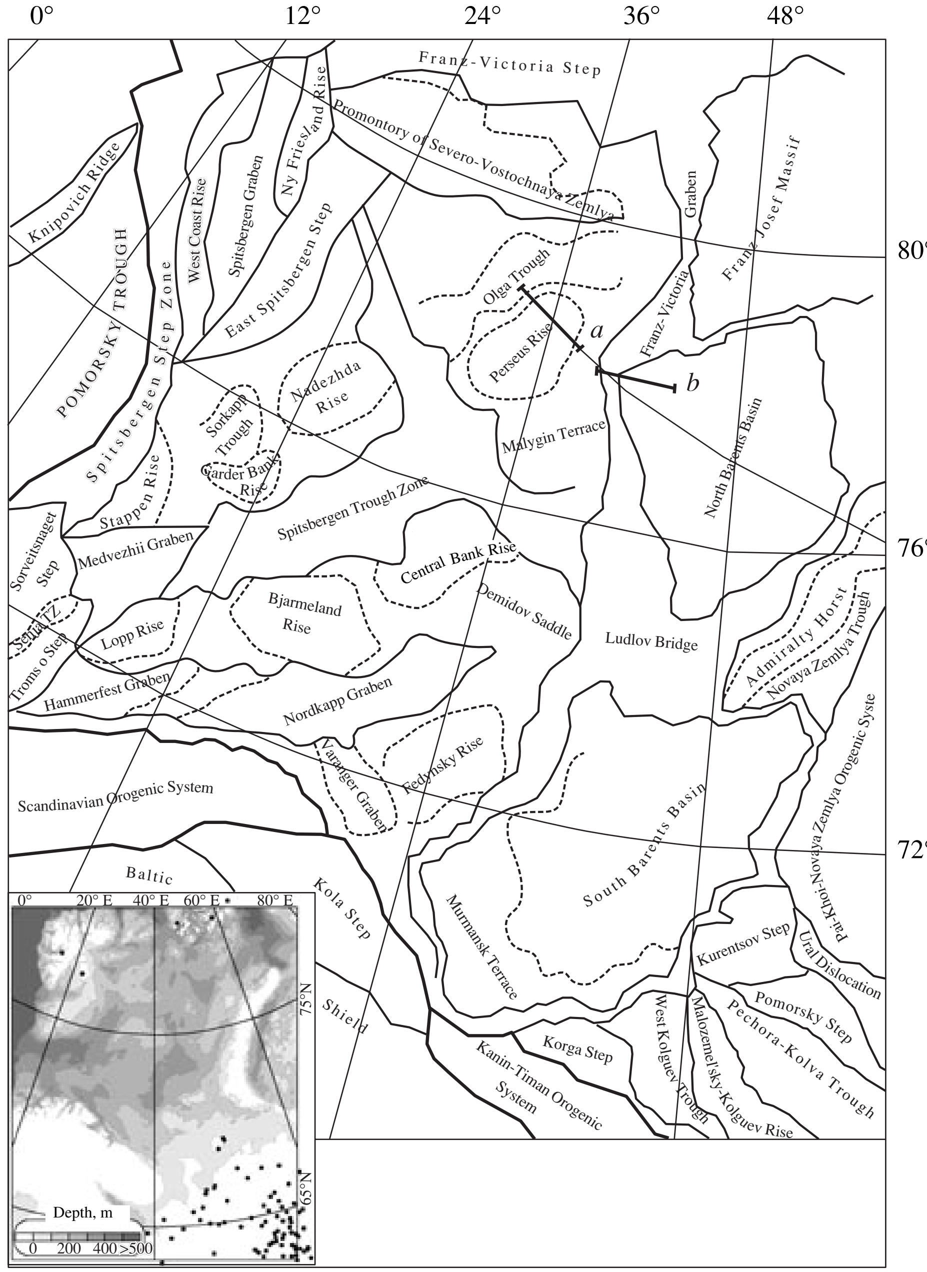

Fig. 1. Tectonic units of the Barents continental margin. Inset demonstrates bathymetry and borehole location. Seismic sections (*a*) and (*b*) are shown in Fig. 2.

belt is characterized by a high density of heat flux that testifies to its present-day activity.

How did the Barents margin respond to the ocean-forming processes, in terms of paleogeographic settings and tectonic pattern? This is a subject of the present communication.

The comparative tectonic study and reconstruction of the geological history in the course of compilation of a new series of state geological maps [3, 4] suggests the following conclusions.

In the Late Cretaceous–Early Cenozoic phase of the Barents region evolution, a considerable portion of the continental margin was drained. Only a narrow tract that bordered Scandinavia in the north (Harstad, Tromsö, Nordkapp, and probably Medvezhii troughs) and the southern part of the South Barents Basin served as the shallow-marine sedimentation zone. Such a sedimentation regime was retained in this zone during Paleocene–Eocene. This is indicated by the presence of clayey member (20–30 m) with diatom assemblages of the respective age in the western area of the South Barents Basin [4]. The land that appeared as a result of an uplift 58–59 Ma ago (chron 24B) obtained a new geodynamic impulse for growth under conditions of compression related to the new phase of opening of the Norwegian–Greenland and Eurasia basins and the onset of transpressive interrelations between Greenland and Spitsbergen segment of the Barents margin. Thus, the newly forming interplate strike-slip boundary promoted the origination of the western flank of the transform-type margin.

In the Paleocene, the entire territory was drained except for the Medvezhii and Nordkapp troughs. Since the middle of this time span, the Barents margin was affected by alternating compression and extension settings, owing to the periodic intensification and attenuation of spreading in the west and north.

In the Eocene, the marine sedimentation was retained in the outer zones of the Medvezhii and Nordkapp troughs. However, the shelf sedimentation environment also cannot be ruled out under conditions of insignificant rise of the World Ocean level at that time.

The Oligocene was characterized by a contrast change of paleogeographic setting due to the involvement of the Barents margin in the next phase of uplift that led to further growth of the already existing arch–block rises (Franz Josef Land and Svalbard) and the adjacent regions, as well as the emergence of a new low mountain in the Novaya Zemlya belt [5]. The drop of ocean level since the second half of the Oligocene, and departure of Greenland from Spitsbergen and emergence of the Molloy spreading center between them, was accompanied by downcutting of valleys and formation of probably the first drainage system in the Barents region. The sea receded toward the continental slope. The peneplain that emerged as a result of previous regression was split into blocks and subjected to fluvial erosion. It is quite probable that the late Oligocene regression and relief growth were accompanied by the first cooling. However, our observations and the published data indicate the existence of numerous casts of thermophilic plants in the Paleogene rocks in Spitsbergen [6].

The regime of attenuating compression of the Earth's crust of the Barents margin and its slow uplift continued during the entire Miocene, owing to the low spreading rate in oceanic basins. At the end of Miocene, this sluggish process was interrupted by a new and perhaps the last appreciable geodynamic impulse that intensified the uplift of the Barents margin. The downcutting of river valleys proceeded simultaneously with the drop of the World Ocean level. The formation of rather thick progradational complexes and fans on the continental slope and foothill widened the shelf area [7].

Starting from the Pliocene, the Barents margin was characterized by variously directed oscillations with a tendency to subsidence. The boundaries of trenches related to the rejuvenation of movements along normal faults and fracture zones acquired the present-day outlines. The emergence of the first thin ice domes is also related to this period.

Transgressive conditions were predominant, but the Novaya Zemlya Ridge was separated in the Neopleistocene.

Thus, the late Miocene–Pliocene boundary was characterized by transition from the primarily regressive evolution of the Barents margin to the transgressive subsidence of shelf.

Further development of the margin in the late Pleistocene and Holocene was related to the alternation of glacial and interglacial epochs with the respective exarational activity, as well as glacial, periglacial, and postglacial sedimentation.

It is important to emphasize that in the first half of the Cenozoic the Spitsbergen segment of the Barents margin was strained due to transpressive relationships between the Greenland and Svalbard plates [8], leading to the formation of the West Spitsbergen and Eureka thrust–fold belts. However, folding and faulting of the sedimentary cover (largely in the pre-Quaternary eroded complexes), correlated with this stage of evolution, was also recorded on seismoacoustic and CDP profiling data [9, 10] far away from Spitsbergen (Central Bank, Perseus Rise, and other areas of the eastern shelf framework) up to Franz Josef Land (Figs. 1, 2). This compels us to suggest the involvement of not only low-angle shear strains in the upper crust, but also detachments in the sedimentary cover at boundaries of contrast lithologies that begin from the western (Spitsbergen) area. The most preferential conditions for propagation of such near-horizontal detachments were provided by seismic boundaries Ia, B, and others, i.e., along boundaries between carbonate and terrigenous sediments, gypsum-bearing and shale units, coal seams, and so on. Judging from the sections, these dislocations were also rejuvenated not only during the subsequent periods of spreading and plate divergence, but also in the Pleistocene and Holocene (Fig. 2). It should be noted that, in addition to the aforementioned transpression, transformation of the Barents margin can also take place owing to the interaction of oceanic and continental lithospheric masses under conditions of spreading and divergence of plates.

Geological examples and modeling calculations show that extrusion of the oceanic lithosphere (a carrier of tectonic energy) in the process of spreading creates very powerful stresses in the continent/ocean boundary zone. These stresses are transmitted in a near-horizontal direction to the continental plate [11, 12]. These data confirm once again that, in our case, some energy could have been consumed by the rejuvenation and reactivation of shears, detachments, and thrusts within the Barents margin in the second half of the Cenozoic, when Greenland started to move away from the Spitsbergen segment of the margin. However, the phases of high spreading activity in oceanic basins alternated with waning phases when spreading centers died off or the

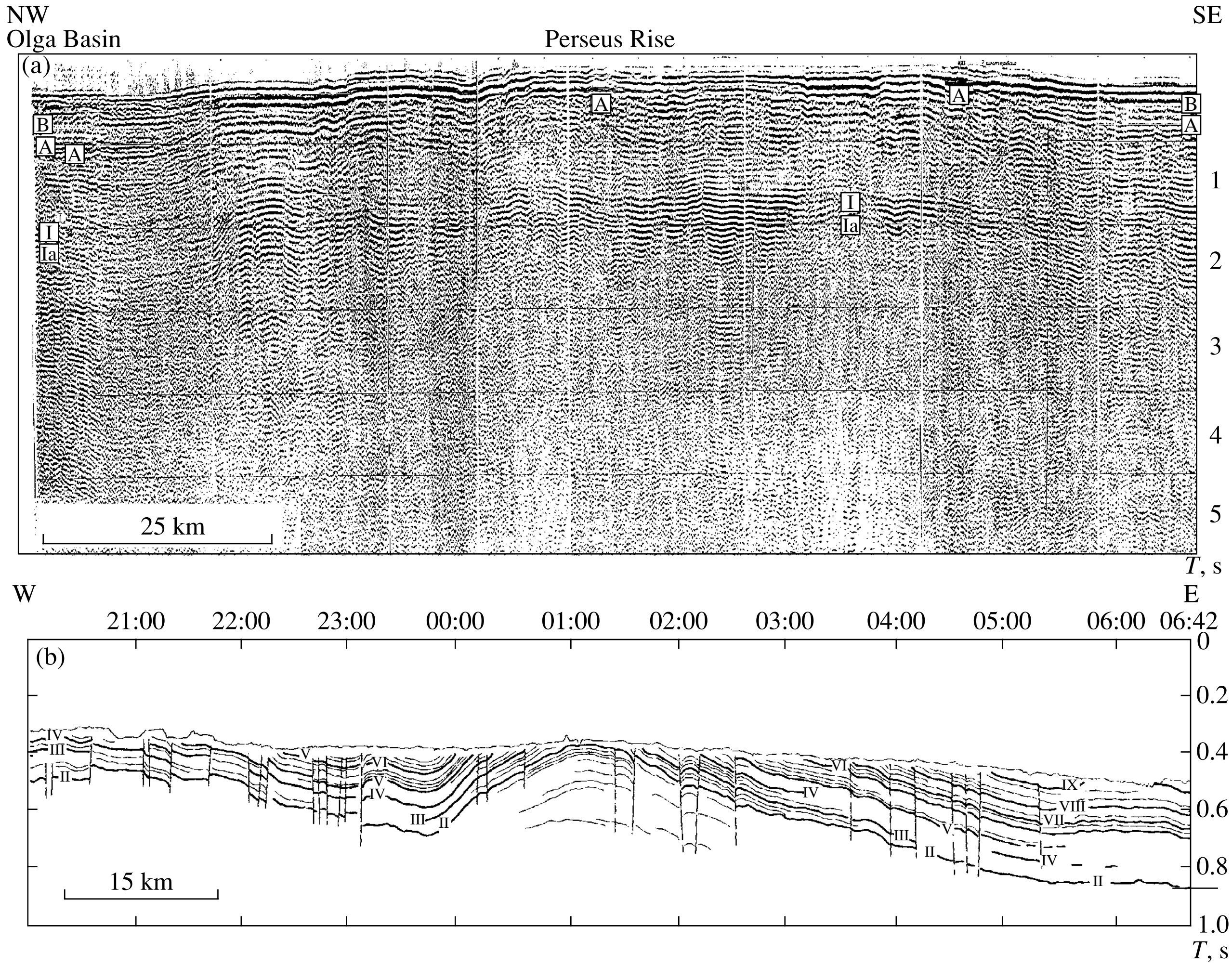

Fig. 2. Fragments of seismic sections showing Cenozoic deformations in the sedimentary cover of Svalbard Plate. See Fig. 1 for location of sections. (a) Fragment of seismic section (northwestern end of profile 81204) that illustrates structure and dislocations of Mesozoic complexes in the sedimentary cover of the northern end of the Perseus Rise (Fig. 1) induced by Cenozoic compression and expressed in the structure of Quaternary sediments. Main reflectors: (Ia) boundary between the Upper Paleozoic carbonate and terrigenous rocks, (I) base of Triassic section, (A) reflector in the lower part of Triassic section, (B) base of Cretaceous section. (b) Latitudinal seismogeological section [10] at the southern extension of the subsided blocks of Franz Josef Land in the North Barents Basin (Fig. 1) that illustrates character of folds and faults in the stratified Barremian–Aptian–Albian sequence between reflectors II and IX. One can see normal and reverse faults expressed in the bottom topography, as well as denudation sections of folds related to the Cenozoic.

spreading rate became extremely slow. As a result, compression at continental margins also became markedly weaker.

In this case, the tectonic regime together with other endogenic factors should have changed the physical state of rocks and induced dynamometamorphism of the Phanerozoic rocks at the northwestern margin. This nearly triangular segment apparently encompasses Spitsbergen and Franz Josef Land archipelagoes and the surrounding shelf.

Drilling of deep parametric boreholes on Spitsbergen and Franz Josef Land archipelagoes (Barents Sea) and detailed geological–petrophysical investigations of their cores [13] provided insights into physical properties of the rocks formed in various geodynamic and structural–tectonic settings (Figs. 1, 3).

Thus, the comparative analysis of petrophysical properties of the rocks from islands and continental periphery of the Barents Sea shelf (Fig. 3) made it possible to reveal their substantial differences and confirm the suggestions stated above.

In comparison with the continental framework (Fig. 3), the northern insular part of the Barents margin is mainly characterized by the following petrophysical differences: (i) higher density and elastic wave velocity of terrigenous and carbonate complexes, and (ii) lower reservoir potential of rocks that controls prospects for hydrocarbon resources.

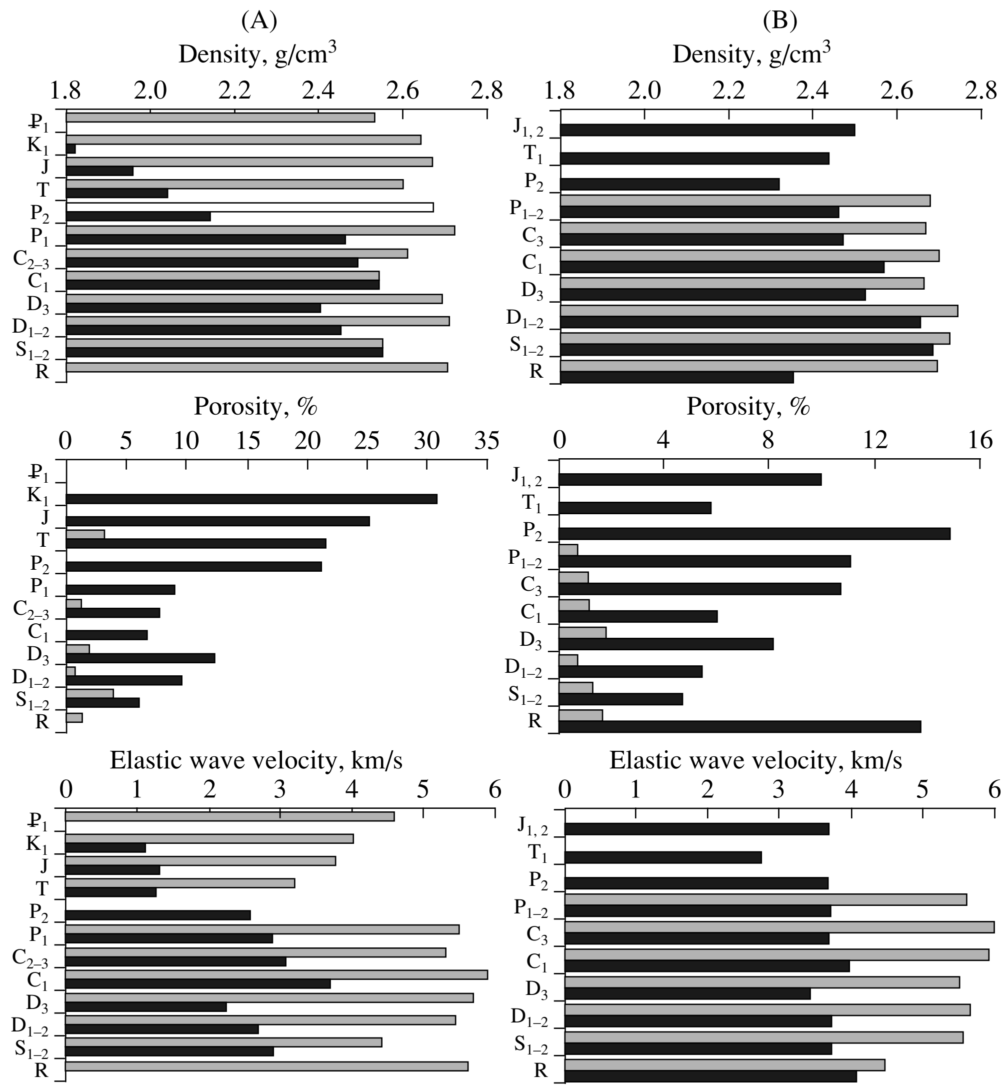

Fig. 3. Variation of petrophysical parameters of rocks penetrated by boreholes (Fig. 1, inset) in the continental (black bars) and insular (gray bars) frameworks of the Barents margin. (A) Terrigenous and (B) carbonate rocks from insular and continental domains of the Barents Sea region.

This implies that the Phanerozoic (Riphean–Paleogene) rocks in the insular (perioceanic) part of the margin underwent more intense catagenesis and dislocation metamorphism than the rocks in the continental (rear) framework. These factors were responsible for the general compaction of the Phanerozoic complexes and cementation of the pore space of terrigenous rocks. Tectonic, seismic, igneous, and thermal activities of the insular and adjacent shelf areas in the Mesozoic and Cenozoic were provoked by the formation of young oceans. These processes resulted in tectonic fracturing, strike-slip and thrust faulting, disintegration of rocks, enrichment of sedimentary sequences in basalts, and so on. All these factors led to the compaction and consolidation of rocks. Consequently, the velocity of seismic wave propagation was increased and the velocities of wave propagation in terrigenous and carbonate rocks became similar.

The aforementioned properties of reservoir rocks in the sedimentary cover testify to a lower petroleum resource potential of the northwestern segment of the Barents margin in comparison with its rear zone [14]. The findings of residual bitumens on the Franz Josef Land [15] confirm this statement. The bitumen occurrences are probably related to not only the thermal impact of the Jurassic–Cretaceous basaltic magmatism on country rocks, but also to the impact of tectonic stresses (multifold uplifts, erosion, extension, and compression) on this segment of continental margin in the Cenozoic (the effect of sponge squeezing).

The result obtained show that the structure of the Barents margin did not remain "conserved" during the Cenozoic, but was modified owing to its response to the main geodynamic and tectonic events in the evolving oceanic basins. This is imprinted in the geological structure of sedimentary complexes, igneous activity, tectonic deformations, and physical properties of rocks.

REFERENCES

1. *Sedimentary Cover of the West Arctic Metaplatform: Tectonics and Seismostratigraphy*, Ed. by E. F. Bezmaternykh, B. V. Senin, and E. V. Shipilov (Sever, Murmansk, 1993) [in Russian].
2. J. Saettem, T. Bugge, S. Fanavoll, et al., Mar. Geol. **118**, 257 (1994).
3. E. V. Shipilov, V. V. Orgo, S. I. Shkarubo, and E. E. Musatov, in *Explanatory Notes to the State Geological Map of the Russian Federation. Scale 1 : 1 000 000 (New Series). Sheet S-38–40 (Matochkin Shar)* (VSEGEI, St. Petersburg, 1999), pp. 85–108 [in Russian].
4. E. V. Shipilov, V. V. Orgo, and E. E. Musatov, in *Explanatory Notes to the State Geological Map of the Russian Federation. Scale 1 : 1 000 000 (New Series). Sheet S-38–40 (Matochkin Shar)* (VSEGEI, St. Petersburg, 1999), pp. 142–152 [in Russian].
5. I. G. Avenarius, Geomorfologiya, No. 3, 53 (2002).
6. D. Worsly, O. J. Aga, A. Dalland, et al., *Geological History of Svalbard* (Statoil, Stavanger, 1986).
7. E. V. Shipilov, Geotektonika, **38** (5), 26 (2004) [Geotectonics **38**, 343 (2004)].
8. E. V. Shipilov, S. I. Shkarubo, N. A. Bogdanov, and V. E. Khain, in *Comprehensive Studies of Nature in Spitsbergen* (Kola Nauchn. Tsentr, Apatity, 2003), No. 3, pp. 41–58 [in Russian].
9. P. Antonsen, A. Elverhoi, H. Dypvik, and A. Solheim, Am. Assoc. Petrol. Geol. **75**, 1178 (1991).
10. A. Solheim, F. Gustavsen, E. Musatov, et al., Norsk Polarinst. Medd., No. 151, 24 (1998).
11. F. A. Letnikov, Dokl. Akad. Nauk **354**, 224 (1997) [Dokl. Earth Sci. **354**, 501, (1997)].
12. Yu. M. Pushcharovsky, Geotektonika **38** (3), 3 (2004) [Geotectonics **38**, 157 (2004)].
13. E. V. Shipilov, V. A. Tyuremnov, V. N. Glaznev, et al., in *Comprehensive Studies of Nature in Spitsbergen* (Kola Nauchn. Tsentr, Apatity, 2005), No. 5, pp. 266–279 [in Russian].
14. E. V. Shipilov and R. R. Murzin, Geol. Nefti Gaza, No. 4, 6 (2001).
15. B. A. Klubov and A. S. Ostroi, Dokl. Akad. Nauk **342**, 785 (1995).