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GEOLOGY

Neotectonics of the Northern Norwegian–Greenland Basin: Specific Features and Evolution of the Knipovich Ridge and Pomorsky Perioceanic Trough

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The Earth's crust beneath the Atlantic Ocean has a heterogeneous tectonic structure. The northern (Arctic and subarctic) region is characterized by a particularly specific structure. The region is located between two demarcation fracture zones. The Spitsbergen fracture zone, which separates the study region from structures of the Polar Basin, is situated in the north. The Charley Gibbs fracture zone (52° N) is located in the south. The Reykjanes spreading ridge, which extends from Iceland to the southwest, is obviously a member of the Mid-Atlantic Ridge system. Iceland and its thick crust separate the Reykjanes Ridge from the Arctic system of Cenozoic spreading ridges (Kolbinsey, Mohns, and Knipovich). All these ridges have nearly similar dimensions but different strikes [2]. The Kolbinsey Ridge represents a gentle NW-oriented arc. The Mohns Ridge separated by the Jan Mayen transverse fault is slightly bent toward the northeast. The northernmost Knipovich Ridge shows a nearly meridional strike. Many researchers have noted that, in contrast to the Mid-Atlantic Ridge, the Knipovich Ridge is not located between continents but shifted toward the Spitsbergen Archipelago.

The study region incorporates numerous diverse structures in a relatively small space. They are characterized not only by the oceanic or continental type of the Earth's crust, but also by the presence of transitional types of crust. The present paper is devoted to the northernmost sector of the Norwegian–Greenland Basin, which includes the Knipovich Ridge and the Pomorsky perioceanic trough. Special attention is given to neotectonics of the study region.

The Norwegian–Greenland segment is the northernmost and youngest member of the Atlantic–Arctic geodynamic system characterized by low-spreading processes of the opening of oceanic basins. This segment is also marked by a very high concentration of structures with signatures of various geodynamic regimes and tectonic settings [1, 5–8]. Figure 1 shows the major elements of the West Barents (Spitsbergen) continental margin and the adjacent part of the Norwegian–Greenland Basin. Deformations related to neotectonic evolution are particularly prominent in this region. Therefore, the Knipovich Ridge, which represents the northernmost segment of the MAR spreading system, deserves special attention.

The outer transitional zone on the western side of the Spitsbergen (Knelegg–Hornsund) fracture zone incorporates the Norwegian–Spitsbergen zone of fore-oceanic shelf terraces. The Vestbakken volcanic province with specific structure and evolution style is outlined south of Bear Island. The Vestbakken province, which represents a submerged block of continental margin with plateau basalt sheets, adjoins the oceanic spreading crust along the Senja fault in the southwest.

The sector between Bear Island and Serkap Cape is called the Knelegg–Hornsund terrace, while the zone adjacent to the western coast of Spitsbergen is called the Prince Charles terrace.

The zone of shelf terraces is characterized by an intricate graben–horst structure of the pre-Cenozoic basement located at a maximum depth of 5 km. The width of this zone varies from 30 to 70 km. Nearly the entire eastern rear margin of terraces is complicated by grabens filled with Lower Cenozoic sediments up to 6 km thick. The outer ridge (border) of grabens is truncated by the bottom floor in some places. However, the ridge is more often buried under a layer of Neogene–Quaternary sediments. Intense fault–block dislocations

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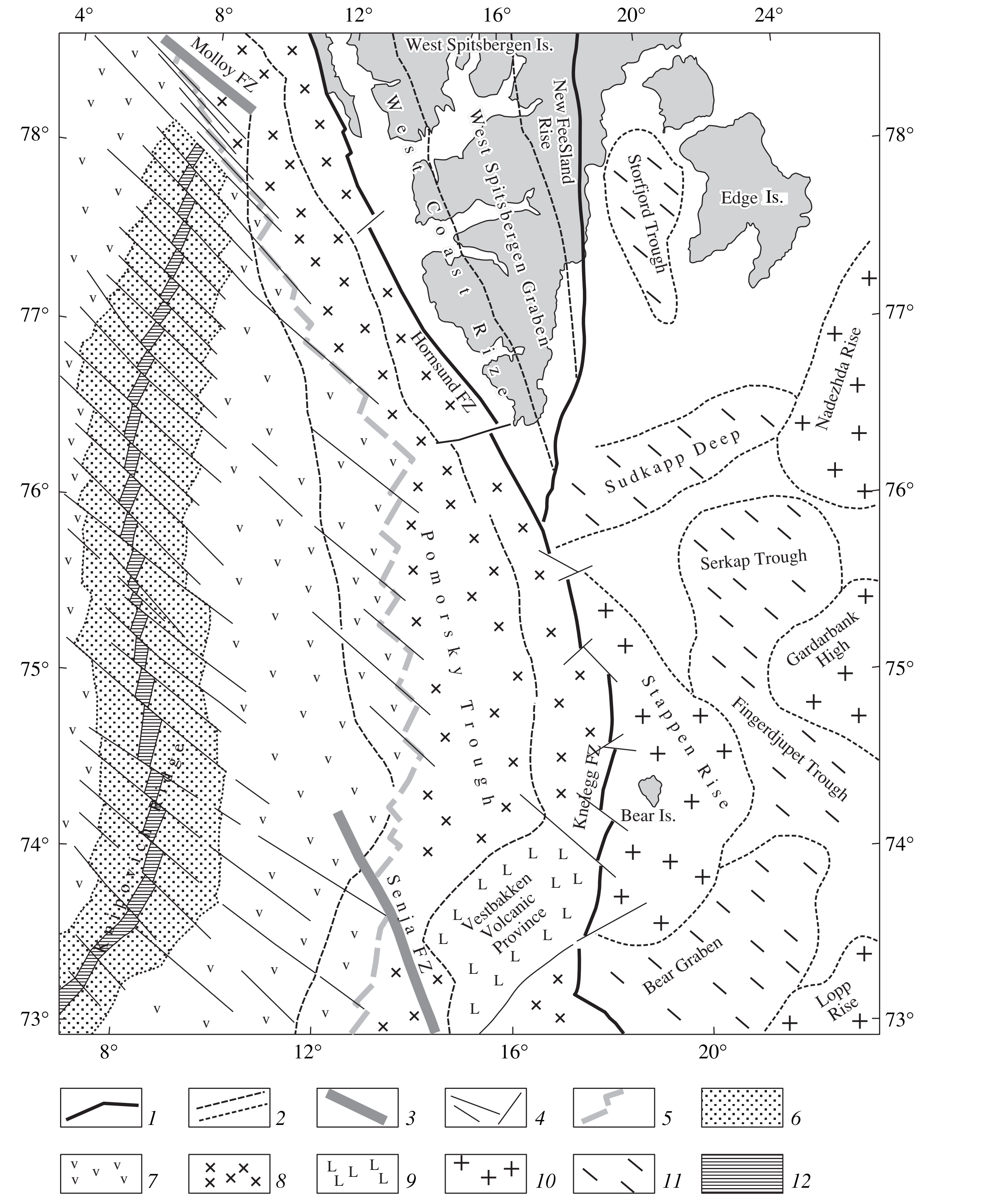

Fig. 1. Sketch map of the major structural elements of the West Barents (Spitsbergen) continental margin and the adjacent sector of the Norwegian–Greenland oceanic basin. (*1*) Major sutures (boundaries of the Barents plate, West Spitsbergen orogenic system, and transitional zone); (*2*) boundaries of structures of different orders; (*3*) major fracture zones (FZ); (*4*) transform and other faults; (*5*) boundaries of the continental (transitional) and oceanic crusts; (*6*) crest zone of the Knipovich Ridge; (*7*) zone of the spreading-type oceanic crust; (*8*) zone of intense destruction of continental crust in the transitional zone; (*9*) basaltic traps of the Vestbakken province; (*10, 11*) structural elements of the Barents Plate: (*10*) rises with the Baikalian (?) basement subjected to rheomorphism in the Caledonian epoch, (*11*) riftogenic troughs and depressions; (*12*) axial valley of the Knipovich Ridge.

of the basement at the contact of the destructed continental–oceanic crust in some marginal sectors along the Knelegg–Hornsund fracture zone reflect the replacement of shear dislocations by the extension regime. The western margin of shelf terraces give way to a prominent scarp of flexure belt of the continental slope. The narrow zone with the highest gradient of basement surface subsidence shows the most drastic thinning of the continental crust. In terms of the sedimentary cover structure, this zone corresponds to the eastern continental flank of the Pomorsky Trough. Thus, the depocenter of the basin apparently shows the approximate position of the continental–oceanic crust boundary. This boundary coincides with the Senja fracture zone in the south up to 74°. North of 76°, the boundary is confined to the axial zone of the perioceanic trough and is displaced in a stepwise manner to the northwest up to the Molloy transform fault.

The 74°–76° N sector incorporates a zone with anomalous geophysical parameters of the Earth's crust (Hornsund maximum) characterized by the maximum rise of the Moho surface and the formation of a thin band between the destructed continental crust in the east and the spreading zone in the west.

The oceanic crust zone includes the crest zone of the mid-oceanic Knipovich Ridge (hereafter, the Knipovich crest zone) and the deepest zone of the oceanic crust underlying the eastern Pomorsky Trough.

Tectonic features of the oceanic zone are governed by near-meridional lineaments (rift zone of the Knipovich Ridge and nearly parallel volcanic ridges), on the one hand, and a series of transverse (transform) faults oriented in the NW (300°–320°) direction, on the other hand. In seismic profiles across the fracture zones, the tectonic structures are observed as prominent scarps (trenches in some cases) in the basement topography. Tracking of all fractures in the study region and their correlation with axis displacement zones of linear magnetic anomalies (LMA) shows a spacing of 10–30 km between the fractures.

In the Knipovich crest zone, gravity anomaly values match the basement topography. The rift valley is outlined by a narrow band of the gravity minimum in free air. The valley is sandwiched between zones with a high intensity of gravity field, where maximum amplitude anomalies are related to volcanic edifices rising above the sedimentary cover.

In terms of magnetic field distribution, the Knipovich Ridge drastically differs from the Mohns Ridge, which is characterized by an intense axial anomaly (up to 1000 nT) and distinct LMA symmetry.

The anomalous magnetic field of the Knipovich Ridge has a mosaic pattern. The axial anomaly (up to 700 nT) is well developed only in the northern part of the ridge. The southern and middle sectors of the crest zone are characterized by poorly correlated maxima (100–200 nT) often shifted relative to the rift valley.

The anomalous magnetic field of the oceanic zone shows a transverse zonality. Axes of LMA fragments shifted relative to fractures are oriented along the strike of the rift valley. Magnetic anomaly 3 is related to the eastern escarpment of the Knipovich Ridge represented by a chain of high crests. LMA 9 is the last linear anomaly identified east of the crest zone.

The significant influence of shear tectonics on the evolution of the northern Norwegian–Greenland Basin is reflected in the very high subsidence rates of the continental crust in the Pomorsky Trough zone as compared to its low lateral displacement relative to the spreading center. The transitional zone between the destructed continental and oceanic crusts includes an anomaly zone with velocity and density parameters typical of the lower crust but without signs of basaltic eruptions. The significant intensification of the contrast pattern of the volcanic topography at the Knipovich Ridge crest is consistent with the formation of magnetic anomaly 3 approximately 30 yr after the onset of basin opening.

The evolution of the Knipovich Ridge near the continental margin under conditions of the intense transport of terrigenous material to the oceanic basin fostered the development of specific features of spreading and accretion of the oceanic crust.

The setting and relationship of sedimentary sequences with the oceanic basement provide insights into the timing of dislocations and sites of neotectonic activity in the Knipovich Ridge. These sites are confined to a 100-m-wide crest zone marked by near-meridional bands of juxtaposed (and obviously post-sedimentary) dislocations of the oceanic crust and the sedimentary cover therein. The eastern continuation of the chain of crests represents a slightly inclined and undisturbed bottom surface of the continental foothill.

The profile across the southern Knipovich Ridge shows that the sedimentary sequence (>1 km thick) in the rift valley is distorted by listric normal faults with the successive thinning of the sedimentary bed up to the point of its complete rupture and exhumation of basement basalts at the rift center (Fig. 2). The asymmetry of basin walls implies that one flank, with a wide fault-related scarp, represents the wall of the riftogenic segment, whereas another flank represents the steep plane of a transverse fault that displaces the adjacent segments of the ridge. It should be noted that the analyzed profiles of the axial center lack any normal cross sections. Therefore, one of the profiles reflects the cross section of a transform strike-slip fault, suggesting the fine-cellular and oblique segmentation of the Knipovich Ridge.

The example discussed above testifies not only to the present-day horizontal extension in the axial Knipovich Ridge, but also to the cyclicity of spreading processes. Impulses of spreading alternated with phases of relative rest with a duration of ~1 Ma, during which a sufficiently thick sedimentary sequence could

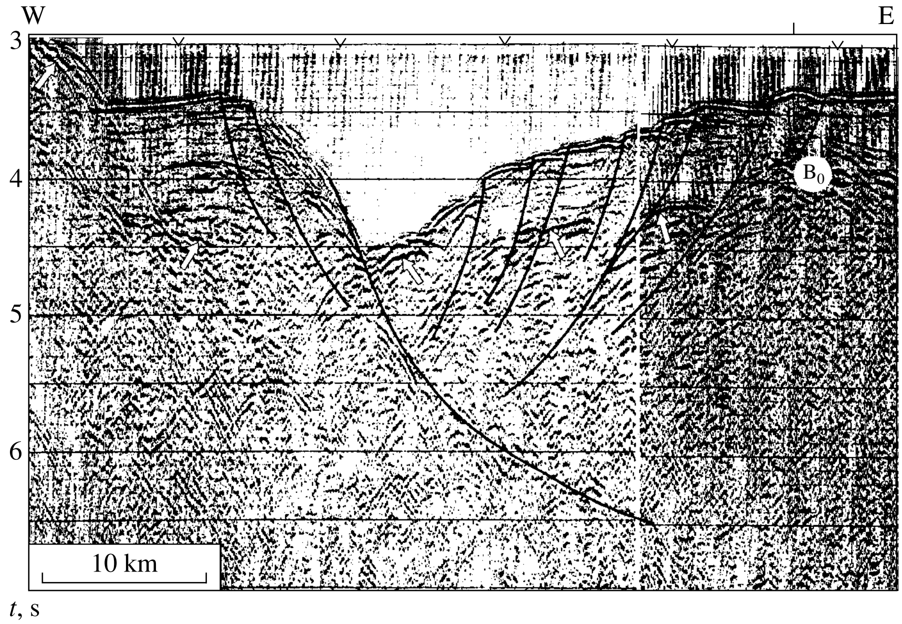

Fig. 2. Seismic profile across the southern Knipovich Ridge (a fragment of the RWM CDP 91237 profile) illustrating the extension and rupture of sedimentary sequence in the rift valley. (B_0) oceanic basement. Arrows show horizons corresponding to basalt sheets and sills.

have been deposited in the basin. When passing from the south to the north, some segments of the axial rift were characterized by asynchronous cyclicity or different intensities of periodic reactivation. For example, extension at the junction of differently oriented elements of the spreading center (the Mohns and Knipovich ridges) provoked rupture of the sedimentary section and exposure of basaltic rocks in the rift valley.

In the middle segment of the Knipovich Ridge (74°–76° N area), the rift valley is buried under a sedimentary sequence (1.0–2.5 km thick) with basalt sheets and sills in some places (Fig. 3). In the northern segment, sediments are absent in the rift valley and volcanic edifices are present at its center (Fig. 4). All these discrepancies in the rift zone structure indicate a gradual northward propagation of the spreading center and an irregular style of the subsequent tectonomagmatic reactivation along its strike.

The Knipovich Ridge and Pomorsky Trough started to evolve after the transformation of the geometry of this segment of the Norwegian–Greenland Basin in the Late Eocene–Early Oligocene (~35–33 Ma ago), resulting in the replacement of transpression by transtension in the marginal zone north of 74° N. This event was responsible for the crustal extension and faulting along the older weakened zones. The next period was characterized by the beginning of spreading and the formation of the Knipovich Ridge, which moved in the northern direction and approached the strike-slip fault boundary. Thus, the oceanic crust was gradually rejuvenated along the northern direction. According to [8], the spreading rate in the 78° N area is estimated at ~1.5–2.3 mm/yr for the eastern wall and ~1.9–3.1 mm/yr for the western wall. In the 75° N area, the spreading rate is ~4.3–4.9 mm/yr.

Analysis of RWM CDP seismic profiles and deep-water drilling data indicates that the breakup of continental margin was immediately followed by its intense subsidence. By the beginning of the Miocene (~22.5 Ma ago), the subsided terraces of the continental basement accumulated a coarse-clastic sequence with an average thickness of 2.5–3.5 km (up to 5.5–7.0 km in axial depressions of the Pomorsky Trough). The lower portion of this sequence could have been deposited even at the rifting stage. However, the sedimentary sequence does not show distinct signs of unconformity prior to the spreading.

The transitional or destruction zone (including the shelf terrace) mainly defined by the eastern wall of the trough and its axial zone ranged from 60–80 to 120–140 km in width. In the Early Miocene, the width of the sedimentary basin extending from the continental platform to the paleoridge escarpment was 180–200 km wide in the middle part of the Pomorsky Trough. Oligocene–Lower Miocene beds rested over the oceanic basement within its western flank.

In the Early Miocene (22.5–13 Ma), the margin continued to subside at a lower rate and became more differentiated. The subsidence amplitude was maximal in the central part of the Pomorsky Trough. The southern part of the trough adjacent to the Vestbakken province was characterized by hiatus at this time.

Erosion surface U_3 identified in the seismic profile in the southern Pomorsky Trough is located in the present-day structure at a depth of 3–4 km at the foot-

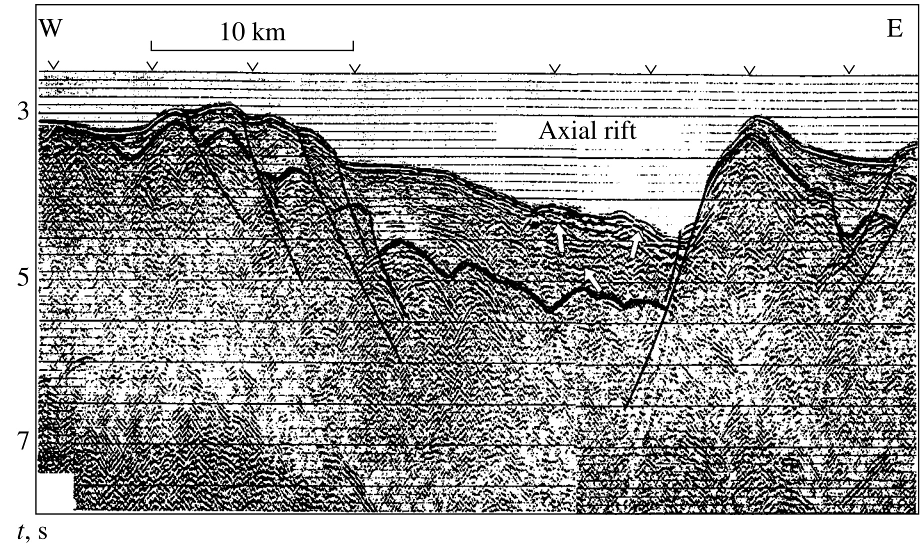

Fig. 3. Seismic profile across a rift valley in the middle sector of the Knipovich Ridge (a fragment of the RWM CDP 91211 profile). Example of the formation of volcanosedimentary sequence in the rift valley. Arrows show horizons corresponding to basalt sheets and sills.

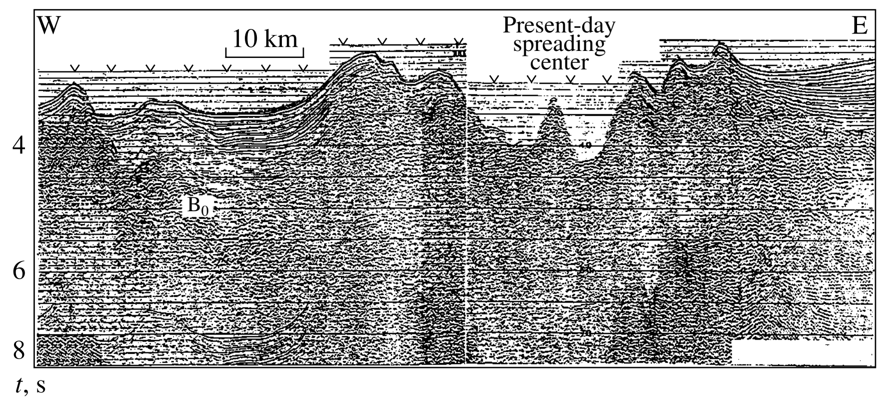

Fig. 4. Seismic profile across a rift valley in the northern Knipovich Ridge (a fragment of the RWM CDP 87770 profile).

hill of the continental slope. Given that this block was located near the sea level as a transit zone for sediments prior to the Late Miocene, the amplitude of its subsidence over the recent 10–12 Ma may also be equal to 3–4 km. Unconformity U_2 (13 Ma) recorded in the central Pomorsky Trough at the maximal depth of 4.5–5.0 km and consideration of the possible paleodepth (up to 1.0–1.5 km) of the oceanic basin yield a similar value of its subsidence during the respective period. The higher rate of basin subsidence at the beginning of the Late Miocene was accompanied by the dumping of avalanche-and-slump masses on the slope foothill.

In the second half of the Late Miocene–Pleistocene, the sedimentation rate exceeded the margin subsidence rate, resulting in the maximum (up to 50 km) progradation of the shelf and continental slope. This process was accompanied by the intensification of tectonomagmatic activity in the rift zone of the Knipovich Ridge and the formation of the highest crests that make up the present-day eastern escarpment. However, although the ridge became higher and the spreading axis retreated from the platformal margin (provenance) boundary over 260–290 km at the end of the period mentioned above, the crest zone (except its highest northern part) was covered by Upper Miocene–Pliocene sediments.

Thus, the evolution history of the Knipovich Ridge and the eastern Pomorsky Trough started from a variation in the style of opening of the northern Norwegian–Greenland Basin in the Late Eocene–Early Oligocene (35–33 Ma ago). This process, which probably corresponded to the onset of the neotectonic epoch in the study region, was followed by the beginning of spreading and the formation of the Knipovich Ridge (presumably, in the Early Miocene 23 Ma ago). Intense breakdown of the basement and its sedimentary cover at the crest of the Knipovich Ridge testifies to the recent and present-day neotectonic activity.

The formation of the Pomorsky Trough was accompanied by its subsidence and the accumulation of a thick sedimentary sequence. This process started at the beginning of the Miocene and continued until the Pleistocene with a variable degree of intensity.

Thus, the data presented above suggest the existence of a correlation between the neotectonic epoch of tectogenesis, on the one hand, and the boundaries of neotectonic reactivation in the Central Atlantic [4] and the northern Norwegian–Greenland Basin, on the other hand. Neotectonic processes were active in the Late Eocene–Early Oligocene and Anthropogene epochs. In both regions, the age boundaries generally correspond to the Early Miocene, ~10 Ma, and 1.5–2.5 Ma.

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