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GEOLOGY

New Geodynamic Model of the Evolution of the Northern Norwegian–Greenland Basin

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The northern Norwegian–Greenland Basin includes the Knipovich Ridge, the youngest segment of the North Atlantic spreading zone, and Molloy spreading center. These two structures separate the basin into two sharply asymmetric parts: the Boreal Basin and the Pomorskii perioceanic trough (buried under the sedimentary cover) (Fig. 1). The younger age of the active Knipovich Ridge as compared with the Mona Ridge is emphasized by its discordant (superimposed) position relative to linear magnetic anomalies in the oceanic basement. Short segments of these anomalies distinctly retain strikes inherent to lineaments in the Greenland and Lofoten basins that accompanied accretion of the oceanic crust in the axial spreading center of the Mona Ridge during the entire Cenozoic. The well-manifested asymmetry of basins (relative to the Knipovich Ridge spreading center), distinct discordance of the ridge with magnetic anomaly patterns, and confinement of earthquake epicenters to the ridge—all these and other features gave birth to continuous debates on the formation geodynamics of this segment of the Norwegian–Greenland Basin. It should be noted that, since the beginning of studies to this day, interpretation of short segments of linear magnetic anomalies mapped from the Greenland and Senja transform fault zones in the south to the Molloy transform fault zone in the north has remained one of the most confused and debatable points. Moreover, the field of these largely NE-trending anomalies is complicated by their near-meridional elements parallel to the Knipovich Ridge. Thus, it can be assumed that the Knipovich spreading center and accompanying young linear magnetic anomalies are superimposed on the older structural patterns of NE-trending linear magnetic anomalies. It should be emphasized that such an assumption is substantiated by the distribution of the anomalous gravity field [11, 12].

In this communication, we propose a new geodynamic model that explains the formation of the present-day tectonic structure of the northern Norwegian–Greenland Basin.

According to recent studies [4, 5], the spreading center of the Knipovich Ridge started functioning after Chron 13. The eastern chain of highest ridge summits corresponds to Anomaly 3 (4 Ma), although DSDP Hole 344 (Fig. 1) recovered a basalt intrusion dated by the K–Ar method at 3 Ma [13]. The oldest linear anomaly identified east of the ridge is Anomaly 9 (approximately 29 Ma). However, the mechanism responsible for sharply asymmetric spreading in this region is also unclear thus far. According to one of the most popular models proposed for this part of the Norwegian–Greenland Basin, small-cell and oblique segmentation of the Knipovich Ridge axial spreading zone could represent such a mechanism. This eliminates, to some extent, the contradiction between the general (practically meridional) strike of the ridge and the northeastern orientation of linear magnetic anomalies. At the moment, this model seems to be most preferable since it explains the formation of a new spreading (Knipovich Ridge) segment by the change in the geometry of basin opening in response to the change in the trajectory of the Greenland motion relative to the Barents Sea ledge of the Eurasian Plate. Nevertheless, the mechanism responsible for the asymmetrical spreading, which follows from the position of the Knipovich Ridge and its anomalous proximity to the Spitsbergen margin (approximately 80 km), seems insufficiently substantiated with regard to some points mentioned above and discussed below. The difference in areas of the oceanic crust generated by spreading on the western and eastern sides of the Knipovich Ridge is too large. Although deviations from the model of the ideal symmetric spreading in the Atlantic (as well as in the Eurasia Basin) are recorded

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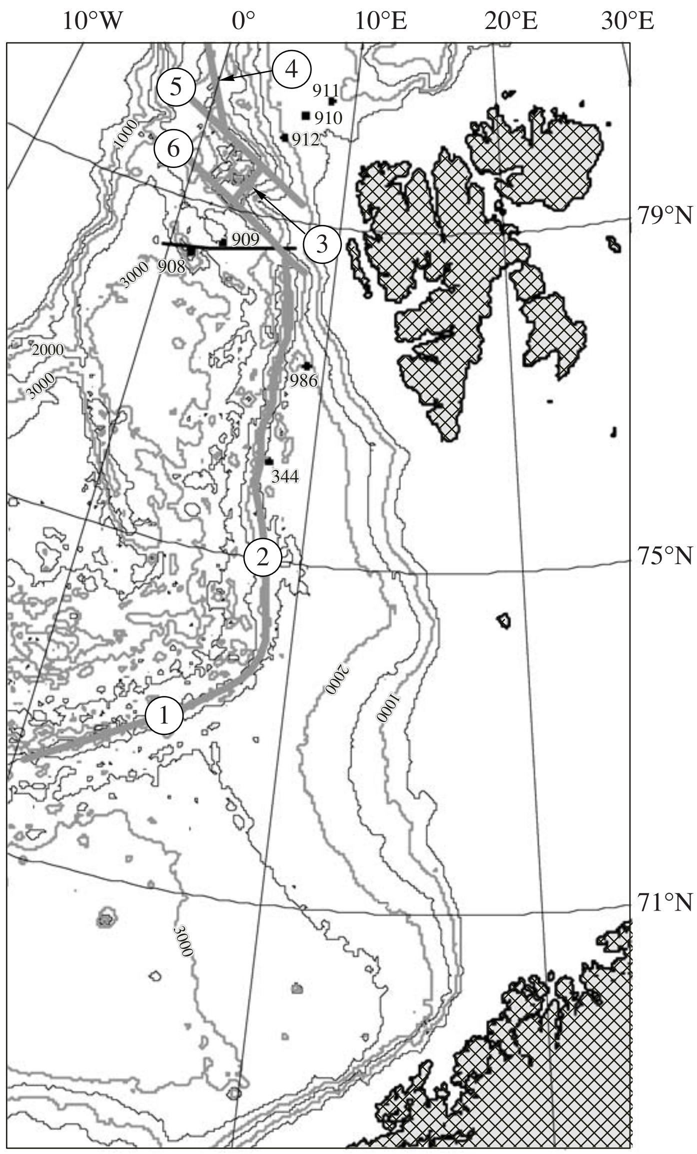

Fig. 1. Schematic bathymetric chart of the northern Norwegian–Greenland Basin with location of deep-sea drilling holes and seismic profiles. Spreading centers (encircled numbers): (1) Mona Ridge, (2) Knipovich Ridge, (3) Molloy; (4) Lena Trough; transform fault zones: (5) Spitsbergen, (6) Molloy.

in many areas, such an anomalous amplitude is atypical of this region.

Based on postulates of the plate tectonics, this situation could be explained by partial subduction of the oceanic crust under the West Barents continental margin. We agree with Khain [3], who supposes the existence of formal conditions for such interpretation. Within the relatively narrow band of the Pomorskii Trough between the West Barents continental margin and Knipovich Ridge, the oceanic basement sharply bends and subsides to a depth of 10–11 km. Its relationships with the thinned oceanic crust are unclear in this area. Taking into consideration even the slow rate of oceanic crust accretion, this situation can be explained by compression at a deeper level. According to existing views, subsidence of the oceanic crust can be explained by an increase of its load due to cooling during its motion away from the spreading center and thermoelastic compression of the crust. According to calculations, this process can last for 80 Ma beginning from the onset of crust generation and the subsidence rate gradually decreases. In the area of the Knipovich Ridge spreading center, the oceanic crust is younger than 30 Ma. In the Pomorskii Trough, its subsidence rate was extremely rapid and sedimentation was characterized by the avalanche mode. It is evident that despite the low spreading rate, the whole process (from the onset of oceanic crust subsidence to its cessation and overcompensation by sediments) was significantly faster in this area.

At the same time, no subduction zone along the West Barents margin is established. It should be noted that based on interpretation of aerogeophysical survey

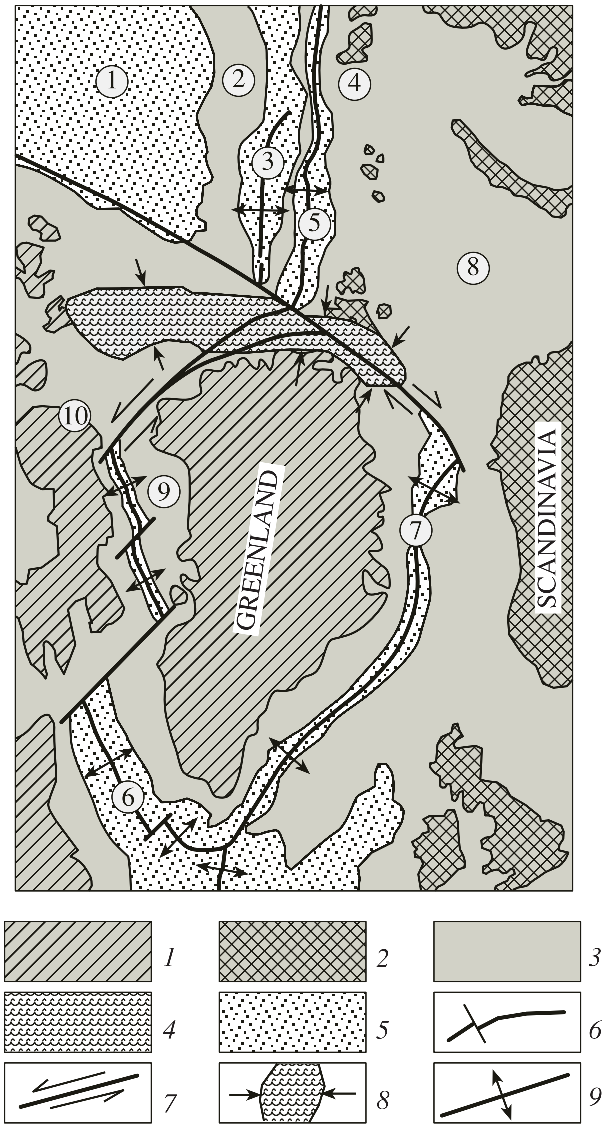

Fig. 2. Paleotectonic reconstruction (out of scale) for Anomaly 21 (after [4, 5, 14, 15]) illustrating the initial opening stage of the Norwegian–Greenland Basin, autonomous development of the Greenland Plate, and progradation of two spreading centers from the North Atlantic to the Arctic basin [4]. (*1–3*) Continental crust of North America and Greenland (*1*), Eurasia (*2*), and their continental margins (*3*); (*4*) Eurican and West Spitsbergen belts of deformations; (*5*) oceanic crust; (*6*) fault zones; (*7*) strike-slip faults; (*8*) vectors of the compression stress; (*9*) axial spreading centers. Encircled numbers: (1) Canada Basin, (2) Alpha Ridge, (3) Makarov Deep, (4) Lomonosov Ridge, (5) Eurasia Basin, (6) Labrador Basin, (7) Norwegian–Greenland Basin, (8) Barents–Kara margin, (9) Baffin Basin, (10) Wegener Fault.

data, the authors of [6] assume a very brief subduction episode in the westernmost part of the Eurasia Basin at the initial stage of its opening, although this conclusion is not substantiated by geological observations. The tectonic compression related to northward motion of the Greenland Plate produced the Eurican and West Spitsbergen deformation belts that were united until Chron 13 (Fig. 2). It may be assumed that a similar (if not analogous) situation existed in another region of the Earth during the Late Eocene, when the Indian Plate (comparable in size with the Greenland one) collided with Eurasia to trigger the formation of the most grandiose mountainous structure.

It is noteworthy that no distinct perioceanic troughs (the more so, similar to the Pomorskii Trough in terms of hypsometry and thickness of the sedimentary cover) have been recorded along the continental foot of northeastern Greenland west of the Knipovich Ridge. This is an additional feature characterizing the specific development of the northern Norwegian–Greenland Basin due to the interference of several factors, such as phases of more intense uplift of the West Barents Sea margin as compared with northeastern Greenland. The West Barents Sea margin delivered huge masses of detrital material to the Pomorskii Trough, where the sedimentation rate in the second half of the Cenozoic was higher than the subsidence rate. Therefore, the basin was filled completely with sediments in the Early Miocene (approximately 22 Ma ago) and even overcompensated at the later stage. Thus, the trough ceased to represent a sedimentation trap. Consequently, mud and turbidity flows, which formed numerous clinoforms and fan lobes at the terminal Cenozoic, gushed over the northern part of the newly forming Knipovich spreading ridge. Therefore, the Pomorskii Trough is not reflected in the bottom topography [4]. It can be stated that alternations of unstable ultraslow spreading regimes in the Knipovich Ridge and uplifts of the Barents Sea margin were responsible for the anomalously rapid tectonic subsidence and formation of a deep perioceanic trough in this region. Pushcharovsky was first to pay attention to these peculiarities in the formation of depressions in the Atlantic Ocean [2]. Consequently, the eastern slope of the Pomorskii Trough is underlain by the transitional continental crust, while the western slope is underlain by the oceanic crust. The depocenter of this trough marks the boundary between these crustal types.

Analysis of the available materials suggests that the Hovgard Ridge block was an element of the West Barents Sea margin until Chron 13 and was located in the lower part of the continental slope. Therefore, the thickness of crust in this region is 12–14 km [7], which is typical of several aseismic ridges. It is conceivable that prior to its separation from the margin, the ridge represented a salient of the basement with the rear zone hosting a graben-shaped trough structurally analogous or similar to the Forlandsun Graben located between Western Spitsbergen and Prince Karl Land. The formation scenarios known for some aseismic ridges (microcontinents) demonstrate the obligatory existence of primary oceanic basins, toward which fragments of these microcontinents migrate in the case of their separation. In the considered situation, such an oceanic basin associated with the Boreal Basin existed west of the Barents

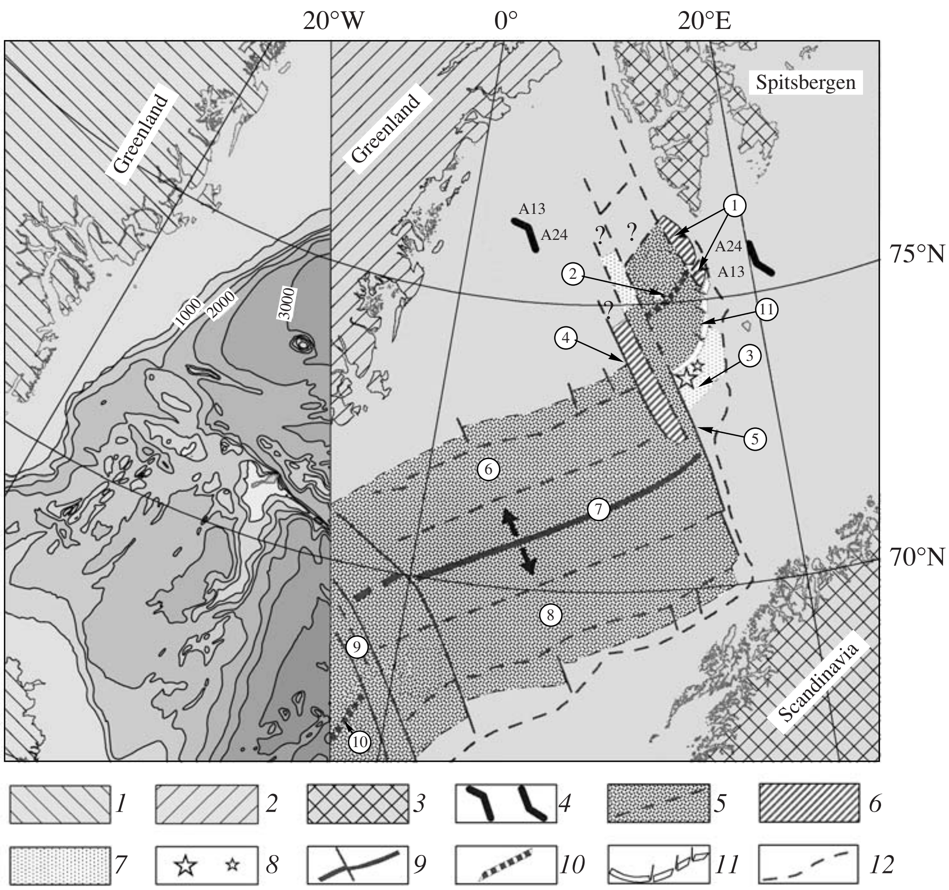

Fig. 3. Paleotectonic reconstruction (right) for Anomaly 13 ([4, 8, 15] with modifications and additions) and present-day position (left) of Greenland (with bathymetry of the oceanic basin) relative the West Barents margin. (*1*) Present-day position of Greenland; (*2, 3*) position of Greenland (*2*), Spitsbergen, and Scandinavia (*3*) for the Anomaly 13 time; (*4*) vectors of relative motion of the Greenland and Barents Sea margin between anomalies 24 and 13 and later on; (*5*) oceanic crust and some magnetic anomalies; (*6*) segmented continental blocks; (*7, 8*) areas of Paleogene flood basaltic magmatism and volcanism, respectively; (*9*) axial spreading centers and transform faults; (*10*) abandoned spreading centers; (*11*) spreading center developed after Anomaly 13; (*12*) rear fault boundary of the continent–ocean transition zone. Encircled numbers: (1) block of the future Hovgard Ridge, (2) assumed abandoned spreading center (Boreal); (3) Westbakken plateau-basalt province; (4) Greenland transform fault; (5) Senja transform fault; (6) Greenland Basin; (7) Mona Ridge; (8) Lofoten Basin; (9) transform fault zone in the Norwegian Basin; (10) abandoned spreading center of the Egir Ridge; (11) initiating spreading center of the Knipovich Ridge.

Sea margin prior to the functioning of the Knipovich spreading center (Fig. 3). Analysis of the geodynamic situation shows that the spreading center was developing synchronously with the Mona Ridge, although the basin was substantially smaller than the combined area occupied by the Greenland and Lofoten basins. This spreading center located in the Boreal Basin died off practically simultaneously with the Egir Ridge. Both mid-oceanic ridges functioned over no more than 25–30 Ma beginning from Chron 24c [4].

The further development scenario of the segment under consideration implies an eastward jump of spreading. Consequently, an extension zone (subsequently, secondary spreading center), i.e., the future Knipovich Ridge, was initiated along the West Barents Sea margin in the terminal Oligocene (after Chron 13). Its development and migration from the margin resulted in the formation of the Pomorskii Trough and separation of the continental Hovgard Ridge block (Fig. 3). Upper Oligocene–Lower Miocene synrift complexes were almost recovered by ODP Hole 986 [9] in the Pomorskii Basin and by Hole 909 [10] in the so-called Greenland–Spitsbergen Threshold area behind the Hovgard Ridge (Fig. 4). Upper Oligocene sediments were also penetrated by Hole 908 [10] in the transverse deep on the Hovgard Ridge. However, Lower Miocene (pre-Pliocene) sediments are missing here. The probable explanation for this fact is as follows. According to the proposed geodynamic model, the Hovgard Ridge block still represented an element of the margin in the terminal Oligocene, whereas sedimentary material transported from the east was dammed by the newly forming Knipovich Ridge after the separation of the Hovard Ridge in the Miocene. This assumption is supported by seismic data on the

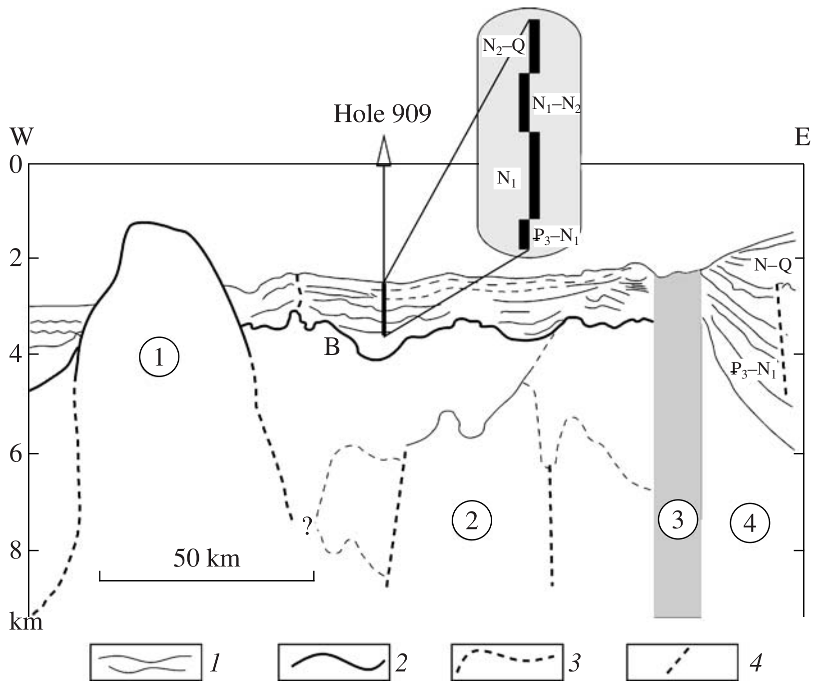

Fig. 4. Seismogeological section along profile 88 218 with the projected Hole 909 section (Fig. 1). (*1*) Seismic reflectors; (*2*) acoustic basement; (*3*) boundaries based on complex geophysical data; (*4*) faults; (B) oceanic basement; encircled numbers: (1) Hovgard Ridge, (2) Greenland–Spitsbergen Threshold, (3) Molloy transform fault zone, (4) Prince Karl Trough. The inset section shows stratigraphic units recovered by Hole 909.

structure and development of the Spitsbergen margin and Knippovich Ridge [1, 5].

Thus, contrary to previous views, the asymmetric structure of the northern Norwegian–Greenland Basin is explained by the two-stage development of this Atlantic segment due to the formation of primary and secondary spreading centers. The position of the aseismic Hovgard Ridge west of the Knipovich Ridge implies the existence of a primary oceanic basin in the present-day Boreal Basin area, where spreading terminated before Chron 13. The secondary spreading center (Knipovich Ridge) was initiated in the Late Oligocene–Early Miocene transition period. Consequently, the continental crust block of the Hovgard Ridge was separated from the Barents Sea continental margin. Accretion of a band of new oceanic crust in this period was accompanied by the westward migration of this aseismic ridge to its present-day position in the Boreal oceanic basin.

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