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GEOLOGY

Tectonic Evolution of the Knipovich Ridge Based on the Anomalous Magnetic Field

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Abstract—Calculation of the downward continuation for the anomalous magnetic field at the Knipovich Ridge showed more complicate segmentation of the spreading oceanic basement than was earlier considered. The structural pattern of the field is evidence that the area consists of no less than four segments separated by transform fracture zones with the azimuth of oceanic crust accretion about 310° and the normal position relative to the rift segments with the azimuth of 40°. The modern location of the axis of the Knipovich Ridge straightens the complicate divergent boundary between the plates in the strike-slip conditions between the spreading centers of the Mohns and Gakkel ridges. The axis is a detachment zone intersecting the oceanic basement having formed from the Late Oligocene. A new magnetoactive layer composed of magmatic products has not yet been formed in this structure.

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The Knipovich Ridge is a segment of the Mid-Atlantic Ridge (MAR) from 73°30′ to 78°30′ N (Fig. 1). Almost all researchers underline its anomalous tectonic structure in comparison with the basic MAR zone stretching for more than 14 000 kilometers. This anomaly identified with the standard geophysical methods (sounding, sonar, seismic acoustics, seismic prospecting, magnetometry, etc.) is characterized by the following peculiarities. The principal structural elements of the MAR in its whole extent, the axial ridge zone with walls and transform fracture zones, have nonstandard angles from 35° to 45° and a strongly asymmetric structure of the ridge flanks at the Knipovich Ridge. Based on [4, 10], there are escarpments with angle of about 40° between the axis inside the near-meridional axial zone. Small isolated volcanic edifices of the central type up to 1 km across and up to 40 m high are located near these escarpments.

The nonstandard structural pattern gave rise to various hypotheses on tectonic evolution of the region. One group of hypotheses concerns that this is not the spreading ridge but a strike-slip transform structure with pull-apart elements [2, 3, 10] and, despite this, with features of a spreading basement, seismic activity, and magmatism typical of the MAR rifting. Such a combination of facts and hypotheses may be related to the spreading center jump, but in this case the jump should be accompanied by a rotation of 45°. The other group of hypotheses assumes that the modern axis of the Knipovich Ridge is an initial spreading center along which the oblique accretion of oceanic crust occurred through the system of short rift segments [6, 9].

Spreading in the MAR zone is accompanied by basaltic magmatism with the formation of a magnetoactive layer variable in thickness and magnetization. The structural pattern of the anomalous magnetic field (AMF) reflects the evolution of the crust accretion along the rift axis. Data on the AMF for the studied area are taken from [13].

The general volume of the oceanic crust along the MAR was formed in the normal spreading direction. Cases of oblique spreading are rare (e.g., at the Reykjanes Ridge between anomalies 18 and 6 [5]). The main peculiarity of the oblique spreading is that the angle of its deviation from the normal rift line does not exceed 10°–15°. In the area of the Knipovich Ridge, the low amplitude straight portions of the linear anomalies have an angle of 45° to the structural axis (Fig. 1). In such conditions [8], the interaction along the plate boundaries should be substantially distinct and turn to the strike-slip setting and accompanying paragenesis.

Study [12] suggests a quite logical tectonic evolution of the region concerning the normal direction of the spreading leading to the formation of the magmatic basement. The strike-slip divergence of Greenland and Eurasia in the Neogene (from anomaly 13 in the Late Oligocene) coincided with the Hornsund Fracture Zone. That is why the plate interaction brought about the “straightening” of the plate boundaries and formation of the transtensional strike-slip zone with the Knipovich Ridge as a detachment zone intersecting the spreading basement cornerwise for the whole MAR segment from the Mohns Ridge to the

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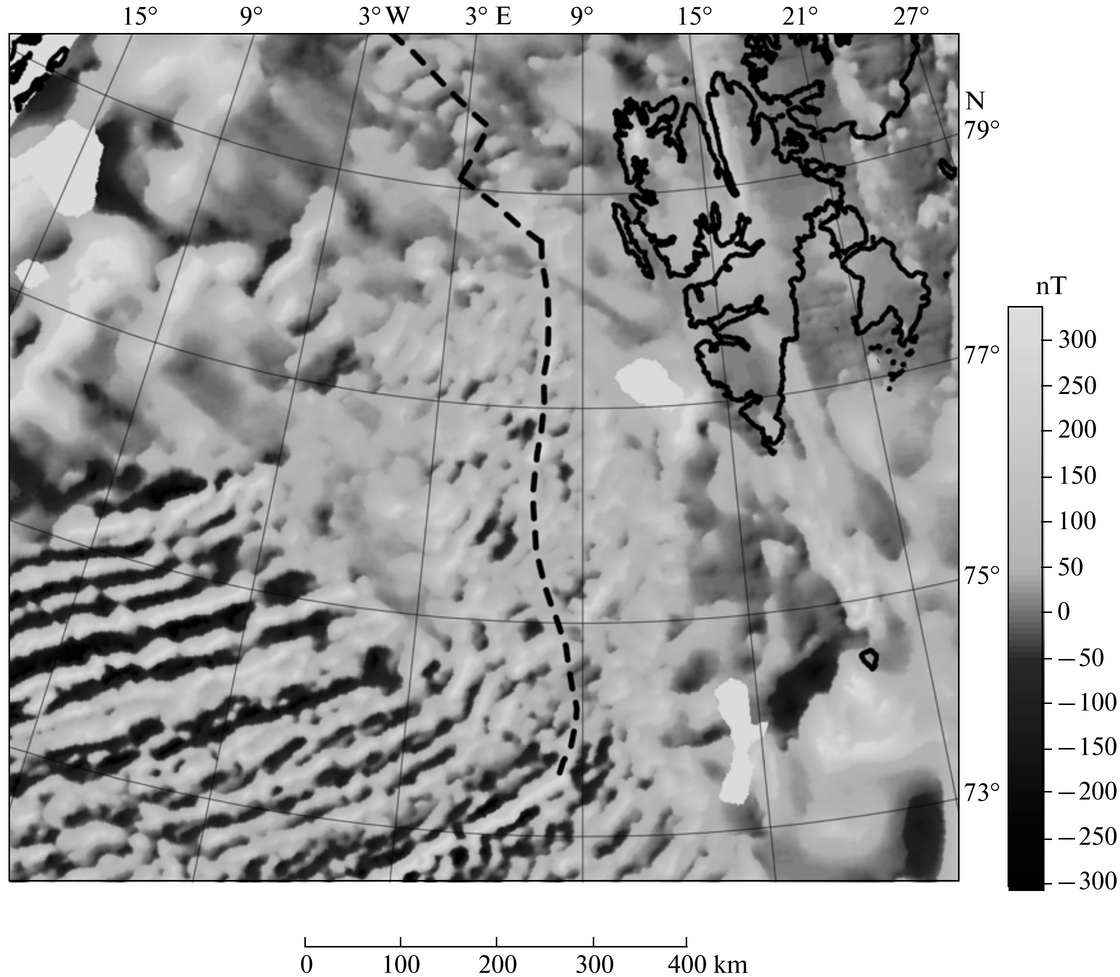

Fig. 1. Anomalous magnetic field of the area of the Knipovich Ridge, after [13]. Here and in Figs. 2 and 3, the ridge axis and offset parts of the Molloy and Spitsbergen Fracture Zones are shown by a dotted line.

junction with the Molloy Fracture Zone. A similar conclusion was drawn in [3] without AMF analysis. More accurate timing determinations of the Knipovich Ridge evolution are absent because of the unclear character of the linear anomalies. Their lack directly along the Knipovich Ridge axis counts in favor of the mentioned theory (Fig. 1), i.e., spreading along this structure had not started yet and the young, probably, Quaternary volcanic edifices indicate the beginning of rifting. Such transfer strike-slip faults straightening the plate boundary and compensating for the difference in velocities and directions of movement are likely the simplest solution for the stress drop [8].

The AMF in Fig. 1 has several peculiarities absent along the rest of the MAR. The general level of anomalies in this segment is considerably lower than in the Mohns Ridge segment adjacent from the south with a typical spreading AMF structure. There are very vast and intense anomalies at the boundary with the continental frame that appeared during the trap basaltic eruptions at the breakup and the initial phase of ocean formation. This can be explained by the deficit in components responsible for the formation of magnetic minerals in magma. The compositions of the chilled glasses dredged in the 24th cruise of R/V *Academik Nikolai Strakhov* are characterized by 8 wt % FeO, on average [7], displaying a decreased FeO content in magma in comparison with the average 10 wt % FeO along the MAR. Because the FeO content in the rock and glass is synchronized, then its decreased content in glasses reflects the same content in the rock forming the magnetoactive layer. Probably, this is related to the extraction of the biggest FeO portion at intense melting during the continental breakup and to further spreading in this area with an anomalous mantle substrate. This is also confirmed by the seismic tomography according to which the negative anomaly of velocity, typical of the whole MAR structure and displaying a heated and partly melted condition at depths, on the Knipovich Ridge changes to a very strong positive anomaly evident from the anomalous (cool) block relative to the rest MAR. In such media, the segments of the linear anomalies near the Knipovich Ridge are poorly identified. It should be noted that the morphol-

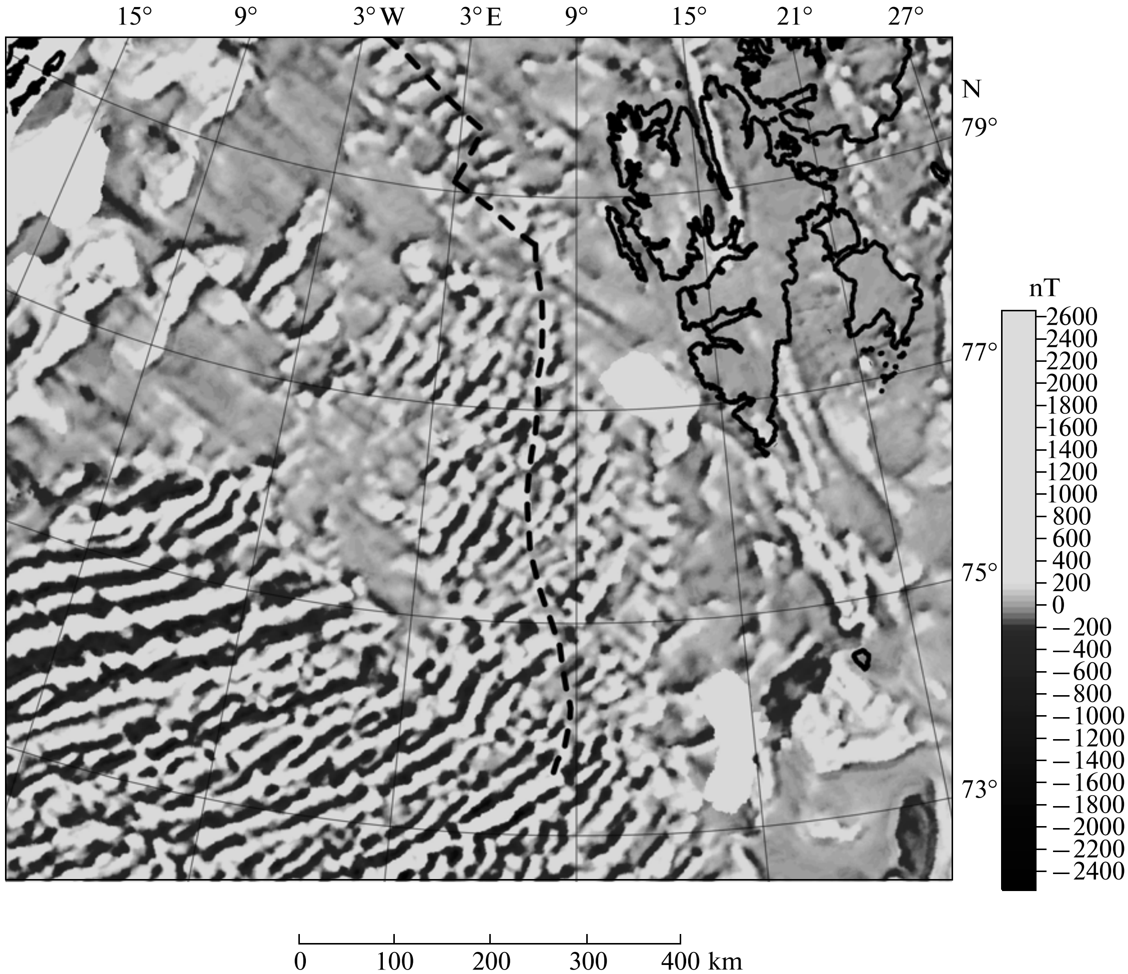

Fig. 2. Calculation of the downward continuation of the anomalous magnetic field from Fig. 1, based on Gauss's formula and 20 km aperture.

ogy and orientation of the spacious marginal anomalies along the periphery of this spreading segment indicate the normal direction of the breakup and further crust accretion and do not coincide with the Knipovich Ridge axis considered to be the initial spreading center.

For a long time, the high quality AMF data have been processed using the downward continuation of the field calculated by Gauss's formula. This sort of calculations increases the spatial high frequency field content and intensifies the anomalies near the weak magnetic masses. The AMF in Fig. 1 was processed with this method based on 20 km aperture for every map point. The result is shown in Fig. 2. The axis of the Knipovich Ridge is not traced by both primary data and the transformed field. In Figs. 1 and 2 it is shown based on the bottom relief. This serves as indirect evidence that the ridge is not a spreading center and recently appeared as a detachment zone, because no significant magnetoactive bodies are observed in the area of the modern volcanism. Most likely, this structure is synchronous to the Quaternary volcanism of the Spitsbergen Archipelago.

It is clear from Fig. 2 that spreading formed a crust with a normal direction of accretion relative to the paleoaxis, the orientation of which has an azimuth near 40°. Such an azimuth is typical of the vast marginal anomalies that appeared at the moment of the breakup and points to the absence of oblique spreading in this MAR segment. The field anomalies are characterized by symmetry axes with an azimuth of 40°. It is obvious that after the intension of the weak anomalies, oblique spreading occurred along the whole flank of the Mohns Ridge between anomalies 6 and 7. This is clearly seen from the typical junctions of the oblique segments of the linear anomalies with the long direct anomalies and small transform displacements of the field similar to the Reykjanes Ridge. The main conclusion may be drawn that the normal spreading in this MAR segment occurred not in one rift segment [12] but in four segments, at a minimum. Exactly four blocks with linear anomalies separated by transform displacements are traced in the region (Fig. 2). South

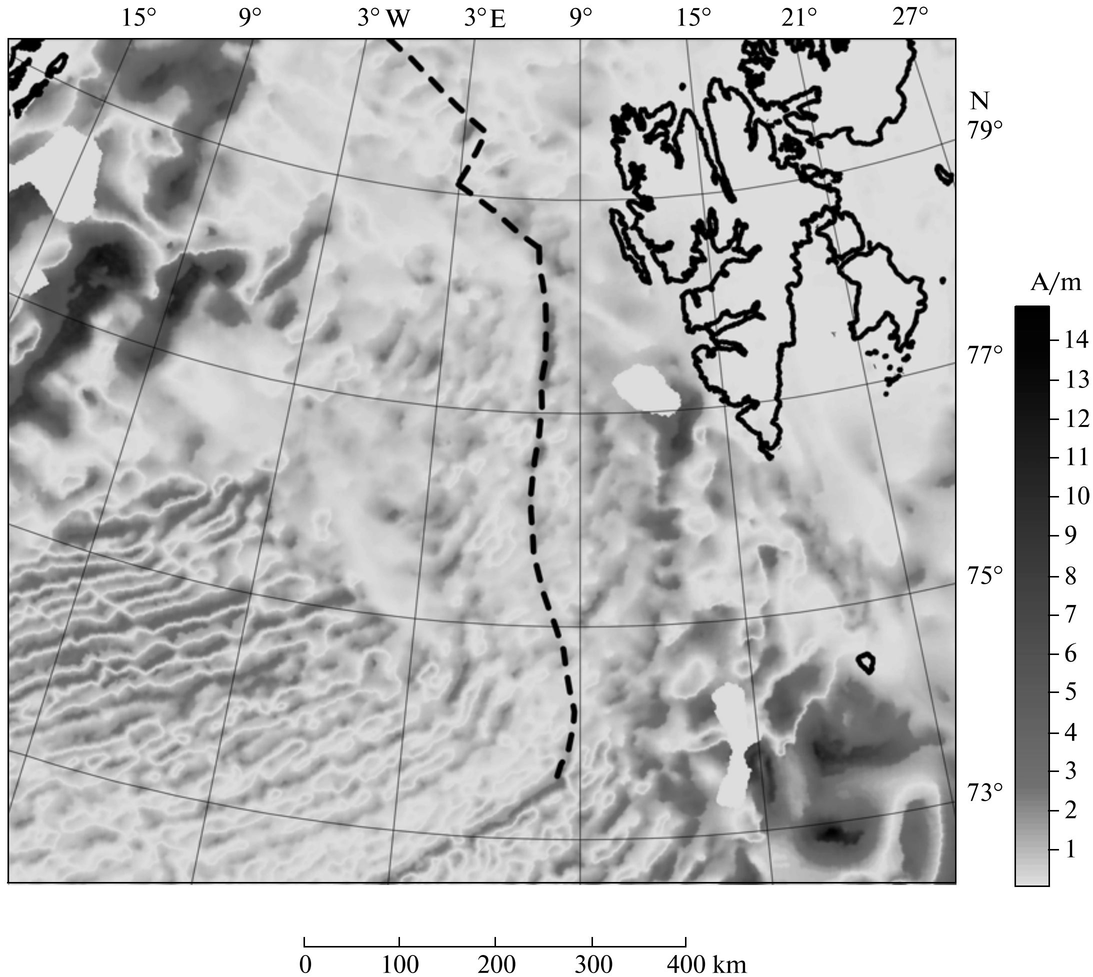

Fig. 3. Magnetization of the basement rocks in the area of the Knipovich Ridge calculated by AMF from Fig. 1, considering the relief and thickness of the sedimentary cover.

of the Molloy Fracture Zone, there is a block which likely represents the multitransform fault system typical of the MAR segments with a high ratio of the offset lengths relative to the lengths of rift segments (Central Atlantic).

The discrepancy in azimuths of the spreading directions of the Knipovich and Mohns Ridges (310° and 330°, respectively) is another important point. Such variance should lead to collision along the Greenland Fracture Zone separating the spreading segments. The East Greenland Ridge is a result of the collision of passive parts of the transform fracture zones. The Cape Verde escarpment in the Central Atlantic at the eastern passive part of the 15°20′ Fracture Zone is an analogue of this structure. Perhaps, the collision of the northern passive parts of the Knipovich and Mohns Ridges, leading to its formation, governed the oblique spreading northward toward the Mohns Ridge.

Figure 3 demonstrates the calculation of magnetization of the basement rocks considering the relief and thickness of the sedimentary cover. Data on the thickness of sediments were taken from [1, 11]. The calculation was based on the prism formula for horizontal size 1 × 1 km, the thickness of magnetized layer of 1 km, and 75° incline. The distribution of magnetization shows that rocks of the magmatic basement of the area have magnetization of 1–3 A/m, which is considerably lower than the average magnetization along the Mohns spreading segment (3–5 A/m). The magnetization of the marginal blocks formed at the moment of the breakup attains 15 A/m. The structural pattern of the magnetization retains the configuration of the field peculiarities revealed along its downward continuation (Fig. 2), but a lower level of magnetization is observed in a band ±50 km wide from the rift axis where correction on the total depth and sedimentary cover is minimal. This is probably related to the difference in the real geometry of the magnetoactive layer and the model chosen for calculations.

The final scheme of the tectonics of Knipovich Ridge is shown in Fig. 4, and the evolution of this

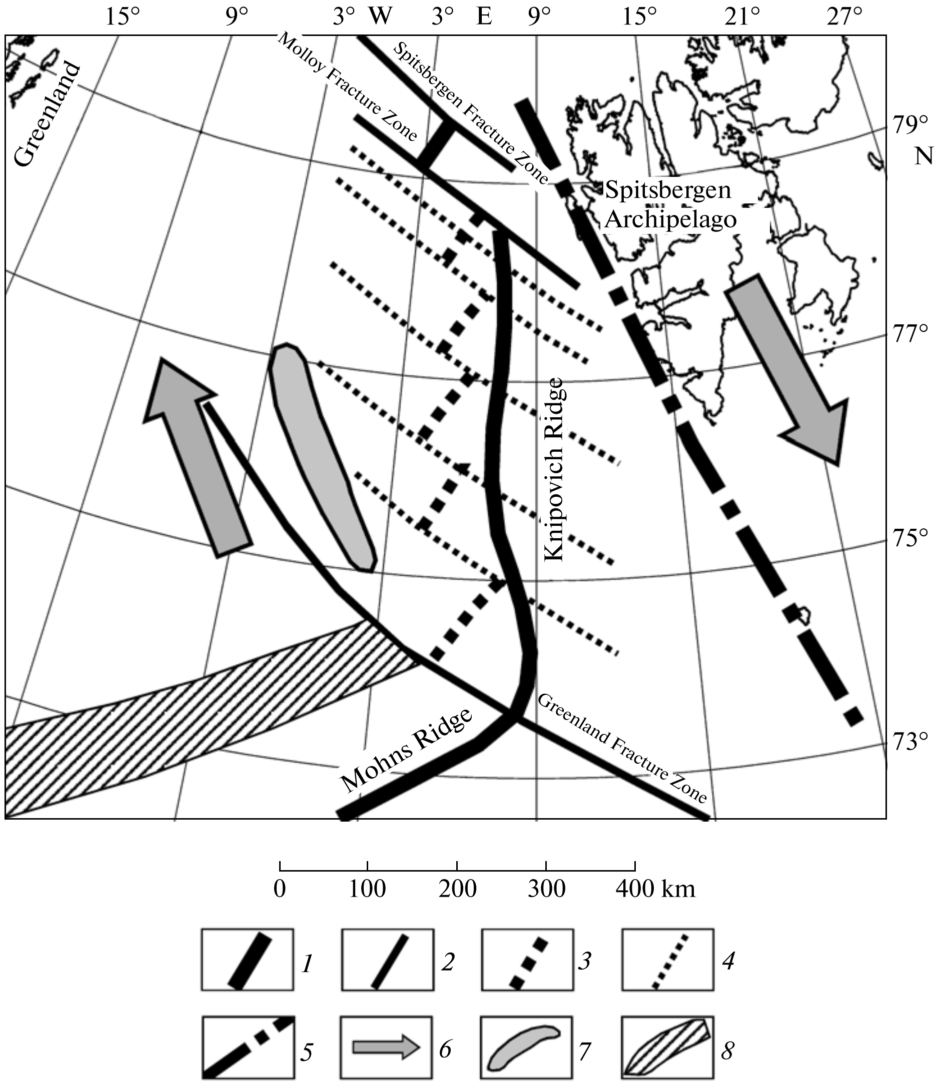

Fig. 4. Tectonic scheme of the Knipovich Ridge. Modern rift (*1*), transform fracture zones (*2*), paleorift (*3*), paleotransform fracture zones (*4*), Hornsund Fracture Zone (*5*), general direction of the plate shear (*6*), East Greenland Ridge (*7*), and zone of oblique spreading of the northern wall of the Mohns Ridge (*8*).

MAR segment is as follows. In the Late Oligocene (anomaly 13), the continental breakup accompanied with formation of high magnetized trap basalts started and further it changed to spreading with an accretion azimuth of 310° (azimuth of paleoaxis is 40°). Accretion of the crust occurred at a lower FeO content in the melt providing a lower AMF. Because the spreading of the Mohns Ridge has a direction about 330°, the collision of the passive part led to the formation of the East Greenland Ridge and the oblique spreading direction at the Mohns Ridge between anomaly 7 and 6. Spreading at the Knipovich Ridge occurred in no less than four rift segments at the azimuth of the general divergence of continents about 330°. Such conditions with a high ratio of lengths of echelon offset zones relative to the lengths of rifts was unstable and logically changed to the "straightening" of the plate boundaries along the detachment zone cross cutting the earlier formed oceanic basement, being now the modern Knipovich Ridge. The almost complete absence of the sedimentary cover in its axis, in the zone of immediate proximity to the source of avalanche sedimentation, and the lack of a magnetoactive layer are evidence of its Quaternary time of formation. The echelon escarpments along the ridge represent the Riedel shears, the formation of which is related to the association of the strike-slip zones [10], but they are not expressed in the AMF. The nontypical angled correlation of these shears with the whole strike-slip direction and coincidence of their orientation with the azimuth of the linear anomalies can be explained by the development of the strike-slip zone at the initial structuredness which was created by the spreading and determines the given azimuth. The general length of the strike-slip zone between the axes of the Gakkel and Mohns spreading centers is about 1130 km. The segment between the Molloy and Spitsbergen Fracture Zones is only one indirect area here, but it will be straighten during its evolution. This zone by scale and plate dynamics relative to the evident spreading centers of the high extension is similar to the Romanche Fracture Zone in the Central Atlantic—the main separator of segments in the developing Atlantic–Arctic ocean system.

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