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GEOLOGY

# Lomonosov Ridge and the Eastern Arctic Shelf as Elements of an Integrated Lithospheric Plate: Comparative Analysis of Wrench Faults

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**Abstract**—The notions of deformations in the juncture area of the Eastern Arctic Shelf and Lomonosov Ridge are highly contradictory. It has been suggested that these geostructures were divided by a large right-lateral wrench fault of the transform type, which is known as the Khatanga–Lomonosov Fault. Data obtained by interpretation of the A7 profile have been compared with seismic sections crossing large-sized wrench faults in other sedimentary basins. The investigations have shown that on the A7 profile there are no structures typical of large-sized wrench faults. The Eastern Arctic Shelf and Lomonosov Ridge, which are located on the same lithospheric plate, form an integrated structure where the ridge is a natural continuation of the shelf.

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The central part of the Arctic Ocean is a vast deep-sea basin. Figure 1 schematically shows a fragment of a southwestern part of the basin with the transition area to the Eurasian shelf. Throughout the past 53 million years, since the Early Eocene, spreading has developed slowly on Gakkel Ridge. Resulting from formation of the basin with the oceanic crust, the underwater Lomonosov Ridge happens to have moved from the Barents Shelf to Podvodnikov Basin.

Deep-sea drilling has shown that Lomonosov Ridge, which is situated close to the North Pole, is characterized by a continental type of crust [2]. The thickness of the crust is ~20 km [3]. The origin of the crust of Podvodnikov Basin located to the east is a matter of discussion. Some researchers consider that the basin is underlain by a continental type of crust [3, 4, etc.] and believe that both the continental and oceanic types of crust occur in the basin [5]. Most researchers, however, state that the oceanic crust with a heavily increased thickness occurs in Podvodnikov Basin. They attribute such thickness to underplating—melting of a great bulk of basaltic magma from the mantle plume [6]. Actually, there is no factual evidence supporting this point of view. Most likely it was initially suggested to explain the deep-sea (up to 3 km) pattern of Podvodnikov Basin.

On Gakkel Ridge spreading occurs at a very slow speed. In the southern part of the ridge, it is several millimeters per year. South of 80° N, below the continental slope, the continental crust is overlapped by sediments removed from the shelf and slope. This type of crust is no longer distinguished under the sediments on the adjacent shelf of the Laptev Sea. It has been [7] suggested that Amundsen Basin and underwater Lomonosov Ridge are separated from the Eastern Arctic Shelf by a large right-lateral wrench fault of the transform type—the Khatanga–Lomonosov Fault. Figure 1 shows this fault on the basis of a recent tectonic map [1]. We consider that Amundsen Basin and Lomonosov Ridge are moving along the fault to the northeast relative to the Asian shelf. Over the past 53 million years, the displacement amplitude is 325 km.

In 2007, the Marine Arctic Geological Expedition worked out the submeridional profile ARCTICA-7 (A7) (Fig. 1) 830 km long [8]. It runs along the eastern slope of the southern part of Lomonosov Ridge, crosses the continental slope, and comes out onto the shelf of the New Siberian Islands between the water areas of the Laptev Sea and the East Siberian Sea. The profile was worked out in conditions highly unusual for the Arctic region, with a complete lack of ice cover. This circumstance made it possible to perform high-precision seismic profiling of the sedimentary cover using a detection streamer 8.1 km long and sounding by refracted waves—deep seismic sounding (DSS), to a depth of 11 s. Therefore, the section of the Earth's

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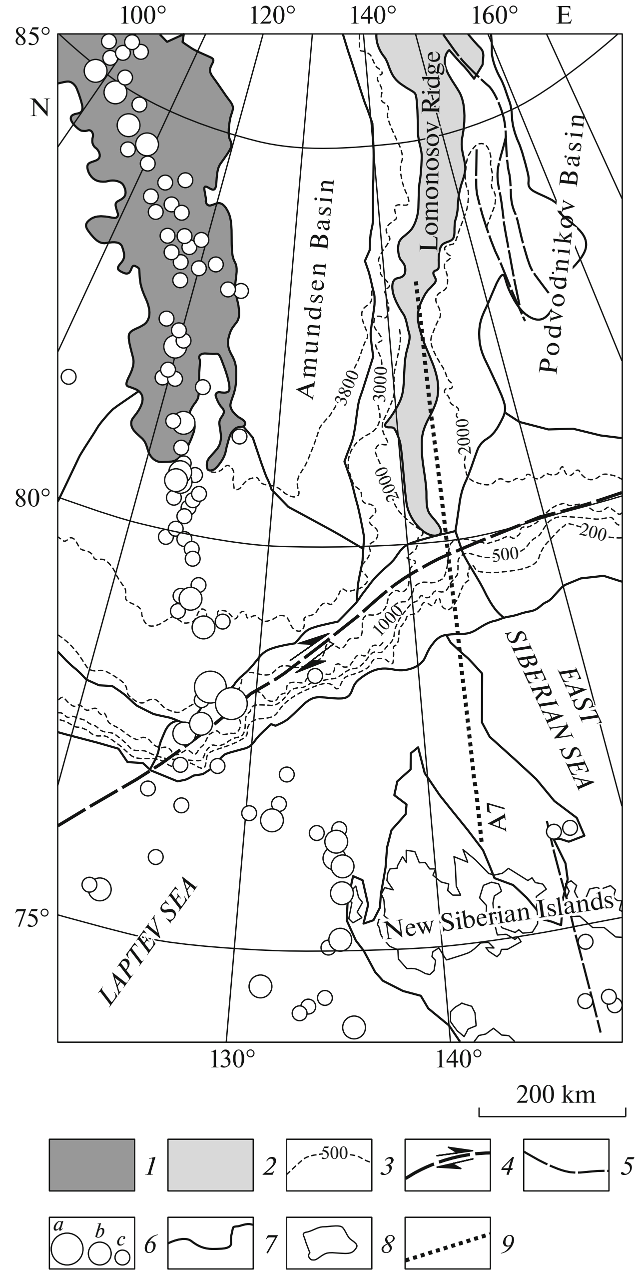


**Fig 1.** The transition area from the Eurasian shelf to the southwestern part of the deep-sea Arctic Basin (fragment of the map [1] as modified). (*1*) Outcrops of the oceanic crust in Gakkel Ridge; (*2*) Lomonosov Ridge; (*3*) isobaths (m) of the sea bottom; (*4*) Khatanga–Lomonosov Fault assumed according to [1, 7]; (*5*) other fractures; (*6*) epicenters of earthquakes with amplitudes (*a*) 6.0–6.6, (*b*) 5.0–5.9, and (*c*) < 4.9 [3]; (*7*) boundaries of the main morphostructural elements of the sea bottom; (*8*) coastline of islands; (*9*) seismic profile A7.

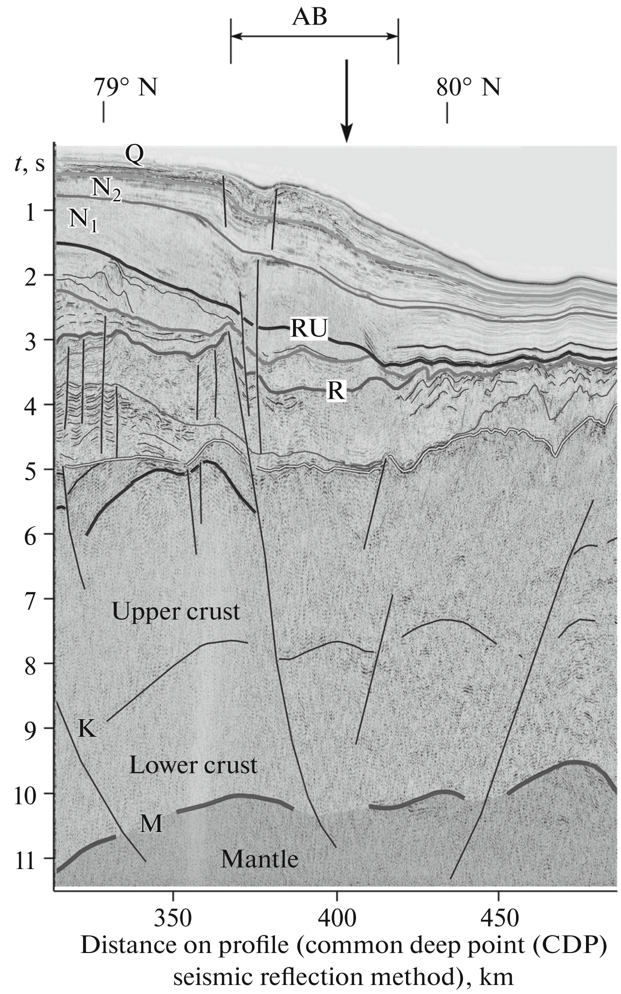


**Fig. 2.** The central part of the seismic geological section along the profile A7 [8]. The profile was plotted on the original section with a high resolution presented by the Marine Arctic Geological Expedition. The line segment AB and an arrow show the place of intersection of the profile and Khatanga–Lomonosov Fault assumed by [1, 7]. RU, regional unconformity; R, post-Campanian unconformity.

crust was compiled up to the Mohorovicic discontinuity (Moho).

Figure 2 shows the central part of the profile A7, where, according to [1, 7], intersection with the Khatanga–Lomonosov Ridge is supposed to occur. Sometimes, one assumes that the intersection is characterized by high lateral heterogeneity of the sedimentary cover of Lomonosov Ridge in the northern part of the reference profile A7 [8]. The heterogeneity can be explained by the almost tenfold increase in the vertical scale in relation to the horizontal scale. No heterogeneity is revealed on profiles with comparative scales, and the structure of the bedded formation of Lomonosov Ridge appears smooth. On the other hand, a lack of large-size faults and the occurrence of a wrench fault zone in the investigated area [3, 5]. Data on gravity and magnetic field anomalies also can show the continuous relationship between the shelf and the ridge [3].

Therefore, the notions of crust deformations between the Eastern Arctic Shelf and Lomonosov

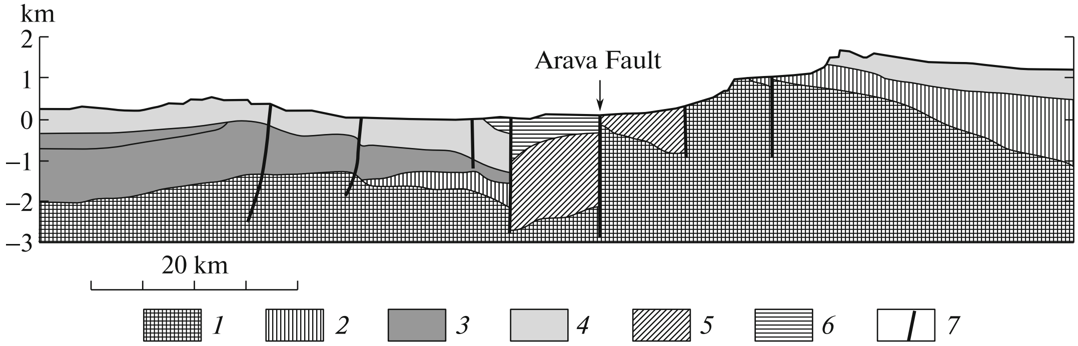


**Fig. 3.** The geological section of the upper part of the Earth's crust along the seismic profile crossing the transform zone of the Dead Sea and its main element, Arava Fault. (*1*) Precambrian basement, (*2*) Lower Paleozoic, (*3*) Permian, Triassic, and Jurassic deposits, (*4*) Cretaceous–Paleogene deposits; (*5*) undissected Phanerozoic sedimentary series, (*6*) Miocene–Pleistocene deposits, (*7*) fractures of transform zone of Dead Sea (modified by [9]).

Ridge are highly contradictory. To define the distinct possibility of the occurrence of a large-size wrench fault in this area, it is necessary to compare the section A7 with the seismic sections crossing large wrench faults in other sedimentary basins. Such structures have been studied in detail in many regions ([9–11] etc.). Crustal blocks located at a great distance from each other and differing in the structure and history of sedimentation were generally brought into juxtaposition on the walls of large wrench faults. Therefore, on wrench faults one can observe not only vertical displacements of the basement and coeval reflectors, but also dramatic changes in the sedimentary cover structure. This is manifested in the change in the total thickness of the section and the thickness of its units, which occur between reference reflectors and were formed over the period of active phases.

In addition to strike-slip displacements, there are transpressional and transtensional structures on many large-sized faults (e.g., Fig. 4 in [11] and numerous profiles in reviews [12, 13]).

A classic example is the transform of the Dead Sea [9] with a left-lateral wrench fault, where the Arabian Plate was displaced to a distance of 105 km in relation to Africa over the past 17 million years. In 2000, the seismic profile DESERT 260 km long was worked out through the southern part of the transform. It crosses the transform in the Arava Valley 20 km wide (Fig. 3), where the thickness of the crust is 35 km (Fig. 11 in [9]). The vertical displacement of the transform acoustic basement varies from 3 to 5 km (Fig. 11 in [9]). The upper part of the section is affected by erosion near the transform. Nevertheless, severe deformations are clearly observed in the interval 45 to 55 km. On the main fault fissure—the Arava Fault—the vertical amplitude on the Precambrian roof is 2 km (Fig. 3). Away from the fault in the western part of the profile, the structure of the section smoothly changes in the interval 0 to 40 km. According to seismic data, the fault continues to a depth of up to the asthenosphere developing a wide mechanically weakened zone in the mantle lithosphere.

The other thoroughly studied zone of a severe wrench fault between lithospheric plates is the right-lateral North Anatolian Fault [10]. It separates the Anatolian microplate which drifts to the west of the Eurasian continent. The displacement along the section is estimated at 80 ± 15 km at an average speed of 6.5 mm/year over the past 17 million years. Like the transform of the Dead Sea, the fault is characterized by dramatically high seismic activity. Figure 4 shows the seismic profile that runs through the upper part of the crust and crosses over the North Anatolian Fault in the northwestern part of the Sea of Marmara. The "flower structure," which is typical for many wrench fault zones, was formed in the sedimentary cover above the fault. The structure is bounded from both sides by normal dip-slip faults, along which sediments were dipped to a depth of ~1 km. As this takes place, transpression of the Pliocene–Quaternary sediments is observed in the southern part of the basin, and weak transtension of sediments occurs in its northern part. Faults with large strike-slip displacements have been described in detail in California (San Andreas Fault), South Island of New Zealand (Alpine Fault), Scotland (Great Glen Wrench Fault), the Gulf of Guinea, and many other regions. One can find good examples of wrench faults in the Calabrian Arc in the southern Apennines and in the water area of the Ionian Sea [11]. In places where such structures run over the sedimentary cover, large-scale deformations are always observed.

Let us consider possibilities for reliable revelation of the structures that are typical for large wrench faults on the profile (Fig. 2). Several reflectors are well-defined in the sedimentary cover. The most distinguished reflector—regional unconformity (RU)—probably divides extremely shallow deposits of the Middle Eocene and pelagic sediments of the Early–Middle Miocene [2, 3]. It is assumed that unconformity corresponds to the nondepositional hiatus, which

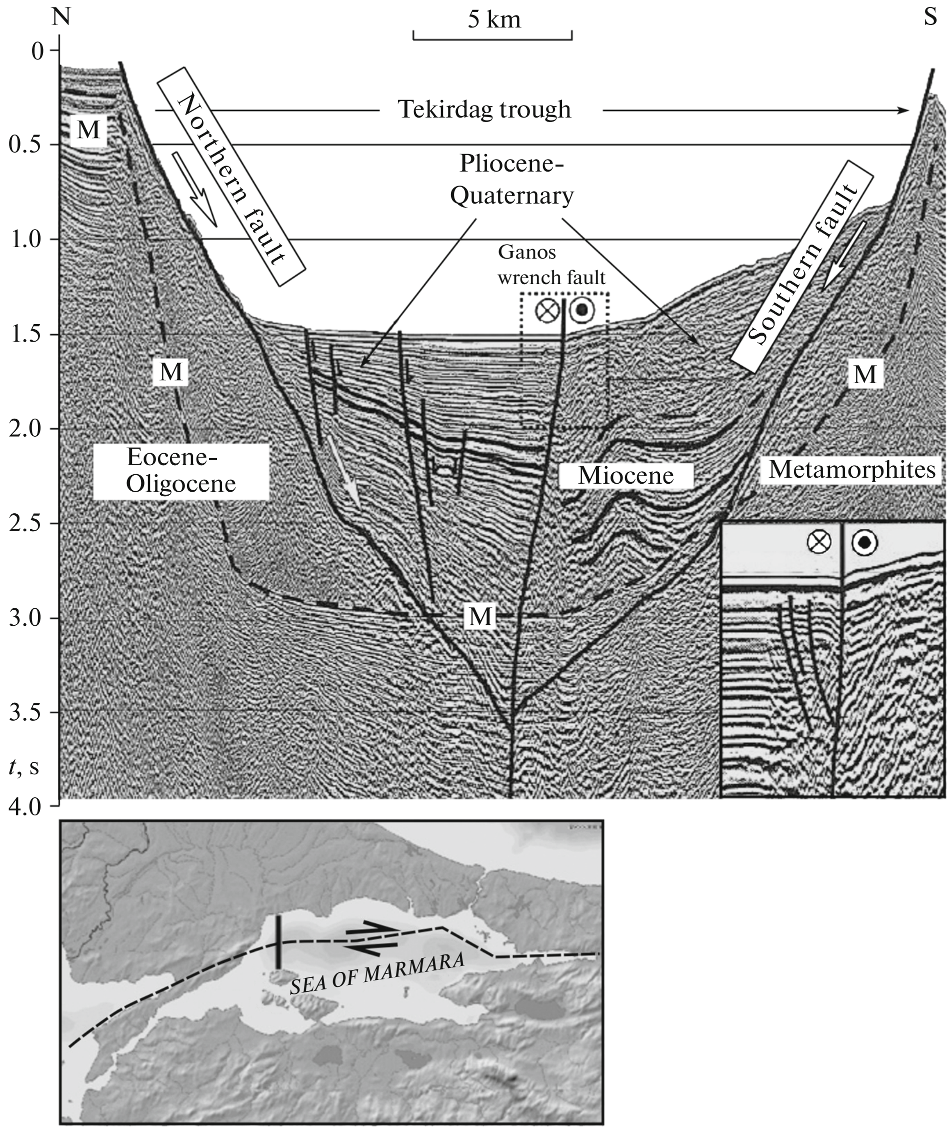


**Fig. 4.** The time section through the upper part of the crust in the zone of the North Anatolian Fault in the northeastern Sea of Marmara (modified by [10]). The dashed line (symbol M) shows the surface of multiple reflection. Symbols ◉ and ⊗ show blocks of the Earth's crust on fault walls, moving toward an observer and away from him. The "flower" structure formed in the uppermost part of the main fracture is shown in the right inset. The location of the profile in the water area of the Sea of Marmara is shown in the lower inset.

lasted 24 million years. The reflector *R* located below is considered as a post-Campanian (Maastrichtian) unconformity, which was formed due to the long-term hiatus in the Late Cretaceous (which probably continued up to the Late Paleocene). In any event, the sedimentary cover contains all sediments accumulated during the period of time during which the presumed Khatanga–Lomonosov Fault was formed.

The most likely area where the profile could be crossed by a large wrench fault separating Lomonosov Ridge from the shelf is the continental slope, more likely its lower part, which is shown with the line segment AB. The place of the intersection of the slope and the Khatanga–Lomonosov Fault, which was assumed in [1, 7] (Fig. 1), is marked by an arrow in Fig. 2. In the upper part of the slope, two dip-slip faults cross the reflector RU, but they do not displace it pretty much vertically. The lack of noticeable displacements is also characteristic for the two faults situated in the Pliocene–Quaternary sediments. Under the slope brow, a break is observed only in the reflector R, but the displacement is very small. No faults in the Cenozoic deposits are distinguished in the remaining part of the slope, particularly in the place of its intersection with the assumed Khatanga–Lomonosov Fault. Therefore, on the profile A7, there are no structures typical of large-sized wrench faults.

It should be noted that, for a large wrench fault to have developed, high seismic activity with earthquake magnitudes M = 6–7 would have been observed in the investigated area, just as for Gakkel Ridge (Fig. 1), the North Anatolian Fault [10], and the Dead Sea Transform [9]. Actually, earthquakes have not been registered for Lomonosov Ridge and the juncture zone of the Asian shelf, or, at least, their magnitudes have been less than M = 3.5. According to the online catalogue of the International Seismological Center, the nearest epicenter with M = 4.7 located on the line of the assumed wrench fault was recorded in 1967 at a distance of 200 km from the location of interest [14].

The data show that the Eastern Arctic Shelf and Lomonosov Ridge located on the same lithospheric plate are inextricably connected with each other forming an integrated geostructure, where the ridge is a natural continuation of the shelf.

A linear zone of high seismic activity located several kilometers westward, on Gakkel Ridge (77° N), diverges in branches developing two narrow belts of epicenters on the shelf of the Laptev Sea; the epicenters are mainly characterized by tension stress [3]. Further to the south, the belt of earthquakes continues to the continent and comes out into the Momskii Rift [7, 15], which is, probably, the southeastern continuation of the boundary between the Eurasian and North American lithospheric plates.

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