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GEOLOGY

Morphology and Sedimentary Cover Structure of Long Segments of the Gakkel Ridge

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Abstract—The rift valley of the Gakkel Ridge was divided into three segments according to sub-bottom profiling and seismoacoustic studies carried out by R/V *Akademik Fedorov* at the Gakkel Ridge in 2019–2020, and on seismic data of 2011–2015. West of 75° E, the rift valley crosses the Gakkel Ridge approximately in the middle, as was expected based on the assumption that the rift valley runs along the spreading axis that formed this ridge. East of 75° E, the rift valley shifts to the southwestern edge of the ridge, and, thus, it can be concluded that the spreading axis jumped to its present position relatively recently (in the Pliocene). Finally, to the south of the the Gakkel caldera (about 120° E, 81° N), the rift valley is manifested in the sections as a young graben through many kilometers of sediments.

Keywords: the Gakkel Ridge, seismoacoustics, rift valley, sedimentary cover, spreading, tectonics

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The Gakkel Ridge is a vast linear submarine elevation with a complex, dissected topography. The ridge is surrounded by abyssal plains along its entire length (1800 km) and is adjacent to a rise towards the Laptev Sea (Fig. 1).

The Gakkel Ridge has a special place in the global mid-ocean ridge system, characterized by a very slow spreading rate. By one estimate [1], the present spreading rate ranges from 12.8 mm yr^{-1} near Greenland and up to 6.5 mm yr^{-1} near the Siberian continental margin. Other assessments assume 4–6 mm yr^{-1}, where the spreading rate becomes lower to the east, decreasing in the Miocene to 3–5 mm yr^{-1} [2, 3]. Another distinctive attribute of the Gakkel Ridge is the presence of large volcanic structures, which were discovered in the western part of the Gakkel Ridge during the AMORE expedition in 2001 [3, 4].

The most unique feature of ultra-slow ridges is amagmatic rifts with outcrops of mantle peridotite (supplemented with outcrops of basalts and gabbro) observed directly on the ocean floor. Such a feature is so pronounced on the Gakkel Ridge that it was proposed to attribute it to a new (fourth) type of plate boundaries [5, 6].

The recent geochemical studies discovered that rocks from the western part of the Gakkel Ridge had geochemical traces of the Early Cretaceous paleo-subduction zone [7]. Another set of geochemical and paleotectonic studies concluded that the formation of the Gakkel Ridge was connected with the initial rift stage of tectogenesis without a significant opening of the Eurasian Basin [8]. The following pattern indicates the complex history of the formation of the Eurasian Basin and the Gakkel Ridge: asymmetry of both the ocean floor relief and the basement of deep-water basins, disorder in the spatial distribution and thickness of individual layers of sedimentary rocks, and an asymmetric and discordant position of gradient zones of gravity and magnetic anomalies with respect to the strike of the Gakkel Ridge [2, 3].

Two expeditions aboard R/V *Akademik Fedorov* with assistance of nuclear icebreakers owned by FSUE Atomflot carried out fifteen intersections of the Gakkel Ridge and its rift valley with a sub-bottom profiler and by seismoacoustic profiling in 2019–2020. The survey used a TOPAS PS18 sub-bottom parametric profiler (Konsberg), which was part of the navigation and hydrographic complex based on the EM122 multibeam echo sounder. CHIRP pulses are applied for optimal penetration, high resolution, and the best signal-to-noise ratio, using linear-frequency modulation and a frequency range from 2 to 6 kHz and a pulse length of 10 or 20 µs. Continuous seismoacoustic profiling was carried out with towed outboard devices that

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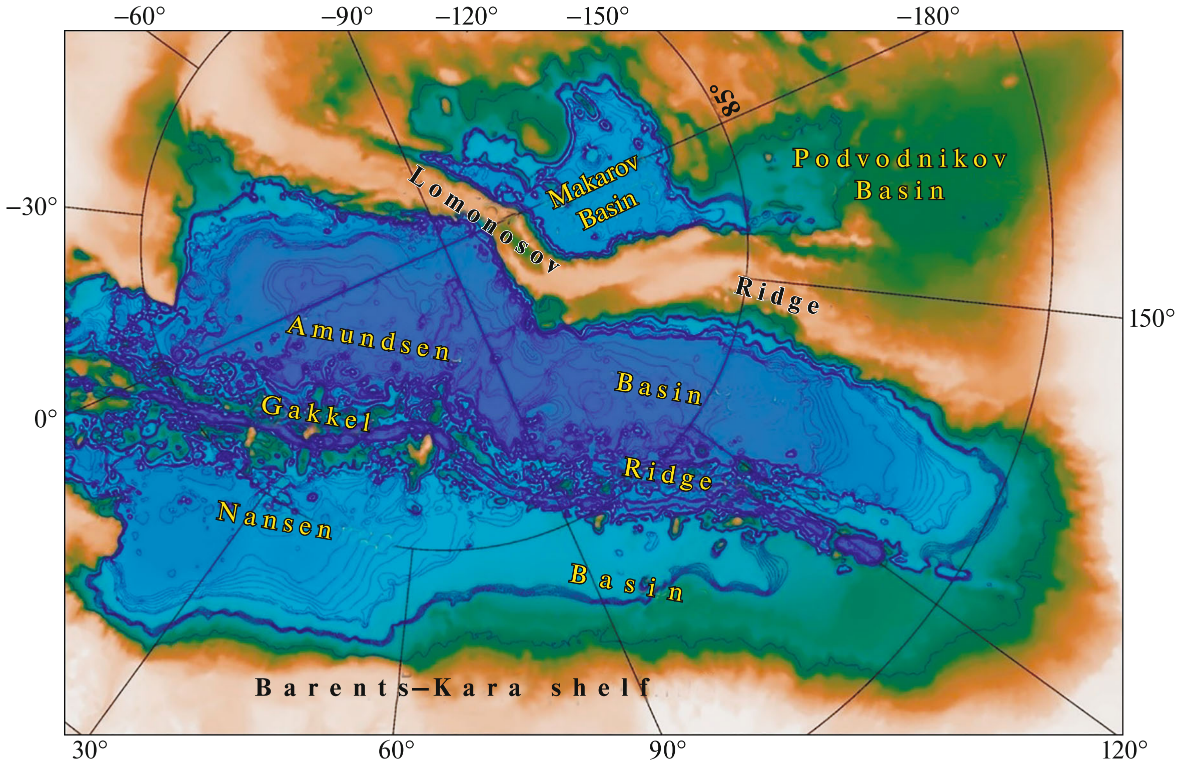

Fig. 1. Bathymetry map of the Eurasian Basin of the Arctic Ocean.

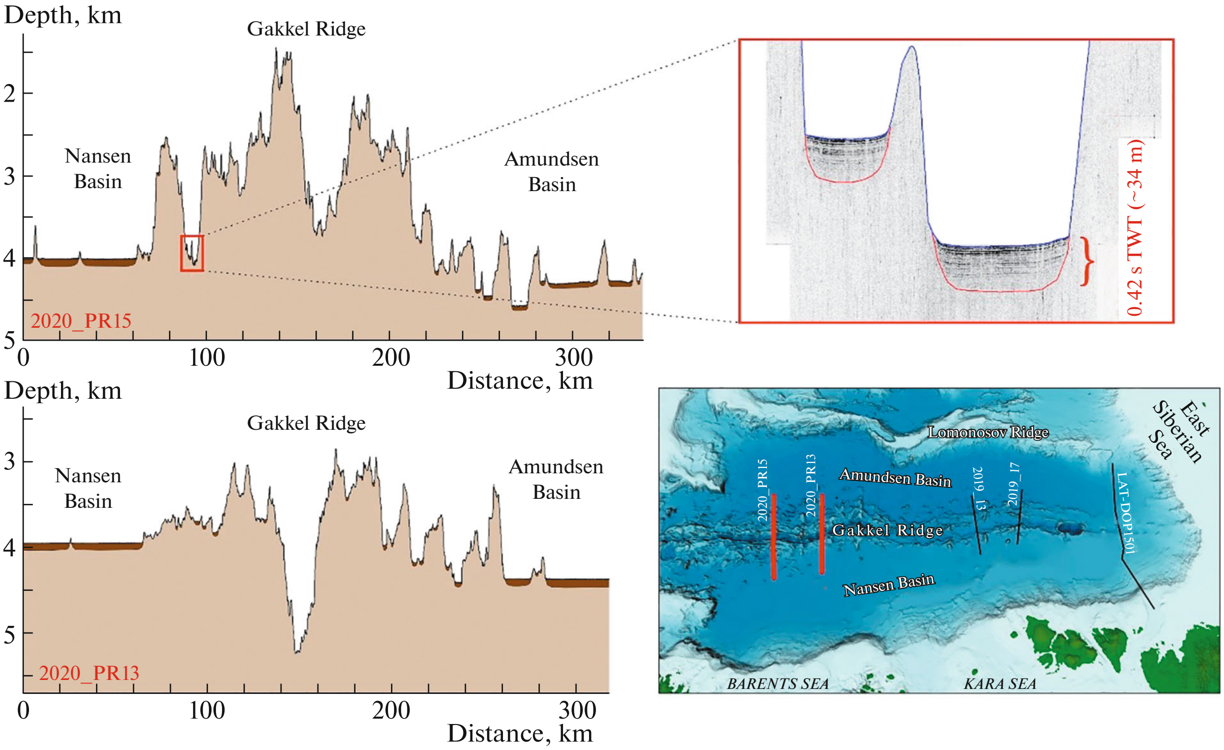

Fig. 2. Sections carried out with a profiler in the western part of the Gakkel Ridge (profiles 2020_PR15 and 2020_PR13 are shown in the figure).

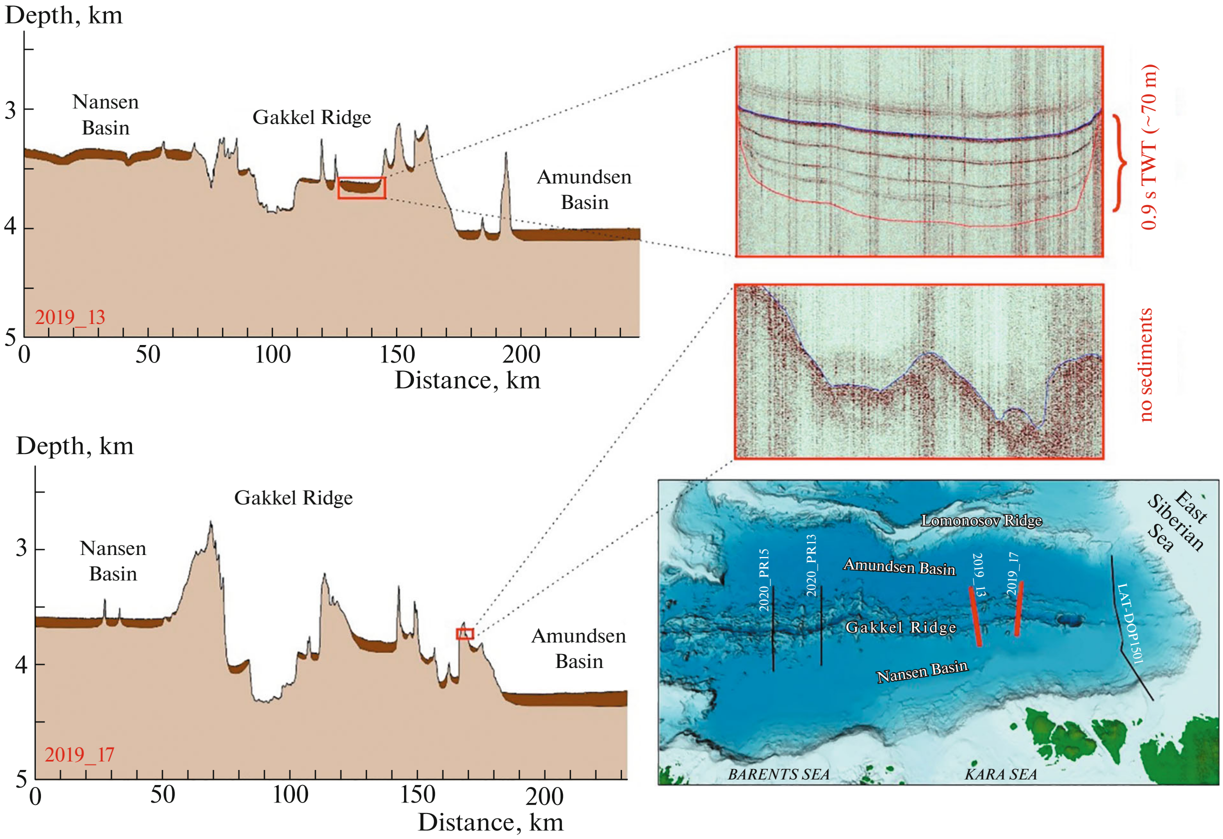

Fig. 3. Sections (lines 2019_13 and 2019_17) carried out with a profiler in the eastern part of the Gakkel Ridge.

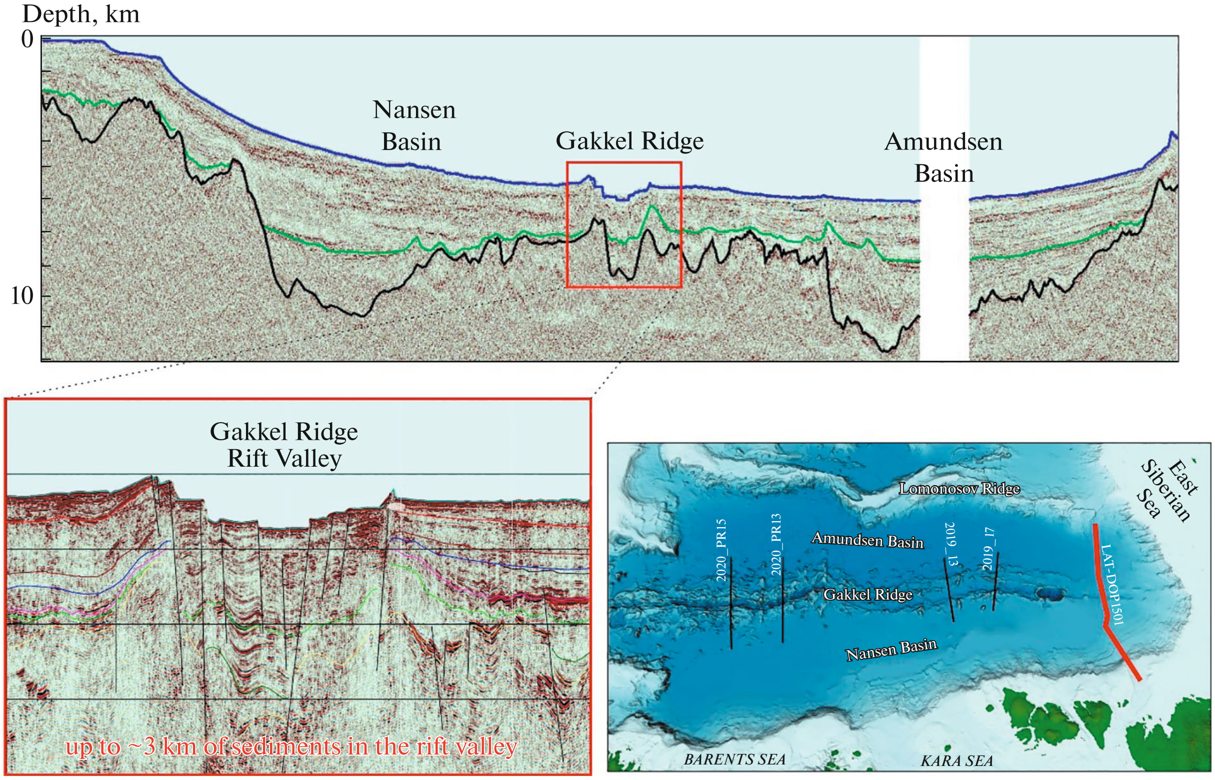

Fig. 4. The structure of the sedimentary sequence along line 2015_1B in the southern part of the Eurasian Basin and a fragment of the upper part of the section under the rift valley of the Gakkel Ridge. The black line is the acoustic basement, and the green line is the presumptive bottom of the Cenozoic deposits [2, 3].

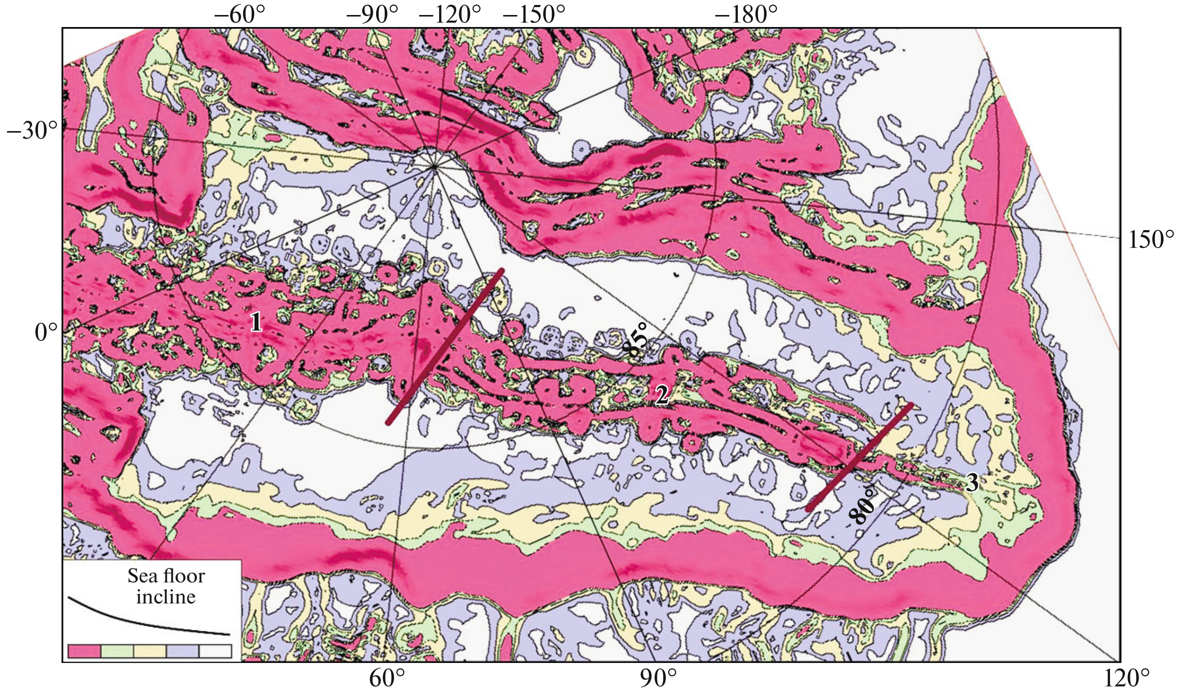

Fig. 5. Three segments of the Gakkel Ridge (1, western; 2, eastern; 3, southern), differences in the structure of which are illustrated by the map of the seafloor incline.

included a sparker with a central emission frequency in the range of 200–300 Hz and a multichannel analog SplitMultiSeis Streamer with a number of channels from 16 to 24 and of two meters. Registration was carried out by seismic stations SplitMultiSeis Station Betta and 24-bit SplitMultiSeis Station with 16 and 24-bit ADCs, respectively.

At the same time, VNIIOkeangeologia compiled a bathymetric database, complementing the IBCAO-4 global database, which made it possible to create a more detailed map of the seafloor inline of the Eurasian Basin. The relief sections of the Gakkel Ridge and the profiling and seismoacoustic data on the distribution of sedimentary strata obtained during the 2019–2020 expeditions are in some cases combined with the previously obtained seismic data and supplemented by line 2015-1B carried out by the Murmansk Arctic Geological and Geophysical Expedition in the southern Eurasian Basin. New data, coupled with the results of the seismic surveys of 2011–2015, revealed to a fuller extent the morphological features of various sections of the ridge and its rift valley.

The rift valley of the Gakkel Ridge can be divided into three segments based on the seafloor incline and the seismic data. In the western part, west of 75° E, the ridge is 180–210 km wide. The rift valley crosses the Gakkel Ridge approximately in the middle. The relief is extremely dissected. Sediments are absent in the deep valley with a downcutting of more than 1.5 km, and sedimentary strata a few tens of meters thick appear only at a considerable distance from the rift valley (Fig. 2).

East of 75° E the rift valley shifts to the southwestern edge of the ridge. The area with the smooth slopes is greater, occupying more than half of this segment of the Gakkel Ridge, the width of which varies between 105–130 km. The rift valley downcutting is around 0.5–1.0 km, and the presence of sedimentary strata with a thickness of more than 70 m was recorded in various parts of the lines, including the rift valley (Fig. 3). According to the seismic data [2], sedimentary strata are also recorded on extended sections of the seismic lines and in some places their thickness reaches more than 1 km.

Finally, the rift valley changes dramatically to a graben of several hundred meters deep south of a giant caldera located on the continuation of the Gakkel Ridge. The graben continues to the edge of the Laptev Sea shelf. The faults that form the sides of the graben are traced deep into the thick (up to 4–5 km) sedimentary sequence, and, according to the available data, the lower layers are composed of Late Mesozoic deposits (Fig. 4).

The size (80 × 45 km) of the caldera, located near the Gakkel Ridge at the point with coordinates 120° E, 81° N, classifies it as a supervolcano with the highest volcanic explosiveness index 8. It was probably the most powerful volcanic eruption, which left significant traces in the topography and sedimentation of the Arctic Ocean [9]. Apparently, it was this eruption that influenced the recent (Pleistocene) restructuring of the spreading of the eastern part of the Eurasian Basin, causing a jump in the spreading axis of the Gakkel Ridge, as a result of which its rift valley and earthquake epicenters are located on its southwestern flank.

The map of the seafloor incline of the Eurasian Basin (Fig. 5) clearly shows variations in the nature of the relief of the Gakkel Ridge and its rift valley along the entire length.

The map shows the division of the Gakkel Ridge into three segments, which differ sharply in structure and, obviously, in the history of their formation. The western part is a classic, slow-spreading mid-ocean ridge. The structure of the eastern segment suggests its formation as a result of several phases of spreading, with the last axial shift occurring in the Pliocene and caused by the formation of a supervolcano at the site of the caldera. In the area of the southern segment of the Gakkel Ridge, the rift valley turns into a graben, the formation of which was probably initiated by the same Pliocene supervolcano.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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