

New Data on Seismotectonics of the Laptev Sea from Observations by Ocean Bottom Seismographs

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Received June 17, 2022; revised June 22, 2022; accepted July 24, 2022

Abstract—The results of new local seismic observations in the Laptev Sea obtained using ocean bottom seismographs were compared with actual data from global and regional earthquake catalogs. Most earthquake epicenters on the Laptev Sea shelf are grouped into several clusters located within the East Laptev province of horsts and grabens and enclosed between two extension detachments. The first one marks the eastern boundary of the Ust–Lena and Omoloi rift systems, and the second one is the eastern boundary of the Anisin, Zarya, and Belkovskii–Svyatoi Nos rift chains. At the same time, the linear zone of epicenters confined to the Gakkel Ridge, when moving to the shelf, shifts along the Khatanga–Lomonosov fault zone to the northeast in the direction of the second extension detachment, which probably remains the only active one. The spatial distribution of earthquakes in the Laptev Sea, taking into account the epicenters of micro- and weak seismic events on the shelf, does not have sufficiently clear boundaries that determine the contours of the previously assumed lithospheric microplate.

Keywords: Laptev Sea, earthquakes, ocean bottom seismograph, tectonic structures, rift system, extension detachment

DOI: 10.1134/S1028334X22600591

The Laptev Sea region is a relatively poorly studied segment of the Eurasian–North American plate boundary in which mid-oceanic spreading in the Eurasian basin is replaced by continental rifting on the Laptev Sea shelf. The mechanism of this geodynamic process is far from being fully understood.

A number of publications are devoted to the seismicity and tectonics features of the Laptev Sea region [1–6]. Assumptions made about the existence of one or even two lithospheric microplates are mainly based on seismological data, namely the distribution of relatively strong earthquakes with magnitudes from 4 to 6 [1, 2]. From another point of view, such “microplates” may be deformable crustal formations capable of making horizontal movements along the plastic asthenosphere [3].

It should be emphasized that the first models of modern geodynamic processes in the Laptev Sea region were based mainly on the distribution of strong earthquakes, with earthquake epicenters determined

using data from ground seismic stations. Later on, as Russian regional seismological networks were developed, the earthquake catalogs were improving due to the decrease in the magnitude of the threshold and errors of the hypocenter localization. A detailed analysis of the seismicity and tectonics of the Laptev Sea, however, requires instrumental observations of local microseismicity on the shelf using bottom seismic stations (BSs), which had not been carried out until recently.

The data from autonomous BSs used in the present work were obtained in a series of offshore expeditions conducted in the years 2018–2020 and aimed at a comprehensive study of the process of massive methane bubble release from marine sediments, which occurs mainly in the vicinity of the Gakkel Ridge junction with the shelf structures [7, 8]. The seismological work was aimed at finding and analyzing the relationship between tectonic processes and methane discharge from marine sediments into the water column, which is especially promising due to the revealed deep origin of the released methane on the outer shelf of the Laptev Sea [9].

Figure 1 shows the design and appearance of the MPSSR bottom seismic stations used in observations in the Laptev Sea, as well as the mounting scheme and location of stations of several modifications in the experiments of 2018–2020. MPSSR are fully auto-

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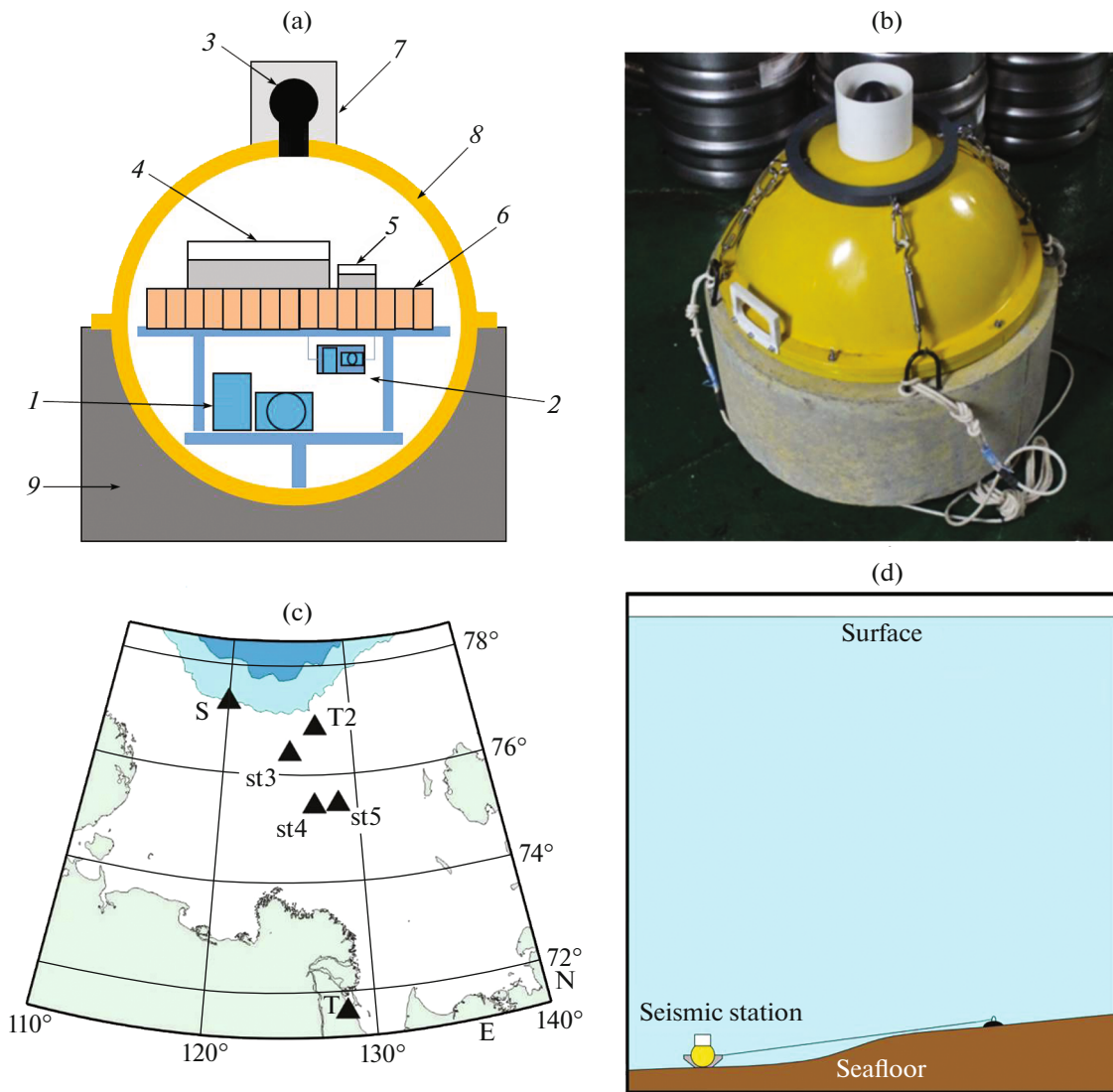


Fig. 1. (a) Design of the MSSR bottom seismic stations developed by the Institute of Oceanology, Russian Academy of Sciences: 1, a three-component broadband seismometer CME-4311; 2, three-component short-period seismometers (SV-10 and SG-10) on suspension; 3, hydrophone 5007 m; 4, seismic signal recorder URS-S; 5, digital compass module; 6, battery pack; 7, protective casing for hydrophone; 8, duralumin sphere; 9, concrete ballast. (b) Exterior view of the MSSR bottom seismic station on the *Akademik Mstislav Keldysh*, autumn 2018. (c) Location of bottom seismic stations that worked for several months and were successfully lifted: st4, st5, S in the 2018–2019 season; st3, T2 in the 2019–2020 season (T is the ground seismic station of the GS RAS in the settlement of Tiksi). (d) Scheme of the mounted seismic station–ropes–ballast system used in the depth range up to 80 m with the possibility of subsequent ascent of the station by trawling.

mous instruments, equipped with broadband molecular–electronic and high-frequency electrodynamic seismic sensors, as well as hydrophones. The recorded frequency range is 0.016–50 Hz. The data from the broadband seismic station Tiksi which belongs to the network of the Geophysical Survey, Russian Academy of Sciences (GS RAS), were also used when processing the seismic records [10]. These materials were included in the most representative and up-to-date catalog of the Laptev Sea earthquakes prepared by the authors, which unites the electronic databases of the GS RAS [10], the International Seismological Centre

(ISC) [11], and the United States Geological Survey (USGS) [12] and was used in this work to describe the seismicity in this region.

The distribution of earthquake epicenters and the scheme of the main tectonic structures in the Laptev Sea are shown in Fig. 2a. One can distinguish a narrow band of epicenters along the Gakkel spreading ridge and an area of epicenters between the Taimyr Peninsula, Lena River delta, and Novosibirsk islands, which covers the main structures of the Laptev Sea shelf.

The zone of numerous epicenters confined to the Lena–Taimyr boundary uplifts [1] stretches along the

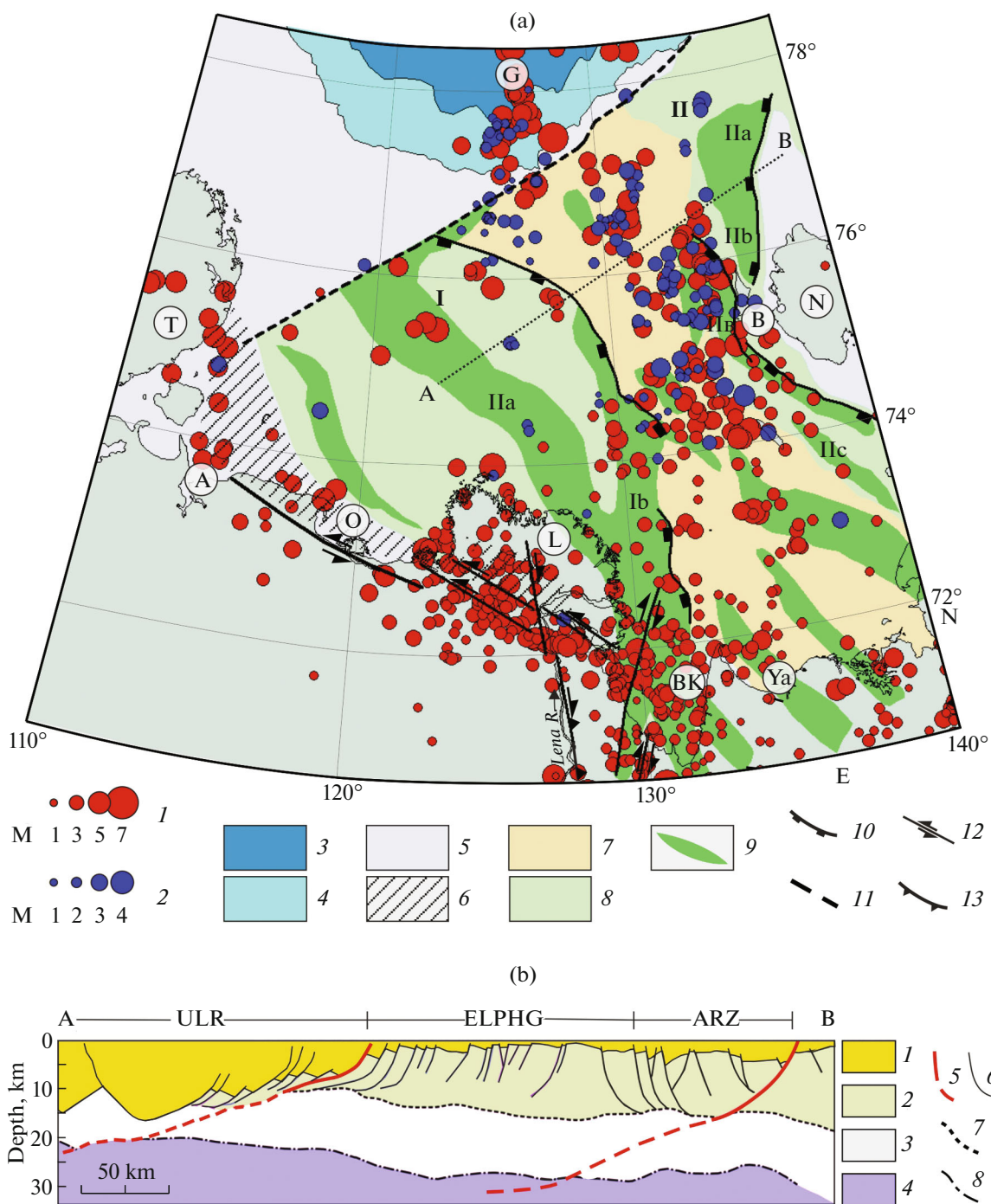


Fig. 2. (a) Seismicity of the Laptev Sea and scheme of the main structural elements compiled using [1, 4–6]. (1) Epicenters of earthquakes from the combined catalog of GS RAS, ISC, and USGS; (2) epicenters of earthquakes registered by seismic bottom stations; (3) Eurasian basin; (4) continental slope; (5) shelf; (6) Lena–Taimyr boundary uplifts; (7) East Laptev Sea province of horst and grabens (ELPHG); (8) rift troughs: I, Ust–Lena rift system; II, Anjou rift zone; (9) main rifts and grabens of the Laptev Sea rift system: Ia, Ust–Lena; Ib, Omoloi; IIa, Anisin; IIb, Zarya; IIc, Belkovskii–Svyatoi Nos; (10) extension detachments; (11) Khatanga–Lomonosov rift zone; (12) shear; (13) thrusts; G, Gakkel Ridge; T, Taimyr Peninsula; L, Lena River delta; N, Novosibirsk islands; B, Belkovskii Island; bays: K, Khatanga; A, Anabar; O, Olenyok; BK, Buor-Khaya; Ya, Yana. A–B, profile shown in Fig. 2a. (b) A fragment of the interpreted section along seismic profile A–B (modified after [5]), for profile position, see Fig. 2a. (1) Syn- and post-rift sediments, (2) upper crust, (3) lower crust, (4) upper mantle, (5) main extension detachments, (6) listric faults, (7) Conrad boundary, (8) Mohorovich boundary. ULR, Ust-Lena rift system; ELPHG, East Laptev Sea province of hills and grabens; RZA Anjou rift zone.

southern margin of the Laptev Sea from the Taimyr Peninsula through Anabar and Olenyok bays to the Lena Delta and Buor-Khaya Bight. Another distinct zone of event concentration is traced from the Gakkel Ridge towards Yana Bay. It is confined to the so-called East Laptev province of horsts and grabens (ELPHG) and is enclosed between two extension detachments, i.e., gentle or subhorizontal faults along which plain shear deformations in the vertical plane occur [13]. The ELPHG is considered as a region affected by tensile deformations [2]. The prevalence of tensile deformations within the ELPHG was confirmed by known mechanisms of earthquake foci [4]. The eastern extension detachment makes up the eastern boundary of the Anisin, Zarya, and Belkovskii-Svyatoy Nos rift chain, while the western one marks the eastern boundary of the Ust–Lena and Omoloyok rift systems. Figure 2b shows a seismogeological section along the profile passing through the Ust–Lena rift system (ULR), ELPHG, and Anjou rift zone (ARZ) [5], demonstrating the position of the above extension detachments in the vertical plane.

The distribution of the epicenters within the ELPHG (Fig. 2a) has several distinctions. First, the band of earthquake epicenters within this structure is shifted towards the northeast from the branch confined to the Gakkel Ridge. The displacement is marked by a cloud of epicenters with sublatitudinal strike and is confined to the place where the Khatanga–Lomonosov fault zone (KLFZ) separates the Eurasian oceanic basin from the intracontinental Laptev Sea rift system. The position of the KLFZ is also reflected in the anomalous geophysical fields and in the wave seismic pattern on the sections [14, 15].

Secondly, the earthquake epicenters within ELPHG are distributed unevenly; they form several large foci clusters. At least three large clusters can be defined visually: the northernmost one extends from KLFZ in the sublongitudinal direction to the south to 76° N; the central cluster adjoins Belkovskii Island from the west and northwest; the longest southern cluster is located to the southwest from Belkovskii Island and stretches towards the Lena River delta. The clustering of the seismic belt within ELPHG may possibly be due to the shear faults crossing this province, the presence of which is suggested by some works [2], and the corresponding partitioning of the eastern strike–slip segment.

Thirdly, two linear chains of epicenters are traced from the junction of the Gakkel Ridge with the Laptev Sea shelf in the southwesterly direction: one extends along the KLFZ to Khatanga Bay, the other, slightly shifted to the south, goes parallel to the KLFZ to Anabar Bay. Structurally, the foci of these earthquakes are confined to the ULR. They are confined to the individual fractures of this rift system near its intersection with KLFZ. It may indicate the continuing activity of this structure.

The analysis of the obtained seismicity pattern and its comparison with the distribution of the main fault zones and tectonic structures in the Laptev Sea allowed several new conclusions to be made.

(1) The earthquake concentration zone, which extends from the Gakkel Ridge toward Yana Bay, is confined to the ELPHG and is enclosed between two detachments. The geometry of the vertical section of the extension detachments given in [5] suggests that only the eastern detachment is currently active. This confirms the assumption of a shift of the extensional axis in the easterly direction [16].

(2) The field of epicenters within the ELPHG is not a continuation of the band of events confined to the Gakkel Ridge, but shifted in the northeasterly direction. The displacement is marked by a cloud of epicenters of sublatitudinal strike and gives reason to assert that the HLZR separating the ridge from the ELPHG is currently active at least in its northeastern segment. Furthermore, the chain of earthquakes traced along KLFZ from the displacement area towards Khatanga Bay may indicate the continuing weak activity of its southwest segment.

(3) The epicenters of earthquakes within the ELPHG form several large foci clusters. Such clustering of the seismic belt may be connected with possible shear fractures crossing this province, the presence of which is indicated in some works [2], and corresponding partitioning of the eastern strike–slip segment.

(4) The spatial distribution of the Laptev Sea earthquakes, including the epicenters of micro- and weak seismic events on the shelf ($1 < M < 3$), shown in Fig. 2a, does not have sufficiently clear boundaries that might define the contours of the lithospheric microplate distinguished in [1]. The geodynamic model of upper mantle convection in the Arctic region presented in [17] is a more suitable explanation for the tectonic setting of the area studied.

FUNDING

This work was carried out within the framework of a State Assignment, project no. FMWE-2021-0004 (description of the modern tectonics of the region), with support from the Russian Foundation for Basic Research (grant no. 20-05-00533, processing of bottom seismograph records); a grant of the President of Russia for young scientists, project no. MK-45.2022.1.5 (analysis of earthquake distribution); and grant no. 21-77-30001 (work on installation of bottom seismographic stations in expeditions).

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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