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VOLCANOLOGY

The Risk of Destruction of Berenberg Volcano (Jan Mayen Island, Norwegian–Greenland Sea)

A. O. Mazarovich[a],* and S. Yu. Sokolov[a]

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Abstract—The volcanic, sesimological, and geodynamic conditions in the region of the Jan Mayen Island are analyzed. It is shown that a part of Berenberg active volcano, located in the northern part of the island, is within the active part of the Jan Mayen transform fault, and historic eruptions took place here. The volcano has a caldera, apparently of landslide origin. The maximum amplitude of the isostasy gradient was revealed in the immediate vicinity of Berenberg volcano. The steepest slopes are located on its northern part. Our analysis gives us grounds to classify Berenberg stratovolcano as a volcanic structure of potential landslide hazard, because its northeastern slopes can collapse to generate a landslide and a corresponding tsunami.

Keywords: Jan Mayen Island, Berenberg volcano, geological hazard, landslide, earthquakes, transform fault

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Throughout geological history, many volcanic edifices have been destroyed by catastrophic landslides. These phenomena have been established to have occurred not only on continents, but also on islands. Destruction can occur very rapidly and can cause catastrophic tsunamis. For example, Ritter Island (Bismark Sea) was destroyed by a landslide in 1888 [11] and Anak Krakatoa Island (Sunda Strait) was in 2018 [13]; those landslides also caused tsunamis, which reached up to 20 m high and traveled up to 600 km. In the Northeastern Atlantic, massive landslides of various ages were identified to have occurred on islands such as Santo Antão, Fogo, São Vicente (Cape Verde Islands); La Palma, El Hierro, Tenerife, La Gomera (Canary Islands); Pico (Azorean Islands); and others. New volcanic edifices have been reported to form in landslide cirques on some of them (for example, Santo Antão and Fogo). Destruction of a volcanic edifice is a natural hazard; hence, revealing objects where landslides can potentially occur is an important task.

One of these objects is Jan Mayen Island, located 600 km north of Iceland, at 70°50′–71°10′ N [5, 6, 8, 9]. This is a NE-elongated island, about 54 km long and up to 15.8 km wide, with a total area of 380 km^2.

Jan Mayen Island has a unique geodynamic position, sitting at the boundary between the microcontinent and the active part of the Jan Mayen transform fault (Fig. 1). The microcontinent is expressed in the bottom topography as the flat-topped Jan Mayen Ridge which trends sublongitudinally by about 200 km, at up to 30 km wide. The depths of the ridge top range from 1400–1500 in the south to 100 m in the north. In the northern part of the ridge's eastern slope, the slope angle of which is about 5° (up to 20° in places), a massive landslide body is located. The detachment wall of this landslide extends 60 km, and its height is up to 350 m. The total volume of the landslide body is 60 km^3 (Fig. 1).

The southern part of Jan Mayen Island is a cracked NE-trending volcanic zone with multiple volcanic cones, flows, and domes of trachybasalts and trachytes of 700000 years or younger in age. Reaching up to 700 m in height, they are clearly expressed in the topography. In the northern part of Jan Mayen Island, the active Berenberg stratovolcano (2277 m high) is located. Its edifice is composed of alkali olivine basalts and began to form in the Late Pleistocene. The volcano is situated on the southern slope of a trough more than 2000 m deep, located in the active part of the Jan Mayen transform fault; the volcano forms a triangular "cape" of about 13 km long in plan view (Fig. 1). Thus, the total height of the Berenberg volcano edifice is more than 4000 m.

On the volcano top, there is a crater about 1500 m in diameter, with a breach in the western part. Judging by the morphology of the crater, it was formed by landslide activity. The slopes of the volcanic edifice have superimposed barrancos. Eruptions on Jan

[a] *Geological Institute, Russian Academy of Sciences, Moscow, Russia*
**e-mail: amazarovich@yandex.ru*

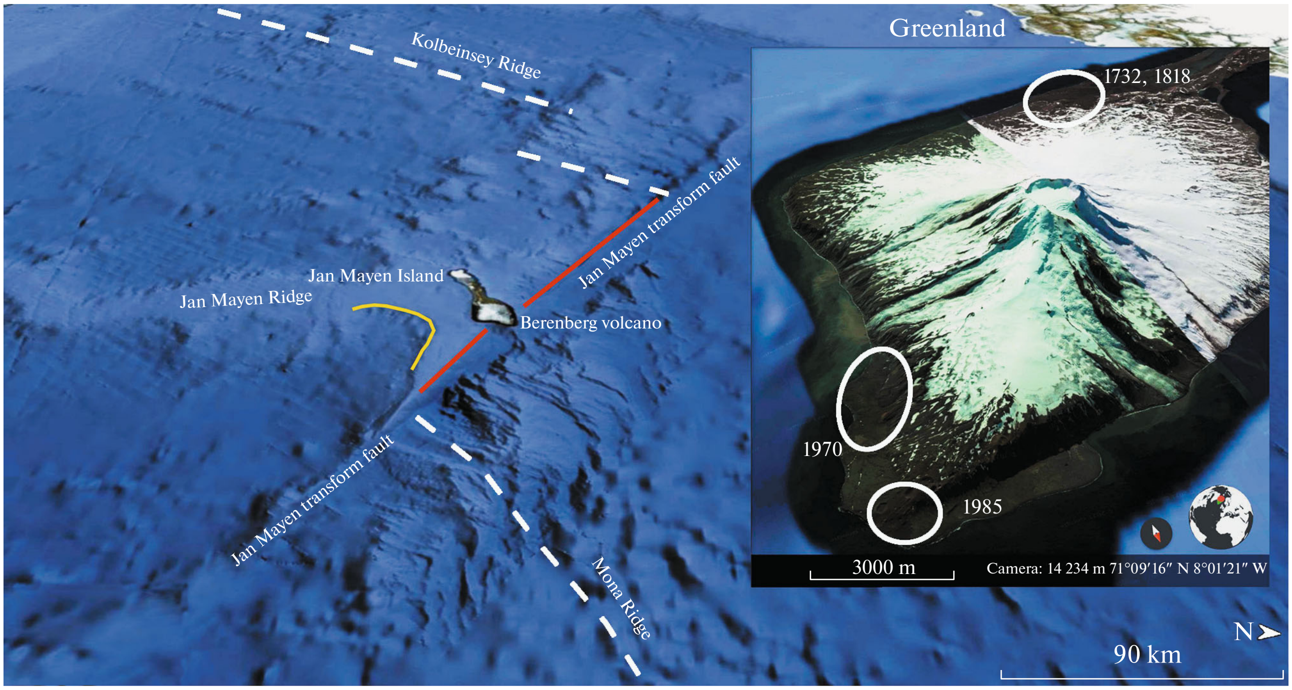

Fig. 1. Position of Jan Mayen Island. 3D shaded elevation, view from the northeast. Dashed line denotes the rift; red line, active part of the transform fault; yellow line, detachment line of a landslide. In the inset, Berenberg volcano, view from the northwest. Ovals mark the locations of eruptions and years. Topographic base is Google Earth Pro.

Mayen Island, including the northern and northeastern peripheral parts of Berenberg volcano, were reported in 1650, 1732, 1818, 1851, 1970, and 1985 (Fig. 1).

A sublongitudinal rift of the Kolbeinsey mid-ocean ridge (MOR) extends 180 km west of the Jan Mayen Ridge. However, judging by the anomalous magnetic field of ΔT_a [7], which has a pronounced axial linear maximum, and the swarm of predominantly shallow-focus seismic events (Fig. 2), the active part of the fault is located 60–70 km west of the Kolbeinsey Ridge. This indicates a possible process of modern transformation of the rift system's geometry with the compensation of eastward right-lateral strike-slip movements in the spreading systems around the latitude 70°45′ N and with rectification of rift segments. North of here, the spreading axis is located east of the Kolbeinsey Ridge, within the NNE-trending Mohns Ridge. The spreading rate in both ridges is estimated at 15–17 mm/yr [5]. The length of the active part of the Jan Mayen transform fault connecting both centers is about 200 km.

Since 1900, several tens of earthquakes with $M > 5$ have been recorded in the region of Jan Mayen Island [8, 9]. On August 30, 2012, and November 9, 2018, earthquakes with $M = 6.7$ and $M = 6.8$, respectively, occurred (Fig. 2).

The distribution of seismic events along the Jan Mayen transform fault shows that, on the west and on the east, near the ends of its active part, there is an elevated concentration of weak shallow-focus seismic events, the occurrence of which does not allow considerable stress to accumulate. In the middle of the ridge's active part, shallow-focus seismic events are absent, although deep earthquakes are reported: their hypocenters are 13 to 40 km deep, and their magnitudes go up to 7. The same earthquakes are observed immediately beneath Jan Mayen Island, and the seismic process characterized by these parameters can become a trigger of landslide processes at the volcanic edifice and cause its partial collapse. It should be emphasized that weak deep-focus seismicity in the southern part of the Mohns Ridge shifts westwards. This indicates that the process of change in the geometry of the main structural elements of the MOR is ongoing nowadays and is taking place within a weakened portion of the lithosphere, where magma chambers may be hosted.

The parameter indicating the unstable state of the lithosphere and the potential for vertical movements of crustal blocks is isostasy [1]. Even more informative for determining the zones of the highest seismic hazard and the largest vertical tectonic movements is the parameter of the horizontal gradient of this reduction of the gravity field [2]. Figure 3 presents a map of the horizontal gradient of isostasy, as calculated based on the data from [3].

The horizontal gradient of isostasy shows the zones with the maximum differentiation of vertical movements of lithospheric blocks, at the boundaries of

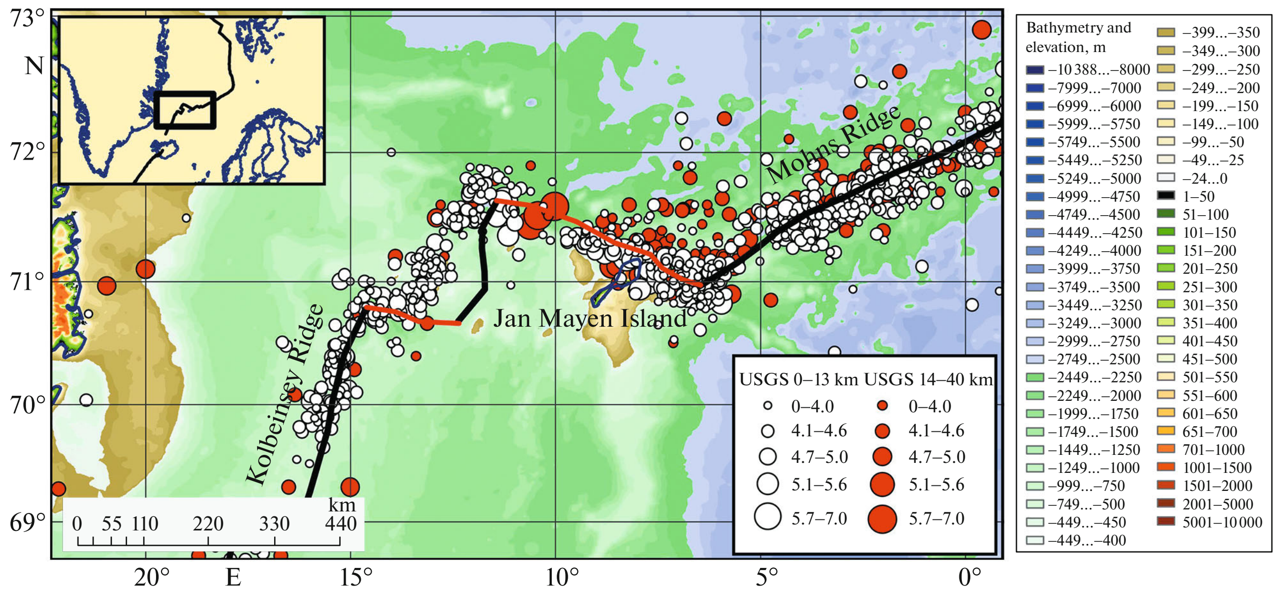

Fig. 2. Seismicity of the Jan Mayen Island area, after [12]; bathymetry is after IBCAO v.3 [4]; and positions of the main structural elements of the MOR: rift axes (black lines) and transform faults (red lines) according to the topographic data.

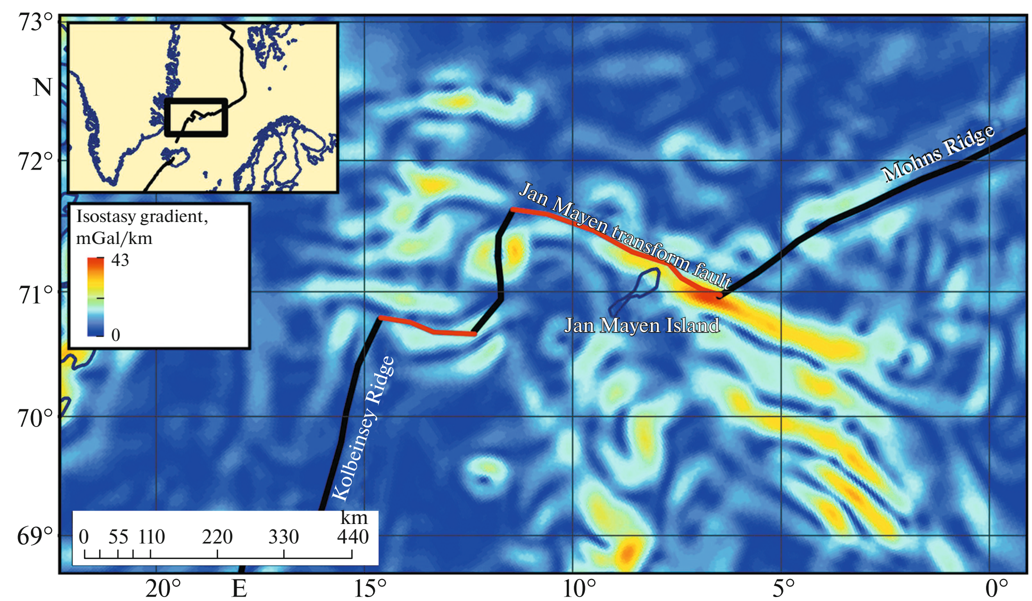

Fig. 3. Map of horizontal gradient of isostasy, calculated using the data from [3]. The positions of the main structural elements of the MOR—rift axes (black lines) and transform faults (red lines)—are constructed from the bathymetric data [4].

which the most high-amplitude tectonic movements and detachments (accompanied by the respective seismic events) are possible. The maximum amplitude of the gradient was revealed at the eastern terminus of the active part of the Jan Mayen transform fault, quite near the vicinity of the volcanic edifice. At present, stress release is accompanied by the occurrence of a large number of weak shallow-focus seismic events (Fig. 2). However, the eastern part also hosts a considerably number of moderate-magnitude deep-focus earthquakes, indicating that the tectonic process runs at all structural layers. Due to the aforementioned fact that this process is determined by the reorganization of the MOR geometry, strong earthquakes that can lead to catastrophic changes in the topography are very likely to occur. Such changes can primarily involve the areas where large volumes of volcanic material are accumulated on relatively steep slopes (Fig. 4).

The steepest slopes are located in the northern part of the volcanic edifice and near the eastern end of the active

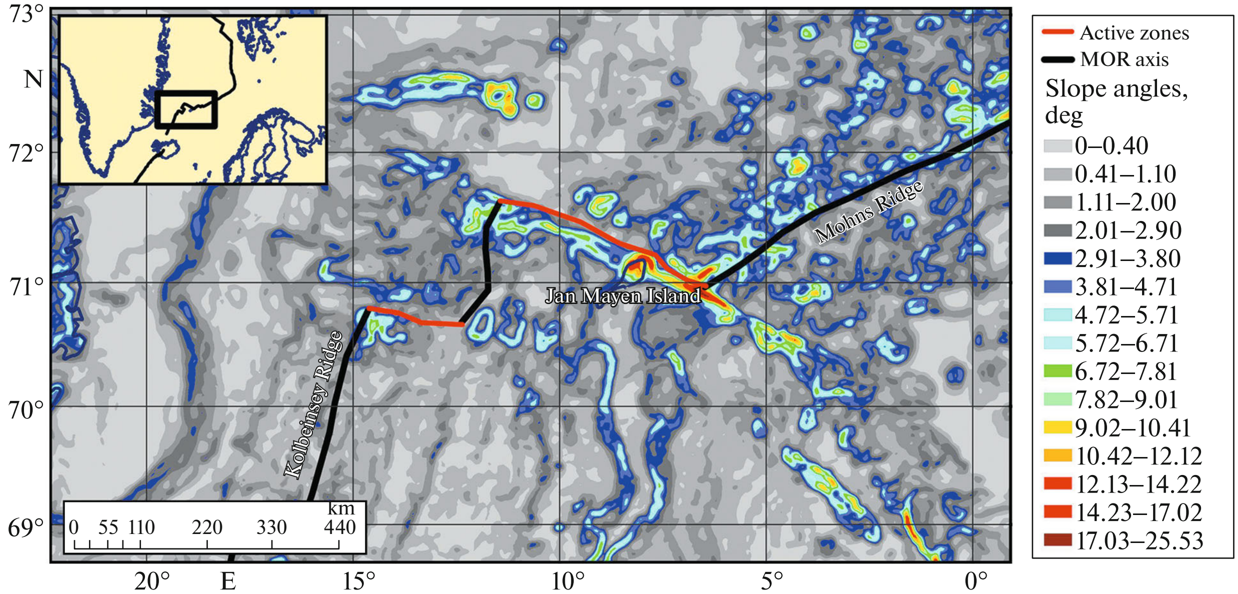

Fig. 4. Slope angles of the bottom topography, as calculated by the data from [4], and the positions of the main structural elements of the MOR—rift axes (black lines) and transform faults (red lines)—as constructed from the bathymetric data [4]. The grid of angles is smoothed in a 5 × 5 km window.

part of the fault. The latter area is unlikely to host a large landslide, but the volcanic edifice itself, being composed of large volumes of volcanoclastic material, is an object of a potential tsunami hazard (a tsunami could be generated by a landslide on a slope of the edifice).

Taking into account the geodynamic setting briefly described above, the seismic and volcanic activity, and the topographic features, the Berenberg stratovolcano can be classified as a potentially hazardous volcanic edifice, the northeastern slopes of which can produce a landslide with subsequent generation of a tsunami and start of an eruption. It appears that the respective area should be considered as one potential hazard for the coasts of Northwestern Europe, Svalbard, and Greenland. Note that the distance between Jan Mayen Island and the Russian economic zone in the Barents Sea is less than 1500 km, while it is known that tsunamis can preserve their amplitudes even after crossing the Pacific.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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