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Seismicity of the Arctic mid-ocean Ridge system

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Abstract

The Arctic mid-ocean ridge system constitutes the most active source of earthquakes in the north polar region. However, the characteristics of its earthquake activity at teleseismic and local scales are not well studied because of the remote location of the ridge. We present here a comprehensive seismicity analysis that compares the teleseismic earthquake record of 35 years drawn from the catalogue of the International Seismological Centre with reconnaissance-style local earthquake records at six locations along the ridge that were instrumented either with ocean bottom seismometers or with seismometers on drifting ice floes. The teleseismic earthquake activity varies along the ridge and reflects ultraslow spreading processes with more and larger earthquakes produced in magma-rich regions than in magma-starved areas. Large magnitude earthquakes $M > 5.5$ are common along this ultraslow spreading ridge. Locally recorded earthquakes are of small magnitude ($M < 2$) and probably reflect the formation of the pronounced topographic relief. Their size and event rate is not as variable along the ridge as that of teleseismic events. Locally recorded earthquakes in the upper mantle are generated at several locations. Their focal depths do not depend on spreading rate but reflect the thermal state of the lithosphere with very deep earthquakes indicating an exceptionally cold lithosphere.

Keywords: Seismicity; Mid-ocean ridge; Ultraslow spreading; Arctic Ocean

1. Introduction

The Arctic mid-ocean ridge system represents the most active source of earthquakes in the north polar region (Fig. 1). The three largest earthquakes north of 75°N occurred along the transform faults of the Spitsbergen and Molloy Fracture Zone (Mw 6.5 and 6.3) but also in an extension-dominated setting near 99°E on Gakkel Ridge (Mw 6.3) (International Seismological Centre, 2012). Earthquakes above about magnitude 3.5 originating at the Arctic ridge system are included in global earthquake catalogues (see Engen et al. (2003) for a compilation). Studies of local seismicity, that are typically conducted at mid-ocean ridges to explore spreading processes (Toomey et al., 1985; Smith et al., 2003; Tolstoy et al., 2006), are rare in the Arctic. Perennial sea-ice prevents the use of ocean bottom seismometers and autonomous hydrophone arrays. Kristoffersen et al. (1982) demonstrated that earthquakes in the Arctic Ocean can be recorded on ice floes. Sohn and Hildebrand (2001) presented hydrophone-detected events from the Arctic mid-ocean ridge.

In 2001, the Arctic Mid-Ocean Ridge Expedition (AMORE) performed detailed geological mapping of Gakkel Ridge (Michael et al., 2003) and discovered that common models of seafloor spreading cannot be extrapolated to ultraslow spreading rates (<15 mm/yr).

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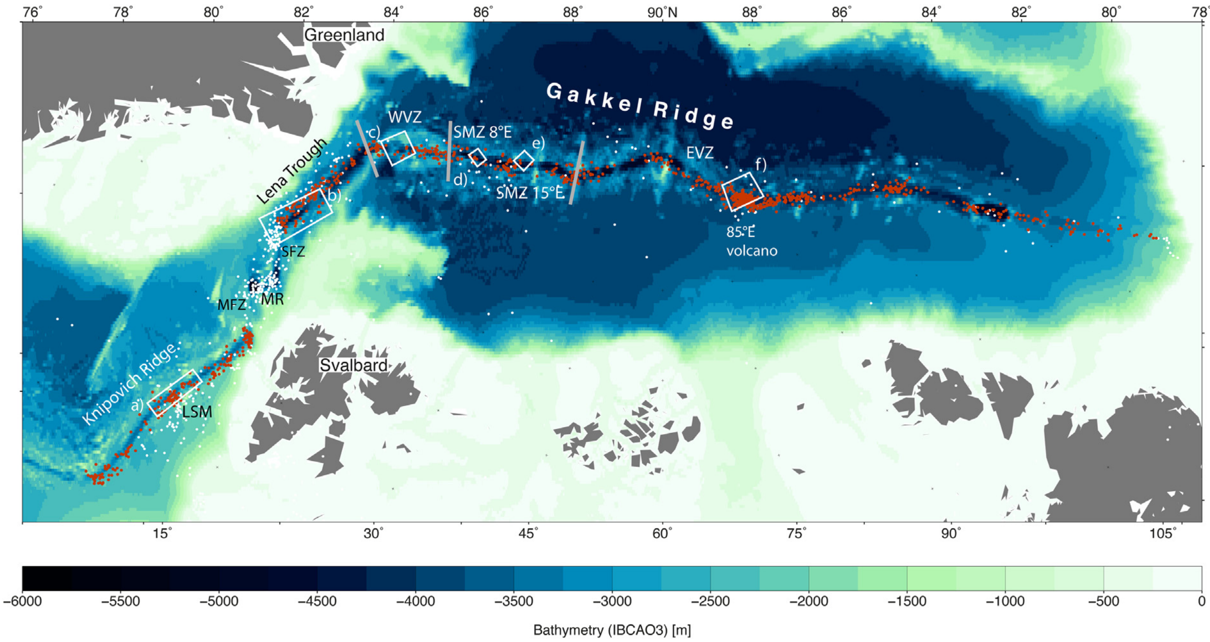

Fig. 1. Epicentres of teleseismic earthquakes in the Arctic are marked by white dots. Earthquakes that occur within 30 km of the axis of the Arctic mid-ocean ridge system, which runs from Knipovich Ridge towards Gakkel Ridge, are displayed by red dots. Epicentres were extracted from the reviewed catalogue of the International Seismological Centre between 1976 and 2010. The transform systems of the Spitsbergen Fracture Zone (SFZ) and the Molloy Fracture Zone (MFZ) and the Molloy ridge (MR) in between are not studied here. Labelled white boxes mark the sites of local seismicity studies (maps in Fig. 4). WVZ: Western Volcanic Zone; SMZ: Sparsely Magmatic Zone; EVZ: Eastern Volcanic Zone; LSM: Logachev Seamount. Bathymetry is IBCAO version 3 (Jakobsson et al., 2012). Polar stereographic projection.

Instead, ultraslow spreading ridges form a particular class of spreading ridges (Dick et al., 2003). In the following years, ultraslow spreading ridges attracted increasing notice of the international mid-ocean ridge research. Individual seismic events like the 1999 earthquake swarm on Gakkel Ridge were studied (Müller and Jokat, 2000).

The Arctic ridge system and the Southwest Indian Ridge (55°S 0°E to 25.5°S 70°E) are the main representatives of ultraslow spreading mid-ocean ridges but are both equally remotely located and difficult to access for seismicity studies. The coverage with seismic stations around the Southwest Indian Ridge is even poorer than in the Arctic where land masses are closer by. A comprehensive analysis of the seismicity of ultraslow spreading ridges has therefore not been attempted. In addition, as spreading processes are expected to cause small magnitude events that go undetected by land stations, the teleseismic record seemed not to include relevant seismic events.

Since 2001, we have systematically acquired reconnaissance-style seismicity data from the Arctic mid-ocean ridge system using seismometers on drifting ice floes (Schlindwein et al., 2007; Läderach and Schlindwein, 2011) and short-term deployments of ocean bottom seismometers in ice-free regions (Schlindwein et al., 2013). In addition, we have examined the record of teleseismic earthquakes of both the Arctic ridge system and the Southwest Indian Ridge and demonstrated their usefulness in studying ultraslow spreading processes (Schlindwein, 2012). In this paper we summarize our efforts to study the seismicity of the Arctic mid-ocean ridge system as an ultraslow spreading ridge and we present a comprehensive overview of all datasets acquired.

2. Data and methods

We present here two types of data: teleseismic earthquake locations obtained from records of the Global Seismological Network and locations of small earthquakes recorded locally either by seismic stations installed on sea-ice or by ocean bottom seismometers (OBS) deployed on the seafloor. Fig. 1 gives an overview of the teleseismic earthquake locations of the Arctic ridge system and shows the areas of local seismicity studies.