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Seismic stratigraphy, structure and morphology of Makarov Basin and surrounding regions: tectonic implications

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A B S T R A C T

The tectonic history of Amerasia Basin, Arctic Ocean, is not well known because of a paucity of data and complexities introduced by the Alpha–Mendeleev Ridge large igneous province. Makarov Basin, at the northern limit of Amerasia Basin and adjacent to Lomonosov Ridge, may provide a window into understanding the larger tectonic framework. The objective of this study is to decipher the sedimentary and tectonic history of northern Amerasia Basin by analysing the seismic stratigraphy, structure and morphology of Makarov Basin and surrounding regions (Alpha and Lomonosov ridges) of the central Arctic Ocean. The principal data sources for this study are a 400 km long multi-channel seismic line, extending from Alpha Ridge to the crest of Lomonosov Ridge via central Makarov Basin, and the Arctic bathymetric chart.

The seismic record within Makarov Basin is divided into five seismic units. The first unit overlying basement hosts Late Cretaceous (minimum age) slope to base of slope sediments. Some of these sediments are interbedded with volcanic or volcanoclastic rocks with a minimum age of 89 Ma. Makarov Basin becomes isolated from proximal sources of sediments after the onset of rifting that separated Lomonosov Ridge from the Barents Shelf, which may have occurred as early as the mid-Late Cretaceous, and led to the creation of Eurasia Basin. Sediments are largely pelagic to hemipelagic as a result of this isolation. This deposition style also applies to the draped sedimentary strata on Alpha and Lomonosov ridges. The uppermost seismic units within Makarov Basin arejump-correlatedto the stratigraphic record of the ACEX drill site on top of Lomonosov Ridge to provide age control. This correlation shows that the 44.4–18.2 Ma hiatus documented in the drill core is not apparent in the basin. Inter-ridge correlations and the absence of an obvious planate surface on Alpha Ridge also suggest that sedimentation was uninterrupted on this ridge during the hiatus.

Seismic data reveal a deep subbasin (~5 km thick) within Makarov Basin. This subbasin is immediately adjacent to Lomonosov Ridge within major bends in the general strike orientation of the ridge. The rhomboid shape of the deep subbasin, the straight and steep morphology of the Amerasian flank of Lomonosov Ridge and the presence of numerous sub-parallel ridges (e.g. Geophysicists and Marvin spurs) created by splay faulting are evidence of strike-slip (transtensional) tectonics. This interpretation supports the "rotational" model of opening of Amerasia Basin with a transform to transtensional margin at Lomonosov Ridge. As spreading continued, however, the tectonics became increasingly extensional perpendicular to Lomonosov Ridge. There is no evidence of major tectonic deformation in Makarov Basin beyond the late Paleocene.

1. Introduction

The Arctic Ocean is the smallest and shallowest of the world's five major oceans. It comprises extensive shallow continental shelves and two major deep-water basins — the Amerasia and Eurasia basins (Fig. 1). The two basins are separated by the Lomonosov Ridge, spanning the Arctic Ocean from the North American shelf off of Ellesmere Island and Northwest Greenland to the East Siberian Shelf. The onset of rifting between Lomonosov Ridge and the Barents Shelf may have commenced as early as the mid-Late Cretaceous (Drachev, 2011), and led to seafloor spreading in Eurasia Basin during the late Paleocene (magnetic chron anomaly 25 or 24; Vogt et al., 1979; Srivastava, 1985; Brozena et al., 2003). Amerasia Basin lies on the opposite side of Lomonosov Ridge. This ridge, Arctic Alaska, Siberia and the Canadian Arctic Archipelago surround the basin (Fig. 1). Prominent geomorphological features within Amerasia Basin include Canada Basin, the Chukchi Borderland, the Alpha and Mendeleev ridges, and the Makarov and Podvodnikov basins (Rowley and Lottes, 1988; Fig. 1). In contrast to

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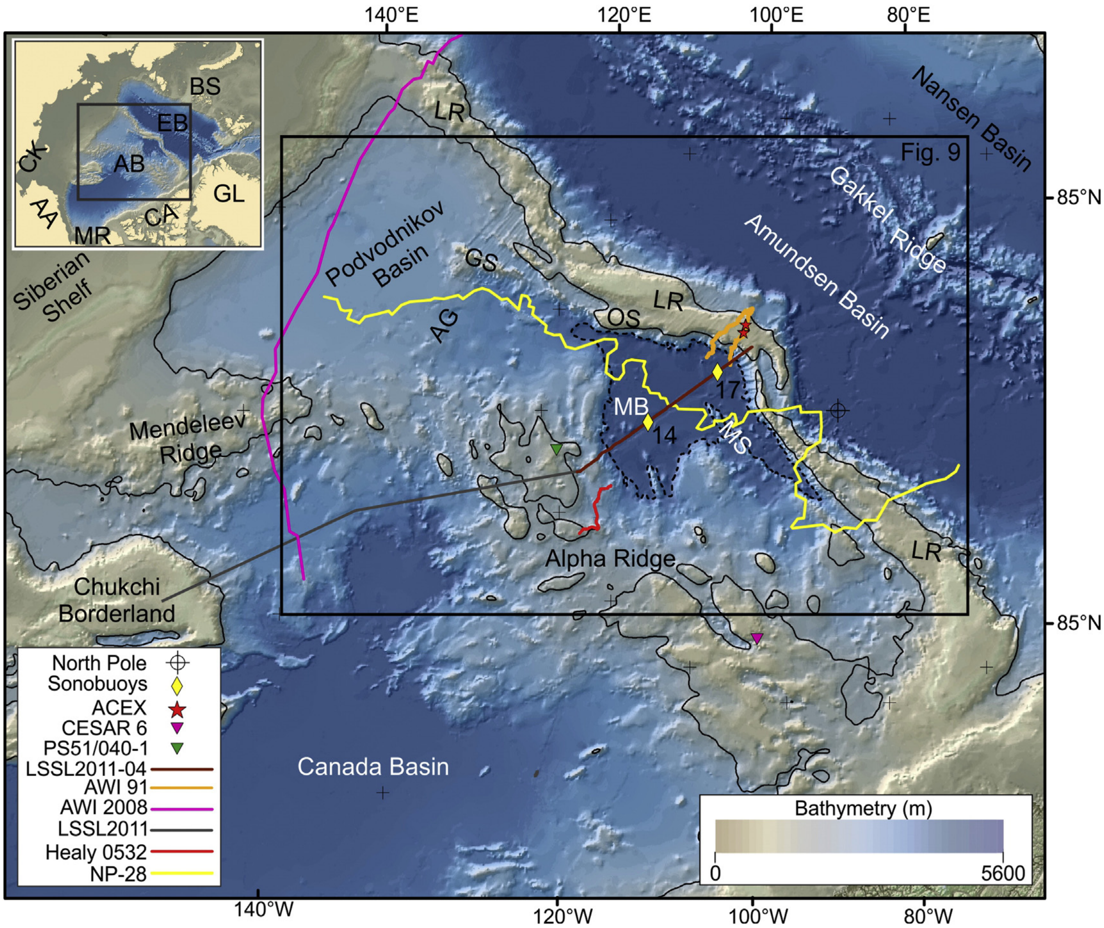

Fig. 1. Colour-shaded bathymetric map of northern Amerasia and Eurasia basins. Makarov Basin is delineated by a dashed line representing the 3700 m bathymetric contour. The thin black like corresponds with the 2000 m bathymetric contour, which is used to describe Lomonosov Ridge. Acronyms used in this figure and others are: AA — Arctic Alaska, AB — Amerasia Basin, AG — Arlis Gap, BS — Barents Shelf, CA — Canadian Arctic margin, CK — Chukotka, EB — Eurasia Basin, GL — Greenland, GS — Geophysicists Spur, LR — Lomonosov Ridge, MB — Makarov Basin, MR — Mackenzie River delta, MS — Marvin Spur, OS — Oden Spur. Note, the name Geophysicists Spur is not officially included in the General Bathymetric Chart of the Oceans Gazetteer (http://www.gebco.net/), but we use it as it is common in the Russian literature (e.g. Morozov et al., 2013; Taldenkova et al., 2014). Other studies shown in this figure are: ACEX [drill sites from IODP Expedition 302; Backman et al., 2006], CESAR 6 [piston core; Mudie and Blasco, 1985], PS51/040-1 [sediment core; Jokat, 1999], AWI 91 [MCS; Jokat et al., 1992, 1995], AWI 2008 [MCS; Weigelt et al., 2014], Healy 0532 [MCS; Bruvoll et al., 2010], LSSL2011 [MCS; Mosher, 2012], NP-28 [seismic reflection from ice-station; Langinen et al., 2009]. Map projection is North Pole Stereographic with a latitude of origin of 75° N and a central meridian of 90° W. Bathymetry and elevation are from the International Bathymetric Chart of the Arctic Ocean (IBCAO), version 3.0 (Jakobsson et al., 2012).

Eurasia Basin, the geological history of Amerasia Basin is not well known. This uncertainty results largely from the paucity of data in Amerasia Basin, which is due to its remote location and perennial cover of sea ice, and due to the geological complexity of the region. Furthermore, plate-reconstructions of the basin are hampered by the absence of well-defined magnetic isochron anomalies (Gaina et al., 2011). Consequently, opposing models for the genesis of Amerasia Basin have been advanced (cf. Miller and Verzhbitsky, 2009; Grantz et al., 2011). Unravelling the history of Makarov Basin, which lies in the underexplored northern Amerasia Basin, will support interpretation of the tectonic origin of the entire Amerasia Basin and its post-formation history. The objective of this study, therefore, is to decipher the tectonic and sedimentological history of northern Amerasia Basin by analysing the stratigraphy, structure and morphology of Makarov Basin and surrounding regions using recently acquired seismic reflection and bathymetric data.

2. Geological setting

Makarov Basin lies at the northern extent of Amerasia Basin between Alpha Ridge and Lomonosov Ridge (Fig. 1). The basin encompasses an area of approximately 63,000 km^2 and its abyssal plain reaches depths of 4000 m (Fig. 1). Lomonosov Ridge is reasonably well-understood to be a continental fragment isolated by opening of Eurasia Basin in the Cenozoic (Rowley and Lottes, 1988; Jackson et al., 2010). The Eurasian margin of Lomonosov Ridge is thus conjugate to the Barents Shelf margin. On the opposite side, Geophysicists, Oden and Marvin spurs are linear ridges that trend sub-parallel to Lomonosov Ridge (Fig. 1). These features are interpreted as continental fragments splintered off of Lomonosov Ridge (Cochran et al., 2006).

Alpha Ridge forms the southern border of Makarov Basin. The Alpha and Mendeleev ridges are part of a large igneous province (LIP), as evidenced by its high amplitude magnetic anomalies (Weber, 1986; Vogt et al., 2006), velocity structure (Funck et al., 2011), and basalts recovered in situ (Van Wagoner et al., 1986; Andronikov et al., 2008; Jokat, 1999). Together with Cretaceous volcanic suites found throughout the circum-Arctic (e.g. Hansen Point volcanics on Ellesmere Island; Estrada and Henjes-Kunst, 2004), the Alpha–Mendeleev ridge complex is assumed to be part of the greater High Arctic Large Igneous Province (HALIP) (Maher, 2001; Tegner et al., 2011). The duration of the HALIP and its timing relative to the opening of Amerasia Basin are disputed (Estrada, 2015). There is also current debate about whether the Alpha–Mendeleev ridge complex is an oceanic plateau emplaced on top of oceanic crust (e.g. Funck et al., 2011; Jokat et al., 2013), or stretched continental crust overprinted by later magmatism (e.g. Lebedeva-Ivanova et al., 2006; Døssing et al., 2013). The distinct