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The nature of the acoustic basement on Mendeleev and northwestern Alpha ridges, Arctic Ocean

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ABSTRACT

The Alpha-Mendeleev ridge complex, over 1500 km long and 250–400 km wide, is the largest submarine structure in the Arctic Ocean basin. Its origin is unknown, but often inferred to represent a large igneous province where domains of continental crust may also be a possibility. We investigate the basement geology of part of this large scale feature using 1100 km of multichannel seismic reflection data, sonobuoy recordings and marine gravity data acquired in 2005 from USCG icebreaker *Healy*. The sonobuoy results show top and intra-acoustic basement velocities in the range of 2.3–4.0 km/s and the seismic reflection attributes define three main acoustic facies: 1) continuous high amplitude reflections often with abrupt breaks, 3) weak wedge geometry and 3) segmented, disrupted to chaotic reflections. The acoustic characteristics and seismic velocities compare more closely with basement on Ontong Java Plateau than normal ocean crust or wedges of seaward dipping reflections at volcanic margins. The acoustic facies are interpreted to represent basalt flows and sills capping voluminous tuff deposits and possible sediments. At least two volcanic centres are identified. The upper volcanic carapace on the surveyed part of Mendeleev and northwestern Alpha ridges was emplaced during a brief igneous episode no later than Campanian (80 Ma) and most likely part of wider Late Cretaceous circum Arctic volcanism. The horst and graben morphology on Mendeleev Ridge is largely a result of post-emplacement faulting where a number of the major extensional faults remained active until a late Miocene intrusive event.

1. Introduction

The Alpha–Mendeleev submarine ridge complex within the Amerasia Basin of the Arctic Ocean has an elongate shape and extends from the Canadian Arctic continental margin to the Siberian margin (Fig. 1). It forms a 250–400 km wide, rugged structure which rises up to 2 km above the adjacent abyssal plains. A saddle centred at about 83º–84º N, 180º E separates the wider Alpha Ridge north of Canada from the narrower Mendeleev Ridge north of Siberia (Fig. 1). The nature and origin of the ridges are disputed (e.g. Alvey et al., 2008; Forsyth et al., 1986a,b; Lebedeva-Ivanova et al., 2006; Miller et al., 2006; Piskarev, 2004; Weber, 1990) due to lack of geophysical and geological data in an ocean covered by perennial sea ice. Trends in the magnetic and gravity anomaly fields are ambiguous with respect to basement structural trends which could reveal the significance of the ridge complex in a plate tectonic framework (Fig. 2). Crustal refraction experiments estimate 32 km thick crust below the crest of Mendeleev Ridge (Lebedeva-Ivanova et al., 2006) and ~38 km below the Alpha Ridge (Forsyth et al., 1986a). The velocity–depth function for the crust below Mendeleev Ridge is considered to represent modified continental rocks (Lebedeva-Ivanova et al., 2006) while similar velocities below Alpha Ridge are compared to oceanic plateaus (Forsyth et al., 1986a) . In any case, the large amplitude magnetic intensity variations associated with Mendeleev and Alpha ridges as well as seismic basement velocities suggest large volumes of basalts are present (Forsyth et al., 1986a,b; Grantz et al., 2011; Lebedeva-Ivanova et al., 2006; Piskarev, 2004; Vogt et al., 2006; Weber et al., 1986).

This study is based on the first modern multichannel seismic survey (MCS) from the Mendeleev Ridge and the northwestern Alpha Ridge and focus on acoustic basement. Sonobuoy and gravity data collected simultaneously with the MCS profiles provide velocity and

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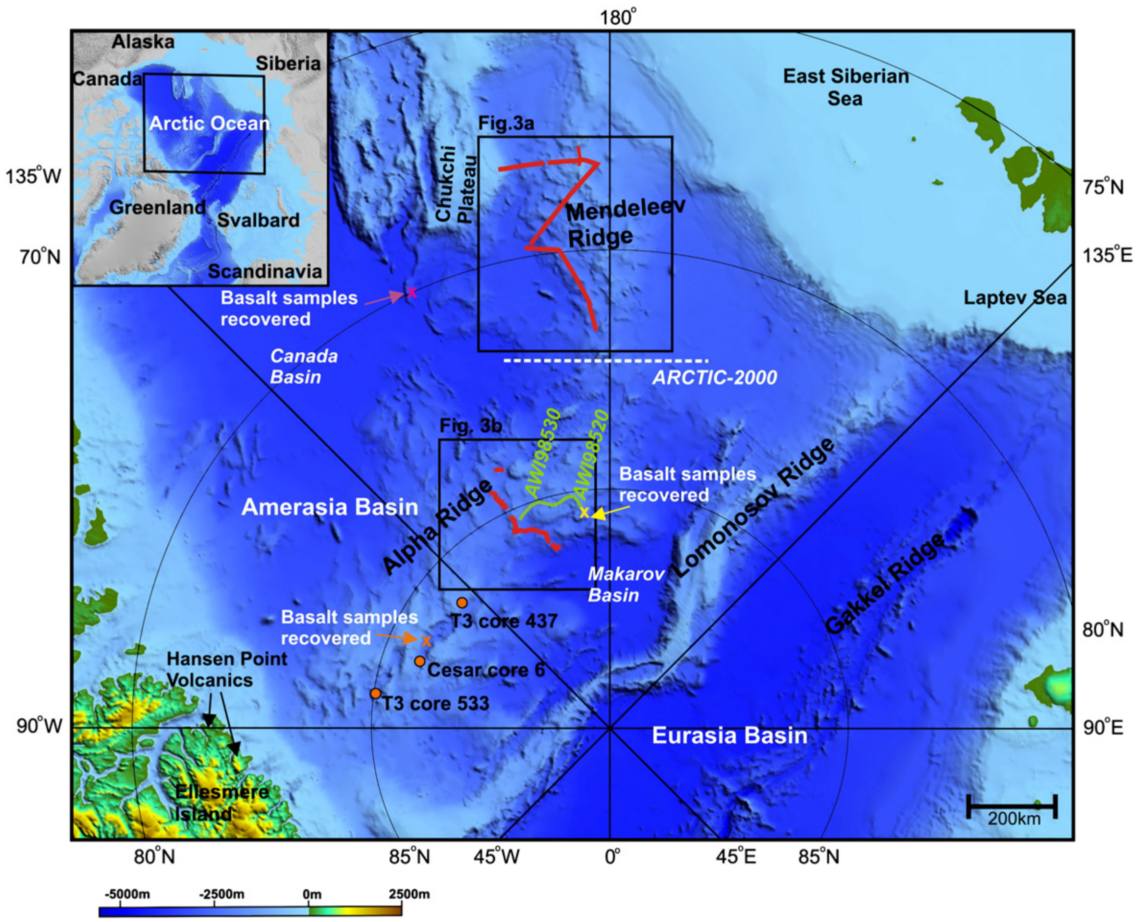

Fig. 1. Overview of the Arctic Ocean basins, ridges and continental margins. Bathymetry and land elevation are from the International Bathymetric Chart of the Arctic Ocean (IBCAO) (Jakobsson et al., 2008). Location of the study areas is marked with black boxes. Red lines mark the seismic reflection profiles from Healy 2005 survey used in this study, white line marks the Arctic 2000 seismic profile (Lebedeva-Ivanova et al., 2006), and the green line seismic profiles of Jokat (2003). Orange dots show the location of shallow cores (Cesar core 6, T3 core 533, and T3 core 437). The cross marks areas where basalt fragments have been recovered (yellow: Mühe and Jokat (1999); Jokat (2003), orange: Van Wagoner and Robinson (1985), and pink: Mukasa et al. (2009a,b)).

density information (Fig. 3). The aim is to unravel basement lithologies and environment at the time of ridge formation by characterizing basement reflections in terms of acoustic facies and compare with acoustic images from other parts of the world's ocean basins where the setting has been calibrated by drilling. We discuss the origin of the Mendeleev and Alpha ridges in relation to the High Arctic Large Igneous Province (HALIP) (Drachev and Saunders, 2006; Maher, 2001; Tarduno, 1996; Tarduno et al., 1998)

2. Geological framework

The Arctic Ocean consists of two large oceanic sub-basins (Fig. 1); 1) the Mesozoic Amerasia Basin and 2) the Cenozoic Eurasia Basin separated by the elongate Lomonosov Ridge. The Amerasia Basin is further sub-divided into the Canada and Makarov basins by the broad Alpha–Mendeleev ridge complex. The ridge complex has an irregular outline, a moderate gradient between its crest and adjacent abyssal plains, and is composed of a complex assemblage of ridges and grabens (IBCAO, Jakobsson et al., 2008) (Fig. 1). The main tectonic trend is NE-SW at the Mendeleev Ridge whereas the Alpha Ridge is disrupted by large NE-SW trending grabens and ridges in the northwestern part, changing to a more N–S direction in the east (Fig. 1).

Sedimentary deposits in the Amerasia Basin locally exceed 10 km (Grantz et al., 1990), whereas sediment thicknesses in the Eurasia Basin is ~2 km (Engen et al., 2009; Glebovsky et al., 2006; Jokat and Micksch, 2004). Observed sediment thicknesses over the central part of the Alpha Ridge are between 0.5 and 1.2 km (Bruvoll et al., 2010; Hall, 1979; Jackson, 1985; Jokat, 2003), and the Mendeleev Ridge is draped by a 0.3–1.8 s thick section of acoustically stratified sediments (Bruvoll et al., 2010; Dove et al., 2010).

Sparker (Hall, 1973, 1979) and single airgun seismic reflection data (Jackson, 1985) have been acquired over the Alpha and Mendeleev ridges, but acoustic basement was not well defined in these data due to limited strength of the seismic sources. Acoustic basement is present in seismic multichannel data along the northwestern slope of the Alpha Ridge where it is interpreted to be of basaltic origin (Jokat, 2003). The most striking feature in the potential field data is the high magnetic field intensity variations (>1000 nT) associated with the Mendeleev and Alpha ridges compared to the adjacent oceanic and continental areas (Coles and Taylor, 1990; Glebovsky et al., 1998; Vogt et al., 1979) (Fig. 2a). Rock samples have been recovered from two sites on the Alpha Ridge where seismic reflection data document basement outcrops; 1) altered basalts dredged from a basement ridge (Van Wagoner and Robinson, 1985), and 2) volcanic fragments recovered by a piston core from a scarp (Jokat, 2003; Mühe and Jokat, 1999).

The Amerasia Basin is believed to have formed during Late Jurassic/Early Cretaceous by rifting and subsequent seafloor spreading of Arctic Alaska and Chukota away from the Canadian craton by a counter clockwise rotation that resulted in a collision with the Siberian margin (Carey, 1958; Grantz et al., 1979, 1998; Lawver et al., 2002; Laxon and McAdoo, 1994; Vogt et al., 1979). The Anuyi suture zone in Siberia and the Brooks Range of Alaska present geological evidence for the collisional event. However, the associated plate boundaries remain controversial (Miller et al., 2006).