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Widespread, multi-source glacial erosion on the Chukchi margin, Arctic Ocean

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ABSTRACT

Multibeam bathymetry and sub-bottom profiler data acquired in 2011 from R/V Marcus Langseth in a broad grid over the Chukchi Sea margin reveal multiple glacigenic features on the top and slopes of the outer Chukchi Shelf/Rise and adjacent Borderland. Glacial lineations record a complex pattern of erosion likely formed by both local glaciation and far-traveled ice shelves/streams sourced from the Laurentide, and possibly East Siberian ice sheets. Multiple till units and stacked debris flows indicate recurrent glacial grounding events. Composite till wedges of several hundred meters thick extend the shelf edge by 10–20 km in places. Distribution of ice-marginal features on the Chukchi Rise suggests stepwise deglacial retreat towards the shelf, backing up the broad bathymetric trough at the eastern side of the Rise. Glacigenic features other than extensive iceberg scouring cannot be identified above 350-m depth, and no glacigenic bedforms are present on the current-swept shallow shelf. Despite the resulting uncertainty with the southern extent of the glaciation, the data suggest a widespread grounded-ice presence on the northern Chukchi Shelf, which makes it an important, previously underestimated component of the Arctic paleo-glacial system.

1. Introduction

Seafloor mapping data from the last two decades indicate the widespread impact of deep-keeled ice from ice sheets/shelves and attendant megabergs on the continental margins and submarine ridges and plateaus in the Arctic Ocean (Polyak et al., 2001, 2007; Kristoffersen et al., 2004; Jakobsson et al., 2005, 2008, 2010; Engels et al., 2008; Dowdeswell et al., 2010). Understanding the extent and timing of these past Arctic ice sheets is important for studies of climate sensitivity, boundary conditions for paleoclimate and ocean modeling, and for insight into the response of existing marine glacial systems (such as WAIS, Greenland margins) to climatic warming and sea-level rise (e.g., Truffer and Fahnestock, 2007; Vaughan and Arthern, 2007). However, relevant data from the Arctic remain fragmentary due to the sparse distribution of bathymetric highs in the central Arctic Ocean and the historical presence of perennial sea ice inhibiting data acquisition.

High-resolution geophysical data (swath bathymetry and shallow seismic reflection) can greatly improve our understanding of past marine ice sheets by revealing remarkably well preserved signatures of sub-glacial processes (e.g., Ó Cofaigh et al., 2008; Dowdeswell et al., 2008). Assimilated evidence may include streamlined bedforms (mega-scale glacial lineations (MSGLs) and drumlins), sub-glacial deposits, transverse ridges, and grounding zone wedges on the shelf and bathymetric highs, as well as associated debris flows and fans on the slope. Finding such features however may be difficult due to pervasive iceberg scouring from the most recent deglaciations, which obliterated the potential record of preceding glacial events. In the Arctic Ocean such scouring has been reported from waters typically shallower than 300–400 m (e.g., Jakobsson et al., 2008); hence, detailed surveys are needed with a focus on the deeper shelf.

Glacigenic seafloor features in the Arctic Ocean, prominent on elevated portions of the central Lomonosov Ridge and the Chukchi Borderland, have been primarily related to ice arriving from the Barents–Kara and Laurentide ice sheets, respectively (e.g., Jakobsson et al., 2008, 2010). Other expanses of the Arctic Ocean perimeter such as broad and shallow Chukchi and East Siberian shelves have not been considered as significant glaciation centers, except for earlier inferences based on geomorphic features of

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unconstrained age and simplified paleoglaciologic modeling (Grosswald, 1989; Hughes and Hughes, 1994). In the initial study of the Chukchi Borderland, Polyak et al. (2001) inferred ice expanding from the Chukchi Shelf, but in later studies glacigenic bedforms in this area have been related to ice impinging only from the Laurentide ice sheet, with possibly local small ice cap(s) on the Chukchi Plateau (Jakobsson et al., 2005, 2010; Polyak et al., 2007). This conclusion has been influenced by evidence from the Chukchi Sea coast and Wrangel Island indicating absence of large ice sheets, at least in the Late Pleistocene (Brigham-Grette et al., 2001; Gualtieri et al., 2005). The interpretation was severely impeded by very scarce data coverage of the northern Chukchi Shelf.

Here we present recently acquired multibeam bathymetry and sub-bottom profiling data (Fig. 1) that reveal evidence of widespread glaciation on the northern part of the Chukchi Shelf (Chukchi Rise) and adjacent Borderland. This evidence, together with that presented by Niessen et al. (2013) from the East Siberian margin, requires reconsidering the Pleistocene glacial history in this part of the Arctic.

2. Study area and methods

The Chukchi Shelf encompasses a broad, predominantly shallow continental margin north of Chukotka and Alaska, with water depths ranging from less than 50 m in the south, to 450–750 m at the shelf break around the northward extension known as the Chukchi Rise (Fig. 1b). The Chukchi Borderland is an adjacent fragment of continental crust extending north into the Canada Basin of the Arctic Ocean (Grantz et al., 1998). The Borderland incorporates the Northwind Ridge and the Chukchi Plateau, with depths on the Plateau as shallow as ~300 m.

Late Cenozoic climatic, sea-level, and tectonic changes radically impacted the Chukchi Shelf, a gateway between the Pacific and Arctic oceans that turned into a Beringian land bridge between America and Eurasia during sea-level lowstands. Growth and decay of ice caps on the Chukchi Shelf and Borderland was clearly a major factor of this history. Knowledge of the yet poorly understood limits, provenance, and timing of glacial events on the Chukchi margin is thus important for reconstructing paleoclimatic and

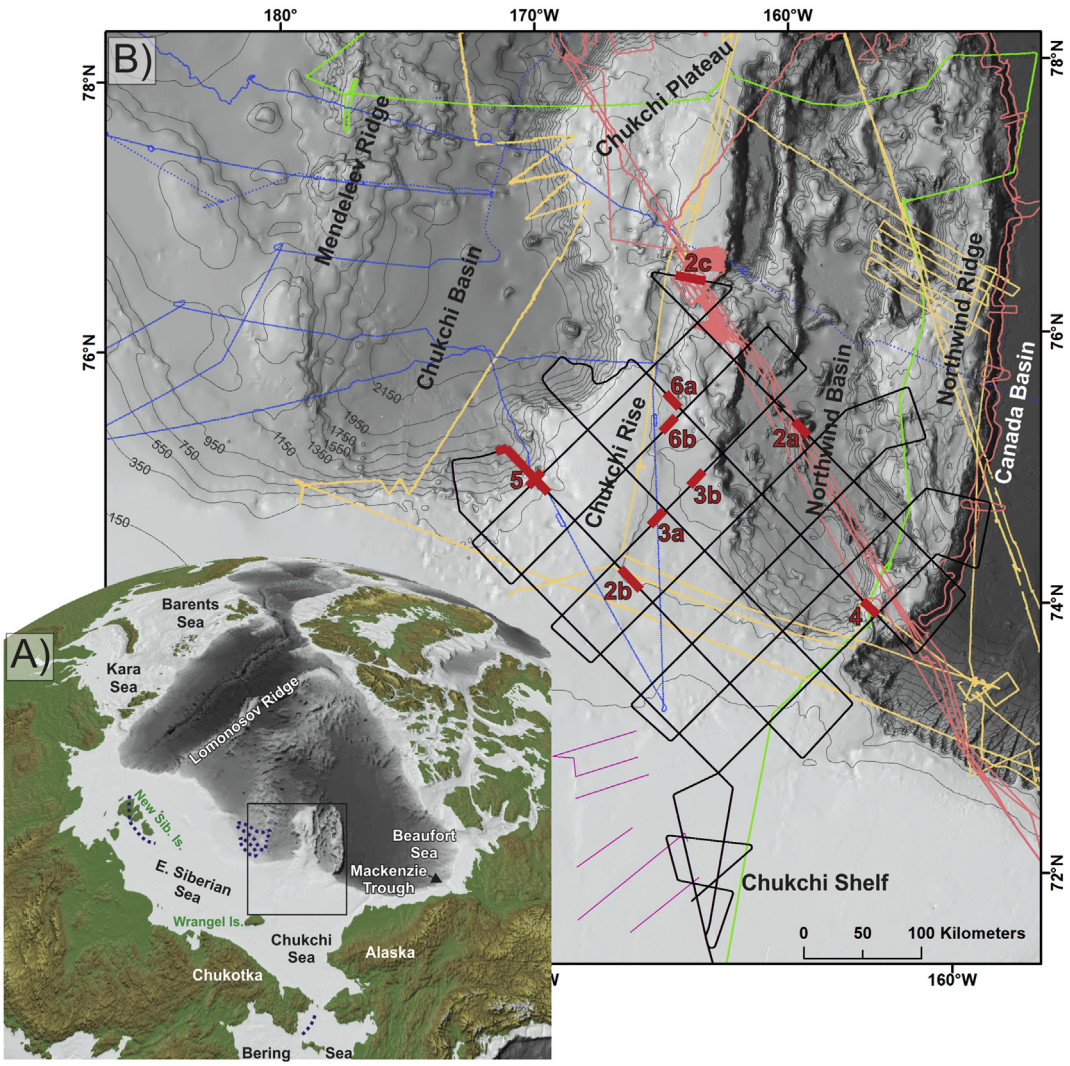

Fig. 1. A) Arctic Ocean bathymetry. Dotted blue lines represent the recently mapped, glacially impacted areas of the outer-East Siberian Shelf (Niessen et al., 2013), the southwestern limit of glaciation on the New Siberian islands (Basilyan et al., 2010), and a buried morainic ridge in the northern Bering Sea (Grim and McManus, 1970). Regional Bathymetry: IBCAO v. 3.0 (Jakobsson et al., 2012). B) Survey location map of the Chukchi Margin showing relevant high-resolution geophysical data which has been used to study the glacial geomorphology of the region. Black lines (this study): RV Langseth 11′; Orange lines: SCICEX-USS Hawkbill – 98′, 99′; Light pink lines: CCOM-USCG Healy – 03′,04′, 07′; Dark pink: USCG Healy – 02′; Green lines: HOTRAX-USCG Healy – 05′; Blue lines: RV Polarstern 08′. Locations for Figs. 2–6 shown in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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