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Late Quaternary ice flow in a West Greenland fjord and cross-shelf trough system: submarine landforms from Rink Isbrae to Uummannaq shelf and slope☆

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ABSTRACT

Sea-floor landforms and acoustic-stratigraphic records allow interpretation of the past form and flow of a westward-draining ice stream of the Greenland Ice Sheet, Rink Isbrae. The Late Pliocene–Pleistocene glacial package is several hundred metres thick and down-laps onto an upper Miocene horizon. Several acoustic facies are mapped from sub-bottom profiler records of the 400 km-long Uummannaq fjord-shelf-slope system. An acoustically stratified facies covers much of the fjord and trough floor, interpreted as glacimarine sediment from rain-out of fine-grained debris in turbid meltwater. Beneath this facies is a semi-transparent deformation-till unit, which includes buried streamlined landforms. Landform distribution in the Uummannaq system is used to reconstruct past ice extent and flow directions. The presence of streamlined landforms (mega-scale glacial lineations, drumlins, crag-and-tails) shows that an ice stream advanced through the fjord system to fill Uummannaq Trough, reaching the shelf edge at the Last Glacial Maximum. Beyond the trough there is a major fan built mainly of glacigenic debris flows. Turbidity-current channels were not observed on Uummannaq Fan, contrasting with well-developed channels on Disko Fan, 300 km to the south. Ice retreat had begun by 14.8 cal. ka ago. Grounding-zone wedges (GZW) in Uummannaq Trough imply that retreat was episodic, punctuated by several still-stands. Ice retreat between GZWs may have been relatively rapid. There is little sedimentary evidence for still-stands in the inner fjords, except for a major moraine ridge marking a Little Ice Age maximum position. On the shallow banks either side of Uummannaq Trough, iceberg ploughing has reworked any morphological evidence of earlier ice-sheet activity.

1. Introduction

Today, the outlet glaciers draining huge interior basins of the Greenland Ice Sheet are among the fastest-flowing on Earth (Rignot and Kanagaratnam, 2006). Their changing dynamics are likely to be a critical control on the rate of sea-level rise during the 21st Century (Rignot and Kanagaratnam, 2006; Pfeffer et al., 2009; Shepherd et al., 2012). Equally, the Greenland Ice Sheet is known to have expanded during the Last Glacial Maximum (LGM), about 20,000 years ago, providing an important increment of global sea-level fall at that time (e.g. Clark and Mix, 2002). Investigations of terrestrial glacial and related deposits have demonstrated clearly that ice expanded through the main fjord systems of Greenland to reach at least the outer coast at the last full-glacial (e.g. Funder and Hansen, 1996; Funder et al., 2011; Roberts et al., 2013). This view is supported by numerical modelling of rebound from past ice-sheet loading which utilises observations of dated raised beaches around the coast and offshore islands of Greenland (e.g. Fleming and Lambeck, 2004). It is less clear, however, both where and how far the ice sheet may have advanced across the wide continental shelf surrounding Greenland, and what the nature of full-glacial and deglacial ice dynamics may have been. Recent marine-geophysical evidence from several parts of East Greenland implies advance to the outer shelf or shelf edge (e.g. Evans et al., 2002, 2009; Ó Cofaigh et al., 2004; Dowdeswell et al., 2010; Winkelmann et al., 2010). Marine evidence from the fjords and shelf of West

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Greenland is relatively limited (e.g. Roksandic, 1979; Kuijpers et al., 2007; Hogan et al., 2011; Schumann et al., 2012); our 2009 cruise to the Disko and Uummannaq systems has yielded much new data on the extent, dynamics and timing of Late Quaternary ice-sheet behaviour (Hogan et al., 2012; Ó Cofaigh et al., 2013a). Ó Cofaigh et al. (2013a) focus, in particular, on radiocarbon-dated sediment cores and the timing of ice-sheet maximum extent and retreat.

In this paper, we present the full details of marine-geophysical observations of sea-floor landforms and sediments from the 250 km-wide continental shelf offshore of Uummannaq Fjord in West Greenland (70°30′ to 71°N), and in the 150 km-long fjord system that links the present ice sheet with the Uummannaq cross-shelf trough beyond (Fig. 1). Thus, our observations extend from within a kilometre of the present margin of Rink Isbrae, a major fast-flowing outlet of the Greenland Ice Sheet (Rignot and Kanagaratnam, 2006), to the shelf edge and continental slope in Baffin Bay; a transect of about 400 km. Swath-bathymetric data revealing sea-floor morphology, and accompanying acoustic-stratigraphic records, allow us to interpret the form and flow of a major outlet glacier of the ice sheet at, and following the Last Glacial Maximum (LGM), including both its past extent across the West Greenland shelf and its flow regime and style of deglaciation (e.g. Dowdeswell et al., 2008a).

2. Background: seismic stratigraphy and glacial history

The Uummannaq Fjord complex consists of eleven individual fjords draining into a single cross-shelf trough (Uummannaq Trough) that is about 50 km wide and extends across the adjacent continental shelf, opening into the deep waters of Baffin Bay (Fig. 1). Bathymetric data show that the deep inland fjords coalesce southeast of Ubekendt Ejland on the inner shelf to form the much larger Uummannaq Trough (Jakobsson et al., 2012) (Fig. 1). This trough is one of several large cross-shelf troughs that dissect the modern West Greenland continental shelf (Batchelor and Dowdeswell, 2013; Ó Cofaigh et al., 2013a); the troughs are probably related to repeated advance and retreat cycles of the Greenland Ice Sheet over the continental shelf during the Quaternary.

The Quaternary glacial history of the Uummannaq system, including that of the LGM, is not particularly well known. Two seismic-reflection profiles from the upper slope and shelf offshore of the Uummannaq fjord system, located in Fig. 1, provide the long-term stratigraphic context for our investigations of Late Quaternary ice flow across the West Greenland continental shelf between 70° and 71°N (Fig. 2). The upper profile is a dip line acquired along the axis of Uummannaq Trough (Fig. 2A), whereas the lower profile is a strike line across the trough in the outer part of the shelf (Fig. 2B). The Late Pliocene–Pleistocene glacial interval is several hundred metres thick and is made up of a number of distinctive units which down-lap onto an upper Miocene horizon. The Miocene–Pliocene sediments offshore dip westwards and reflect uplift and tilting of the West Greenland coast (Fig. 2). Uplift and erosion of adjacent landmasses is also supported by Miocene unconformities and an angular unconformity at the base of the onshore Plio-Pleistocene sediments (Henriksen, 2008). Time-equivalent uplift to the east

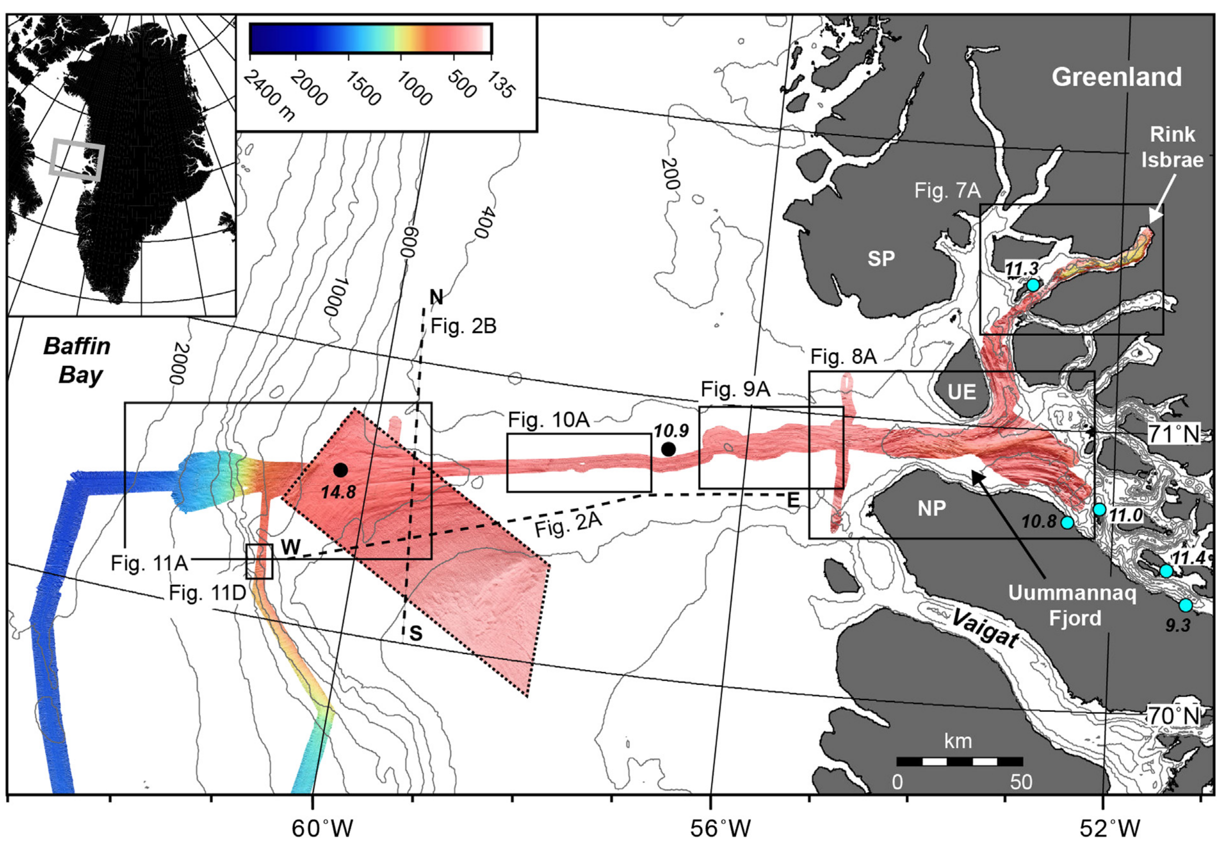

Fig. 1. Map of the central West Greenland continental margin between 69° and 72°N showing the area covered by swath-bathymetric data (colour shaded). Bathymetric contours are at 200 m intervals. Minimum dates for deglaciation for Uummannaq Trough are shown as black circles (marine ^{14}C dates in cal. ka) and blue circles (terrestrial cosmogenic radionuclide exposure dates in ka); dates from Ó Cofaigh et al. (2013a,b), Roberts et al. (2013) and McCarthy (2011). UE is Ubekendt Ejland, NP is Nuussuaq Peninsula, SP is Svartenhuk Peninsula. The locations of subsequent figures are shown. The position of the study area within Baffin Bay and Greenland is inset. The large rectangular block of swath-bathymetric data on the outer shelf (dotted outline) is reproduced courtesy of Cairn Energy. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)