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Deglaciation of a major palaeo-ice stream in Disko Trough, West Greenland

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ABSTRACT

Recent work has confirmed that grounded ice reached the shelf break in central West Greenland during the Last Glacial Maximum (LGM). Here we use a combination of marine sediment-core data, including glacimarine lithofacies and IRD proxy records, and geomorphological and acoustic facies evidence to examine the nature of and controls on the retreat of a major outlet of the western sector of the Greenland Ice Sheet (GrIS) across the shelf. Retreat of this outlet, which contained the ancestral Jakobshavns Isbræ ice stream, from the outer shelf in Disko Trough was rapid and progressed predominantly through iceberg calving, however, minor pauses in retreat (tens of years) occurred on the middle shelf at a trough narrowing forming subtle grounding-zone wedges. By 12.1 cal kyr BP ice had retreated to a basalt escarpment and shallow banks on the inner continental shelf, where it was pinned and stabilised for at least 100 years. During this time the ice margin appears to have formed a calving bay over the trough and melting became an important mechanism of ice-mass loss. Fine-grained sediments (muds) were deposited alternately with IRD-rich sediments (diamictons) forming a characteristic deglacial lithofacies that may be related to seasonal climatic cycles. High influxes of subglacial meltwater, emanating from the nearby ice margins, deposited muddy sediments during the warmer summer months whereas winters were dominated by iceberg calving leading to the deposition of the diamictons. This is the first example of this glacimarine lithofacies from a continental-shelf setting and we suggest that the calving-bay configuration of the ice margin, plus the switching between calving and melting as ablation mechanisms, facilitated its deposition by channelling meltwater and icebergs through the inner trough. The occurrence of a major stillstand on the inner shelf in Disko Trough demonstrates that the ice-dynamical response to local topography was a crucial control on the behaviour of a major outlet in this sector of the GrIS during retreat.

1. Introduction

During the Last Glacial Maximum (LGM) in Greenland (24–16 ka BP; Funder et al., 2011) ice expanded onto the adjacent continental shelves, although how far the ice sheet extended across the shelf is still a matter of debate in many areas. Based on coastal landforms and, less often, evidence from marine geophysical datasets, ice-sheet reconstructions indicate that the LGM Greenland Ice Sheet (GrIS) was drained at its periphery by a number of confluent ice streams and outlet glaciers (e.g. Evans et al., 2002; 2009; Winkelmann et al., 2010; Roberts and Long, 2005; Roberts et al., 2009; 2010; 2013), at least some of which extended to the shelf break in the cross-shelf troughs that dissect the Greenland continental margin (e.g. Dowdeswell et al., 2010; 2014; Ó Cofaigh et al., 2013a). These fast-flowing corridors of ice must have been a critical factor affecting the mass balance of the ice sheet, in particular during deglaciation, because they would have dominated the overall discharge in the same way that ice streams and outlet glaciers do for ice sheets today (cf. Bamber et al., 2000; Bennett, 2003).

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Reconstructing the retreat patterns and chronologies of major marine-terminating outlets since the LGM provides centennial-to millennial-scale records of their behaviour in response to a variety of factors including climatic change and ice-dynamical controls. Improved understanding of these controls is critical in order to increase our ability to predict future responses of the polar ice sheets to ongoing climate change (cf. Velicogna, 2009; Nick et al., 2013). Such palaeo-records also serve as important long-term context for recent and ongoing ice-sheet change, which is occurring today through the thinning and retreat of marine-terminating outlet glaciers and ice streams, in Northwest and Southeast Greenland (Rignot and Kanagaratnam, 2006; Moon et al., 2008; Khan et al., 2010; Velicogna, 2009) and around West Antarctica (Joughin et al., 2003; Rignot et al., 2014).

Generating new records of ice retreat from offshore areas in central West Greenland in particular is important for several reasons. Firstly, a large amount of terrestrial geomorphological and deglacial chronological data is available for the Disko Bugt and Sisimiut regions (Weidick, 1972; Kelly, 1985; Funder, 1989); this is because this area is an important drainage route for the modern GrIS via the Jakobshavns Isbræ ice stream, which drains c. 7% of the ice sheet (Joughin et al., 2004). Despite this, information on how the ice sheet was configured on the wide continental shelf in the past, and how and when it deglaciated, is only just emerging (Ó Cofaigh et al., 2013a; Dowdeswell et al., 2014; Jennings et al., 2013; Rinterknecht et al., 2014; Sheldon et al., this volume). Furthermore, based on onshore and offshore deglacial chronologies around Greenland it is clear that the final retreat of the GrIS after the LGM was asynchronous, and that it was influenced by both topographic effects and local ice-sheet dynamics, and was not driven solely by climatic change (Bennike and Björck, 2002; Funder et al., 2011; Ó Cofaigh et al., 2013a). Identifying and understanding this asynchronicity provides important new information on the behaviour of the GrIS during periods of climatic warming, as well as insights into the dynamic response of ice sheets and their outlets on timescales longer than the observational record.

This paper integrates sediment-core data from 10 marine cores with multibeam-bathymetric data and high-resolution acoustic profiles acquired in Disko Trough during cruise JR175 to central West Greenland in 2009. By generating sedimentary lithofacies, IRD proxy, and acoustic facies datasets we determine the style and relative rates of retreat of a major GrIS outlet from its Younger Dryas maximum on the outer shelf, and we examine the importance of local topography on the stability of the outlet's grounded margin during deglaciation. This study also forms part of a wider research agenda to investigate the nature and behaviour of western GrIS ice streams and outlet glaciers over the last glacial-deglacial cycle (Hogan et al., 2011; 2012; Ó Cofaigh et al., 2013a; b; Dowdeswell et al., 2014) and the palaeoenvironmental conditions influencing ice-sheet decay (Lloyd et al., 2005; 2011; Perner et al., 2011; McCarthy, 2011; Jennings et al., 2013; Sheldon et al., this volume) from marine geophysical and geological datasets. The work fills an important gap in our knowledge of Greenland's glacial history from offshore areas surrounding the landmass (cf. Funder et al., 2011) and compliments the wealth of terrestrial studies available in the literature (see, for example, Weidick, 1972; Kelly, 1985; Funder, 1989; Bennike and Björck, 2002; Funder and Hansen, 1996, and references therein).

1.1. Regional setting

Disko Trough is a large bathymetric trough that crosses the continental shelf offshore central West Greenland at around 68° 24′N (Fig. 1). The broad, generally u-shaped cross-profile of the trough(Fig. 1b) is evidence that it has been eroded by glacial ice; however, the trough appears to be fault-bounded on its northern side (Hofman et al., this volume) and most authors believe that successive Quaternary ice advances have followed an older (Pre-Quaternary) drainage system on the shelf (Henderson, 1975; Funder and Larsen, 1989). The trough extends for 195 km from a basalt escarpment on the inner shelf to the outer shelf where there is a small dog-leg diverting the trough axis to the south-west (Fig. 1). Trough width is typically around 40 km but it is variable along its length, with a notable narrowing on the mid-shelf (57° 15′W), east of which the trough widens and deepens; water depths are generally between 400 and 550 m on the mid-outer shelf. On the inner shelf, the trough is flanked by relatively shallow banks: Disko Banke to the north has typical water depths of 150–250 m, and Store-Hellefiske Banke to the south has water depths of <50 m–200 m. The shallow banks and escarpment on the inner shelf comprise Palaeogene basalts (Chalmers et al., 1999; Larsen and Pulvertaft, 2000), whereas the continental shelf consists of prograded beds of Late Cretaceous-Quaternary sediments (Rolle, 1985; Hofman et al., this volume). East of the basalt escarpment, over which water depths shallow to 300–350 m, is a NNE-SSW trending trough - Egedesminde Dyb - that connects Disko Trough to the Disko Bugt embayment. Taken together, this trough-bay system has a sinuous or “kinked” central axis suggesting that former ice flow of any expanded ice sheet draining through this system may have been strongly affected by topography (cf. Long and Roberts, 2003). At present, water masses on the central West Greenland shelf are dominated by the relatively warm, saline West Greenland Current (WGC), an admixture of the North Atlantic Irminger Current and the East Greenland Current (EGC) (Buch, 1981). The WGC flows northwards over the entire West Greenland shelf, although cold, low-salinity water originating in the EGC, dominates surface waters near the coast (Ribergaard and Buch, 2008).

The traditional view of LGM glaciation in central West Greenland, locally termed the Sisimiut Stade (Kelly, 1985), places the ice-sheet margin at the Fiskebanke moraines which lie on the inner shelf between 10 and 50 km from the coast south of 68°N (Brett and Zarudzki, 1979; Roksandic, 1979). A further set of moraines, the Hellefiske moraines, is found on the outer shelf in southwest Greenland but lies on the middle shelf in central West Greenland (Fig. 1) (Funder and Larsen, 1989). The Hellefiske moraines are usually assigned a Saalian age and the Fiskebanke moraines a Sisimuit age based on correlation of the latter moraines with coastal weathering limits (Kelly, 1985), and extrapolation across the shelf from coastal ice thicknesses (see Funder, 1989; Funder and Hansen, 1996; Funder et al., 2011). However, several studies have since suggested that the LGM margin may instead have extended to the shelf break (e.g. van Tatenhove et al., 1996; Weidick et al., 2004; Roberts et al., 2009), and the compromise view is of a LGM GrIS extending to a limit at the inner shelf moraines with the possibility of ice extending to the shelf break particularly in glacial troughs where increased ice thicknesses and discharge may have promoted ice-stream stability (Long and Roberts, 2002; Roberts et al., 2009). Recent studies from the continental shelf confirm that the GrIS did indeed expand on to the outer shelf in both the Disko and Uummannaq cross-shelf trough systems (Ó Cofaigh et al., 2013a; Dowdeswell et al., 2014). On land, glacially-sculpted landforms suggest that ice in the troughs was fed by confluent ice streams draining into one main outlet on the inner shelf (Roberts and Long, 2005; Roberts et al., 2013); this preferential drawdown of ice into the troughs has been cited as a possible explanation for the widespread evidence of only thin ice at the coastline (Roberts et al., 2013). Ice occupying Disko Trough during the LGM is thought to have been fed by several outlets including the ancestral Jakobshavns Isbræ (ice stream) indicating that the trough