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Ice stream retreat dynamics inferred from an assemblage of landforms in the northern Barents Sea

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ABSTRACT

Palaeo-records of rapid ice stream retreat are important as they can be used to identify the processes involved, and inform investigations of present-day ice masses. Here we document a previously unknown retreat stage in northernmost Bjørnøyrenna (Bear Island Trough) in the northern Barents Sea, representing the youngest stage in a stepwise retreat of the Bjørnøyrenna Ice Stream. We present a descriptive landsystem model for retreat of a marine-based ice stream, which provides new insights into the glacial dynamics of the episodic retreat stages. This model captures the landforms produced during a cycle of 1) fast ice stream flow, 2) intense calving of large icebergs locked in a dense matrix of smaller icebergs, probably from a collapsed ice shelf, 3) ice-stream stagnation, 4) ice-stream floating off, forming an ice shelf as the grounding line retreats, and eventually 5) ice-shelf disintegration. We hypothesize that the presented ice-stream retreat model reflects glacial surging. The formation of corrugated furrows in the study area is consistent with interpretation of similar features in Pine Island Bay, West Antarctica, which are interpreted to have been formed during a massive ice shelf break-up and associated grounding line retreat.

Two directions of past ice flow are indicated from streamlined glacial landforms in the study area. Ice flow from north north-east is indicated for the Last Glacial Maximum and an early phase of deglaciation, whereas a shift to flow from north north-west, from an ice dome located over Hinlopenstretet, Svalbard is indicated for the latest deglaciation phases of the Bjørnøyrenna Ice Stream.

1. Introduction

Investigations of glacial landforms and sedimentary records of palaeo ice sheets can provide important information about former subglacial conditions and glacial processes (Smith and Murray, 2009; Ó Cofaigh and Stokes, 2008). Marine geophysical datasets with increasingly high resolution are providing imagery of well-preserved subglacial landforms, adding new insights about the configuration, dynamics and retreat patterns of former marine-based ice-sheets (Ó Cofaigh and Stokes, 2008; Jakobsson et al., 2012).

Ice extent and deglaciation patterns for the south-western Barents Sea, polar north Atlantic, since the Last Glacial Maximum (LGM, ca 20 cal ka) have been fairly well reconstructed from 2D and 3D seismic (Andreassen et al., 2008), including terrestrial remote sensing data (Winsborrow et al., 2010) and radiocarbon datings in outer Bjørnøyrenna (Rüther et al., 2011). The configuration and dynamics of late Weichselian ice in the northern Barents Sea is, however, highly debated (Landvik et al., 1998; Siegert and Dowdeswell, 2004; Svendsen et al., 2004; Dowdeswell et al., 2010a,b; Hogan et al., 2010; Bjarnadóttir et al., 2013), largely due to the scarcity of datasets in this area. Here we present new multibeam bathymetry, chirp sonar and seismic profiles from the seafloor east of Svalbard that provide unprecedented insights into ice stream retreat dynamics. The data also constrain ice divides during retreat from the LGM, with implications for delivery of ice and sediments from the Barents Sea Ice Sheet to the Norwegian Sea and Arctic Ocean.

2. Background information

The Barents Sea is characterized by relatively shallow banks of 100–200 m depth, separated by troughs opening towards the

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Norwegian Sea in the west and Arctic Ocean in the north (Fig. 1A). Troughs have typical water depths of 300–500 m, with Bjørnøyrenna the most prominent. The Barents Sea has been subjected to repeated glaciations during the late Cenozoic (Elverhøi and Solheim, 1983; Vorren et al., 1998; Andreassen et al., 2007; Knies et al., 2009). During LGM (ca 20 cal ka) this area was covered by the Barents Sea – Svalbard Ice Sheet (Fig. 1B; Svendsen et al., 2004), with the Bjørnøyrenna Ice Stream as the main drainage outlet. A series of grounding zone deposits in Bjørnøyrenna indicate that the ice stream's retreat from the shelf break was punctuated by stillstands or readvances (Solheim et al., 1990; Andreassen et al., 2008; Winsborrow et al., 2010; Bjarnadóttir et al., 2013). This is similar to episodic retreat in the existing generalized model for marine ice stream retreat (Ó Cofaigh et al., 2008; Dowdeswell et al., 2008). As a supplement to their model, we here present a descriptive landsystem model for retreat of a marine-based ice stream, which provides new insights into the glacial dynamics of the episodic retreat stages. This is based on data from a remarkably well preserved, previously unknown retreat stage at the northern onset of Bjørnøyrenna (Fig. 1A, ice margin position in black), representing the youngest of the ice marginal positions in Bjørnøyrenna (Fig. 1A, ice margin positions in orange and white) and comparison with landforms associated with retreat stages farther downstream (Bjarnadóttir et al., 2013).

Chronological control on deglaciation of the Bjørnøyrenna Ice Stream is sparse. Available radiocarbon dates indicate an age of 16.9–17.5 cal ka for the oldest retreat stage, located ca 100 km from the south-western continental shelf break (Fig. 1A, yellow dot; Rüther et al., 2011). A minimum age for the northern Bjørnøyrenna ice-stream retreat stage presented herein is constrained by raised beaches on Kong Karls Land (Fig. 1A, red dot), radiocarbon-dated to 11.1–11.6 cal ka (Salvigsen, 1981).

3. Material and methods

Several different marine datasets were used to map the seafloor geomorphology, to reveal glacial landform assemblages in order to reconstruct palaeo-glacial environments. The Olex database, with the broadest coverage but lowest resolution, was used for regional-scale mapping of the seafloor in the Bjørnøyrenna Trough area. This database, compiled and processed by Olex AS (www.olex.no), is a collection of single- and multi-beam data acquired by the users of this seafloor mapping, navigation and fishery system. The cell size is 5 × 5m, with a vertical resolution of 0.1–1 m, a lateral resolution from 5 to a few tens of metres and position accuracy inferred to be <10 m (Bradwell et al., 2008). However, as these are gridded point data that in areas have been interpolated, the true horizontal resolution may be much more than a few tens of metres. High-resolution swath bathymetry was collected using a Kongsberg

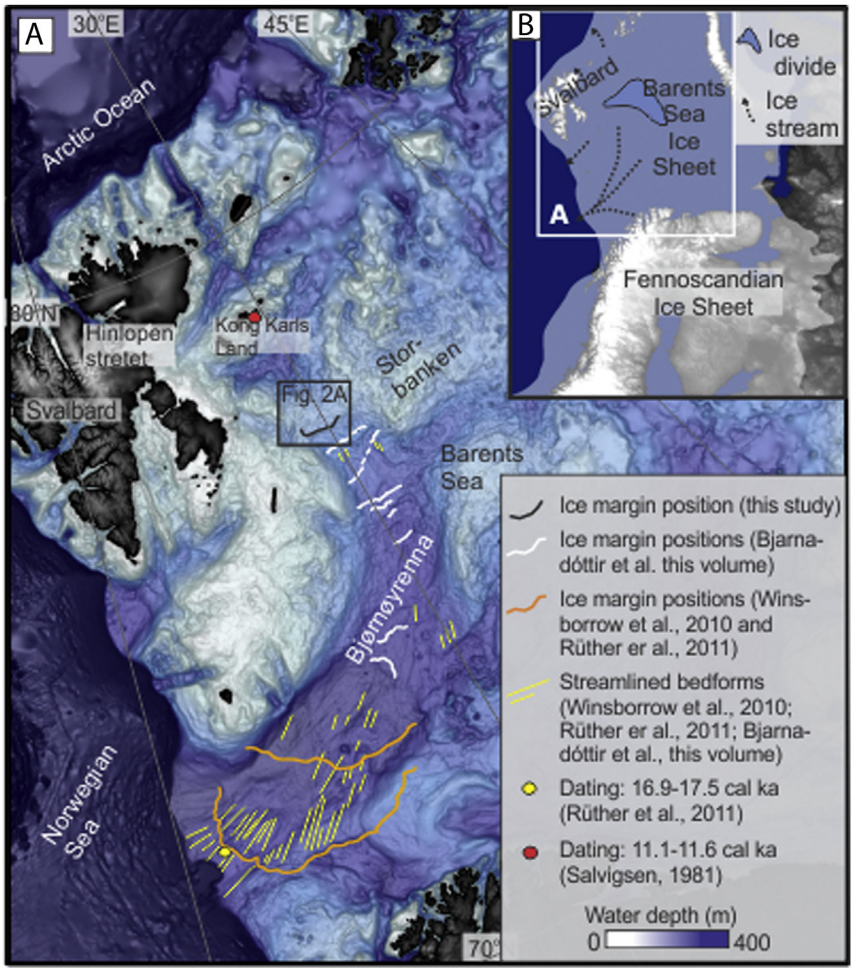

Fig. 1. Study area location maps. (A) Bathymetry of the Barents Sea with inferred retreat stages (orange, white and black lines) and streamlined bedforms (yellow) in Bjørnøyrenna. (B) Maximum extent of the Late Weichselian Barents Sea, Svalbard and Fennoscandian ice sheets (modified from Svendsen et al., 2004). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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