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Submarine landforms and glacimarine sedimentary processes in Lomfjorden, East Spitsbergen

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ABSTRACT

Understanding the role of fjords in modulating the long-term interaction between ice sheets and glaciers with the surrounding ocean requires the investigation of glacigenic landform and sediment archives. In Svalbard, there is a wealth of data from fjords in west Spitsbergen that constrains the glacial history of this sector of the Svalbard-Barents Sea Ice Sheet (SBIS) since the Last Glacial Maximum (LGM), and the nature and timing of subsequent ice retreat. In contrast, however, very little is known about the glacial history of fjords in east Spitsbergen.

This paper combines multibeam swath-bathymetry, sub-bottom profiles, lithological data and radiocarbon dates from Lomfjorden, Svalbard, to provide the first insights into the dynamics of tidewater glaciers and associated glacimarine sedimentary processes in a northeast Spitsbergen fjord. At the LGM, a fast-flowing ice stream drained the SBIS through Lomfjorden, serving as a tributary to a south-north flowing ice stream in Hinlopenstretet. Ice advance is recorded by streamlined bedrock, glacial lineations and drumlins. A radiocarbon date of ~9.7 ka BP from the outer fjord provides a minimum date for retreat of this ice stream, and suggests that Lomfjorden was ice-free earlier than fjords in west Spitsbergen. Ice retreat occurred in a slow and step-wise manner, indicated by the presence of recessional moraines and De Geer moraines. By 4.5 ka BP the local tidewater glaciers had probably retreated inland of their present positions. The limited extent of glacigenic landform assemblages in front of these glaciers implies that any Holocene re-advances were probably restricted.

The principal sedimentary processes during deglaciation were suspension settling from meltwater, causing deposition of weakly stratified, bioturbated mud in ice-distal settings at rates of 0.02–0.08 cm a^{-1}, and gravitational mass flows forming sandy turbidites in ice-proximal areas. Iceberg ploughmarks and ice-rafted debris provide evidence for the presence of large icebergs during deglaciation.

Our data suggest an early and extensive deglaciation in east Spitsbergen fjords and show that previous reconstructions of the extent of the SBIS need to be revised as new data emerges from east Spitsbergen. The data confirm that tidewater glaciers from different regions of Spitsbergen behaved differently since the LGM, and that variations in landform-sediment assemblages occur even within geographically adjacent fjords.

1. Introduction

The landforms and sediments deposited beneath and in front of modern glaciers are an important archive of past glacial dynamics and of glacier response to climatic forcing (e.g. Cottier et al., 2010; Forwick et al., 2010), but glacier beds and submarine forelands are often relatively inaccessible due to the presence of overlying glacier ice or sea ice in fjords. In this context Svalbard is of particular interest, as the ongoing retreat of many fjord-terminating tidewater glaciers has recently exposed well-preserved glacial and glacimarine landform-sediment assemblages (e.g. Plassen et al., 2004; Ottesen and Dowdeswell, 2006; Ottesen et al., 2008; Forwick et al., 2010; Kempf et al., 2013; Flink et al., 2015; Streuff et al., 2015). Furthermore, fjords in Spitsbergen, the largest island of the archipelago, are usually ice-free during summer and thus enable the acquisition of high-resolution seismic data and sediment cores. These data provide valuable insights into the nature of the glacial deposits, and thus, by inference, into the associated glacigenic processes (e.g. Syvitski, 1989; Sexton et al., 1992; Boulton et al., 1996; Cai et al., 1997; Forwick et al., 2010). Fjords along the west coast of Spitsbergen have received increasing attention during the last two decades and resulting studies have documented characteristic landform assemblages in front of many tidewater glaciers. These include

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(overridden) recessional moraines, glacial lineations, eskers, terminal moraines, debris flow lobes, in some cases crevasse-squeeze ridges, and annual push moraines (e.g. Ottesen and Dowdeswell, 2006; Ottesen et al., 2008). Terminal moraines in the fjords commonly mark the extent of glacier advances during the Holocene, which occurred either due to climatic cooling, particularly during the Little Ice Age (LIA), or as a consequence of glacier surges (e.g. Plassen et al., 2004; Ottesen and Dowdeswell, 2006; Ottesen et al., 2008; Forwick and Vorren, 2011; Flink et al., 2015; Streuff et al., 2015; Burton et al., 2016). Conversely, very little is known about the fjords along Spitsbergen's eastern coast, where, to our knowledge, only Hambergbukta in the south has been studied in detail (Noormets et al., 2016a,b). Hence, our limited understanding of oceanography, glaciology, glacigenic landform assemblages and sedimentary processes in east Spitsbergen fjords inhibits the development of accurate ice sheet models, which are crucial to understanding the complex climatic system and the role of its individual components on ice sheet dynamics and deglaciation history in Svalbard and the Barents Sea (Patton et al., 2015; Stokes et al., 2015; Gowan et al., 2016; Kirchner et al., 2016).

This study is the first to address in detail the glacimarine environment, including oceanography and sedimentary processes, as well as landforms in a northeast Spitsbergen fjord, and the first to provide constraints on the timing of ice retreat in this area. We present and analyse multibeam swath-bathymetric and sub-bottom profiler data, sediment cores, CTD data and a suite of radiocarbon dates from Lomfjorden, northeast Spitsbergen, from which we reconstruct the Holocene dynamics of the local tidewater glaciers and evaluate whether glaciers in east Spitsbergen behaved differently to those in the west.

2. Study area and background

2.1. Physiographic setting

Lomfjorden is located in northeastern Spitsbergen between ~79°21'N, 17°40'E and 79°43'N, 18°20'E. It is orientated south to north, opens into Hinlopenstretet, a strait between Spitsbergen and Nordaustlandet, and is located in a relatively protected environment (Fig. 1). Lomfjorden is 35 km long, 2–10 km wide and up to 200 m deep. A major fault zone, the Lomfjorden-Agardhbukta Fault Zone, runs through the centre of the fjord, with Palaeozoic and Mesozoic sediments defining Lomfjorden's eastern coast, and Neoproterozoic basement rocks defining the west (Dallmann et al., 2002). There are three tidewater glaciers along Lomfjorden's shore, Glintbreen and Kantbreen in the east, and Valhallfonna in the northwest (Fig. 1). At the head of Lomfjorden, the Veteranen glacier previously reached tidewater but has now retreated onto land where it formed several moraines (Fig. 1). Other currently terrestrial glaciers are Odinjøkulen and Frøyabreen along the eastern shore and Bivrostfonna, Frostbreen, Skinfaksebreen and Gullfaksebreen along the western shore (Fig. 1). Two small embayments are located along the fjord's western shore, Faksevågen in the south and De Geerbukta in the north, which host Skinfaksebreen and Gullfaksebreen, respectively (Fig. 1). The catchment areas of the tidewater glaciers are mainly underlain by carbonate bedrock (dolomites and limestones) with lesser quartzites and metagreywacke (Dallmann et al., 2002). In terms of oceanographic setting, little is known about Lomfjorden. Investigations from the eastern side of Svalbard document that the waters there are mostly fed by relatively cold and fresh Arctic Water and that the inflow of warm and saline Atlantic water, so common in west Spitsbergen, is absent in the east (cf. e.g. Svendsen et al., 2002; Hald et al., 2004; Ślubowska-Woldengen et al., 2007). Nevertheless, inflow of warmer Atlantic water into Hinlopenstretet was indicated by lithological records from the northern Svalbard margin (e.g. Koç et al., 2002; Ślubowska et al., 2005).

2.2. Glacial background

Contrary to the well-investigated history of the Svalbard-Barents Sea Ice Sheet in west Spitsbergen and north and east of Svalbard (e.g. Mangerud et al., 1992; Elverhøi et al., 1995; Landvik et al., 1998, 1995; Ottesen et al., 2005; Ingólfsson and Landvik, 2013), very little is known about the glaciological evolution of fjords in east Spitsbergen, including Lomfjorden. Only recently have summer sea ice conditions allowed the acquisition of geophysical and lithological data in eastern Svalbard and thus enabled the reconstruction of the glacial history around Kong Karls Land and Edgeøya (Dowdeswell et al., 2010; Hogan et al., 2010). General consensus is that large parts of the Barents Sea and all of Svalbard were glaciated during the LGM, ~20 ka BP, when the large fjord systems on Svalbard channelled fast-flowing ice streams that extended to the continental shelf edge (e.g. Elverhøi et al., 1993; Landvik et al., 1998; Svendsen et al., 2004; Ottesen et al., 2005; Ingólfsson and Landvik, 2013). During this time ice flowed eastwards through Olgastretet and Erik Eriksenstretet, westwards towards Isfjorden, and northwestwards through Hinlopenstretet and Wijdefjorden from a large ice dome located just west of Kong Karls Land at the southern entrance of Hinlopenstretet (Fig. 1a; Landvik et al., 1998; Dowdeswell et al., 2010; Hogan et al., 2010). The timing of the onset of deglaciation in this part of the Barents Sea is still debated, with ages ranging from 15 ka BP to 13.4 ka BP (Jones and Keigwin, 1988; Elverhøi et al., 1995; Kleiber et al., 2000). During deglaciation ice retreated relatively slowly and in a step-wise manner, depositing recessional moraines in Erik Eriksen Strait (Dowdeswell et al., 2010; Hogan et al., 2010). Edgeøya and Barentsøya southeast of Spitsbergen became ice-free around 10.3 ka BP, when a major calving event resulted in the disintegration of the marine-based sector of the SBIS (Landvik et al., 1995).

3. Material and methods

Multibeam swath bathymetry, subbottom profiler (chirp) data, and seven sediment cores provide the basis for this study. Bathymetric data were collected by the Norwegian Hydrographic Survey in July and August 2011, using a Kongsberg Simrad Multibeam EM3002 on the vessel *Hydrograf*. The data were processed in DMagic, gridded to a resolution of 5 m and visualised and interpreted in the Fledermaus v7 Software. Chirp data were acquired by the University Centre in Svalbard on *R/V Helmer Hanssen* in September 2014, using an EdgeTech 3300-HM subbottom profiler operating at a pulse mode of 2–16 kHz bandwidth and 3 ms pulse length. The data were processed using the EdgeTech Software and visualised in IHS The Kingdom Software. Seven gravity cores were taken during the same cruise and provide the basis for the lithology section (Table 1). At two of the core sites and one additional site conductivity-temperature-depth (CTD) information was obtained from the water column (Table 1). Gravity cores were retrieved with a 1900 kg heavy gravity corer with a 6 m long steel barrel. Upon retrieval the cores were cut into sections of up to 110 cm long and run through a loop sensor to measure the magnetic susceptibility of the sediments. The cores were then split into working and archive halves. For the water content 1 cm-thick sediment slabs were taken in 8-cm intervals, weighed, dried at 60°C and weighed again. The samples were subsequently wet-sieved through mesh sizes of 500, 250, 125 and 63 μm to determine the grain size distribution within the cores. Core logs were generated based on the visual description of the sediment surface aboard the ship and at the University Centre in Svalbard. The archive halves (in some cases the working halves) were subsequently x-rayed using a GEOTEK Thermo Kevex PSX10-65W-Varian2520DX with a voltage of ~95 kV and a current of around 150 μA. Correlation between seismo- and lithostratigraphy and calculation of acoustic facies thickness were done by converting sediment core depth from m to ms, and facies thickness from ms to m, assuming an average p-wave velocity of 1500 m s^{-1} (two-way travel time). Conversions are estimates only and may lead to slight inaccuracies concerning core penetration depth and