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Seismic architecture and sedimentology of a major grounding zone system deposited by the Bjørnøyrenna Ice Stream during Late Weichselian deglaciation

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ABSTRACT

A 280 km wide sediment wedge in outer Bjørnøyrenna (Bear Island Trough), south-western Barents Sea, has been investigated using 2D and 3D seismic data, sediment gravity cores, as well as regional swath and large scale bathymetry data. The bathymetry data indicate a division into an up to 35 m high frontal wedge with large depressions, and an upstream part characterized by mega scale glacial lineations (MSGL). From seismic sections increasing erosion is demonstrated for the upstream part, coinciding with the location of MSGL. Whether the latter are depositional features postdating an extensive erosional event or formed by erosion remains inconclusive. Based on the distinct morphology and internal structures, we infer that the system was deposited during a rapid readvance whereby the ice front pushed and bulldozed predominantly soft, diluted proglacial sediments. Analyses in the eastern part of the sediment system reveal the existence of imbricated thrust sheets in the frontal part of the wedge. This is suggested to imply upstream erosion of sedimentary rock and incorporation of thrusted blocks into the moraine, forming a composite ridge locally. We argue that observed large scale depressions are dead-ice features in the marine environment. It is envisioned that intense englacial thrusting may have developed into a decollement as the cold glacier snout got overrun by ice masses from the interior, thereby enabling the inclusion of slabs of ice in the push moraine mass. Radiocarbon dates indicate that the sediment wedge was deposited around 17,090 cal yrs BP (14,530 ^{14}C yrs BP) and that the ice front probably remained stable until 16,580 cal yrs BP (13,835 ^{14}C yrs BP).

1. Introduction

As the most dynamic parts of ice sheets (Bamber et al., 2007), the margins of the Greenland and Antarctic Ice Sheets are of key importance in the light of anticipated climatic warming and sea level rise (Oppenheimer, 1998; Overpeck et al., 2006). The majority of ice, meltwater, and sediment are discharged through ice streams – corridors of fast-flowing ice (Bentley, 1987). Subglacial elongate bedforms are indicative of fast flow, and have received much attention in the literature (e.g. Solheim et al., 1990; Clark, 1993; Canals et al., 2000; Stokes and Clark, 2001). However, they are only one of several geomorphological features which can be employed in the reconstruction of past ice sheet extent and dynamics (Stokes and Clark, 1999). Sediment deposits resulting from focused sediment delivery at the mouth or grounding line of ice streams can also be useful indicators of periods of stand-still and/or readvance (e.g. O'Brien et al., 1999; Anderson et al., 2001; Mosola and Anderson, 2006).

We refer to such deposits as grounding zone systems. This is a non-generic term for sediment deposited at or near the grounding line of a glacier or ice stream terminating subaqueously, which, unlike terms such as morainal bank or grounding zone wedge, does not make specific inferences about depositional mechanisms (Powell and Alley, 1997). Grounding zone systems are thought to have a stabilizing effect against retreat of the grounding line in response to relative sea level rise of at least several metres (Alley et al., 2007; Anandakrishnan et al., 2007). Furthermore, the position of palaeo grounding lines may be used to validate the predictability of grounding line positions with numerical ice sheet models (e.g. Vieli and Payne, 2005; Schoof, 2007; Nick et al., 2010). Geomorphological mapping of grounding zone systems plays an important role in the reconstructions of palaeo-ice sheet configuration and pattern of deglaciation (e.g. in the Barents Sea area: Ottesen et al., 2005, 2008a; Andreassen et al., 2008; Winsborrow et al., 2010).

The Barents Sea experienced repeated glaciations during the late Cenozoic (Elverhøi and Solheim, 1983; Vorren et al., 1988).

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During the most recent Late Weichselian glaciation, grounded ice reached the shelf break twice on the western margin (Laberg and Vorren, 1996): prior to 26.5 cal ka BP (22 ^{14}C ka BP) and between 21.5 and 18.1 cal ka BP (18–15 ^{14}C ka BP; Vorren and Laberg, 1996). It is well established that Bjørnøyrenna was the main drainage area of the Barents Sea Ice Sheet during subsequent glacial maxima (Vorren and Laberg, 1997; Andreassen et al., 2008) and that the last deglaciation of the Barents Sea shelf took place stepwise (Polyak et al., 1995; Landvik et al., 1998; Winsborrow et al., 2010). The outer Bjørnøyrenna sediment wedge (OBSW), explored in detail in this study, was identified by Andreassen et al. (2008) and coincides with the ice marginal position of stage 2 in the Late Weichselian deglaciation reconstruction by Winsborrow et al. (2010).

In this paper, high resolution bathymetric data complements previously published large scale bathymetry (Andreassen et al., 2008; Winsborrow et al., 2010), enabling us, for the first time, to distinguish two geomorphological facies in the frontal and upstream part of the studied sediment wedge. Its internal characteristics are analysed based on hitherto unpublished single channel seismic lines as well as 2D and 3D industry seismic data. Seismic analyses includes mapping of the eastern, buried part of OBSW and observations have important implications for the genesis of the system. Furthermore, studied sediment gravity cores yielded unprecedented deglaciation ages for outermost Bjørnøyrenna. We argue that inferred upstream erosion and the deposition of a frontal arcuate rim encompassing large depressions can be best explained with a rapid readvance scenario. We suggest this ice stream readvance is dominated by ductile failure as upstream ice masses push diluted proglacial sediments and overrun slabs of the frozen glacier snout which are incorporated in the moraine mass. Brittle failure does, however, occur in the eastern area where outcropping Cretaceous bedrock is found upstream. Finally, we give a sediment flux estimate for the grounding line.

2. Study area

The epicontinental Barents Sea covers one of the widest continental shelves in the world (Fig. 1B). It is bounded to the north and west by continental slopes, to the east by Novaja Zemlja, and to the south by the Fennoscandian coast. The most prominent geomorphological feature is the 500 km long, 150–200 km wide and 300–500 m deep Bjørnøyrenna cross-shelf trough. Bjørnøyrenna is flanked by shallow bank areas (<300 m): Spitsbergenbanken and Sentralbanken to the north and east, as well as Tromsøflaket and Nordkappbanken to the south (Fig. 1B). Two north-east to north-west trending troughs just off the coast of Norway (Ingøydjupet and Djuprenna) reach water depths of 450 m. Quaternary sediment cover in the Barents Sea is generally thin (<100 m), but local areas of high accumulation with thicknesses of up to 200–300 m occur, particularly off the Finnmark coast (Elverhøi and Solheim, 1983; Vorren et al., 1989; Sættem et al., 1992). Over most of the Barents continental shelf an erosional boundary, referred to as Upper

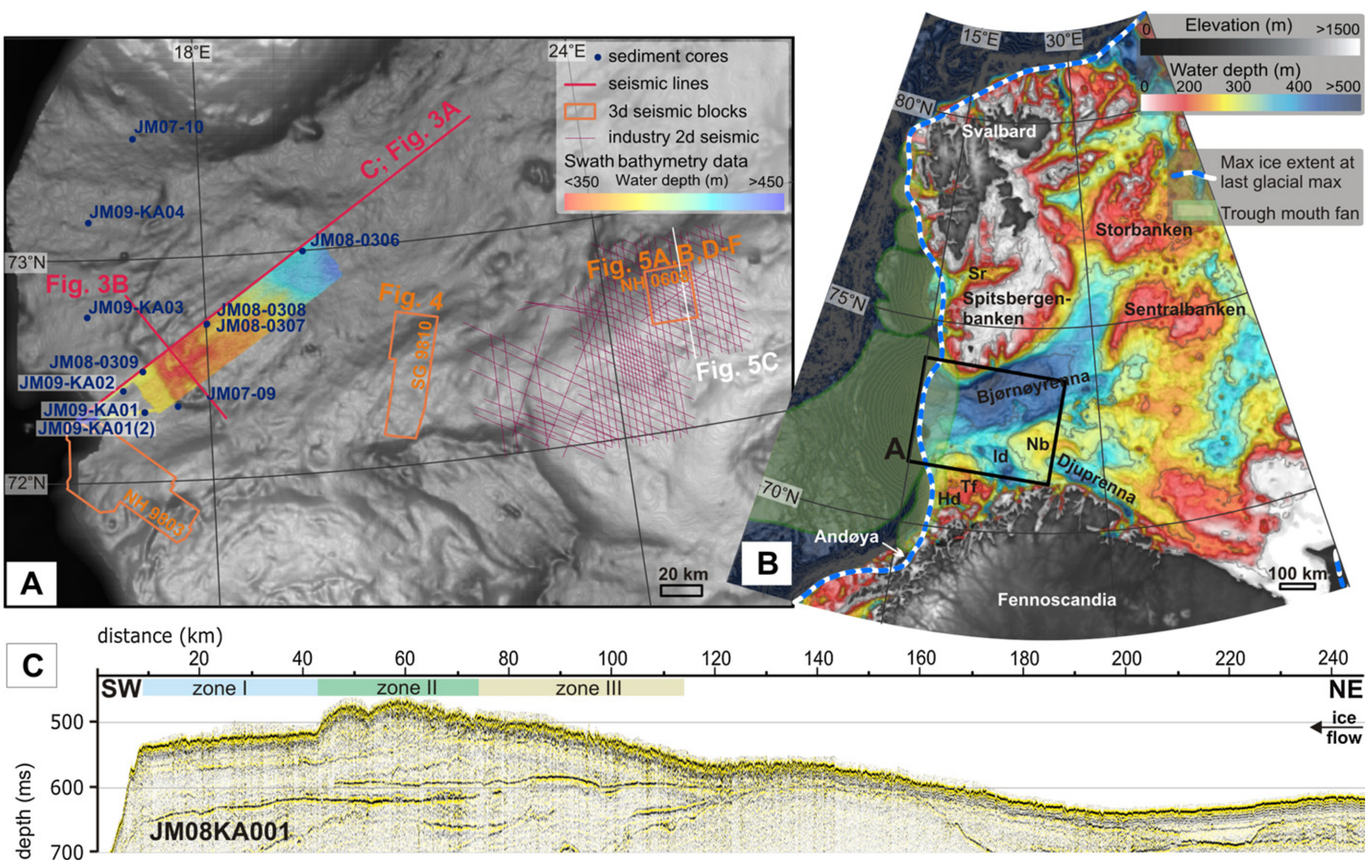

Fig. 1. (A) Bathymetric map showing the studied sediment wedge system together with the locations of sediment gravity cores, seismic data, as well as acquired swath bathymetry data. Large scale bathymetry of the south-western Barents Sea based on the interpretation of seismic seafloor reflections on a relatively dense grid of industry 2D multi-channel seismic data (Andreassen et al., 2008; Winsborrow et al., 2010). (B) Larger overview map and place names for the Barents Sea shelf area, western slope and northern Fennoscandia (bathymetry with 100 m contour interval). Maximum extend of the Late Weichselian Fennoscandian and Barents Sea Ice Sheets is based on Svendsen et al. (2004) and encompasses the maximum ice sheet extent in all areas, which did not necessarily occur time synchronously. Trough mouth fans along the western margin are digitized from Dahlgren et al. (2005) and based on the analyses of Vorren and Laberg (1997). Sr: Storfjordrenna, Nb: Nordkappbanken, Id: Ingøydjupet, Tf: Tromsøflaket, Hd: Håkjerringdjupet. (C) Seismic transect across the studied sediment deposit.