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High-resolution 3D seismic exhibits new insights into the middle-late Pleistocene stratigraphic evolution and sedimentary processes of the Bear Island trough mouth fan

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ABSTRACT

Arctic Ocean trough mouth fans (TMFs) represent a valuable archive of glacial-interglacial sedimentary processes that are especially important when reconstructing pre-Weichselian glaciations that may lack distinct imprints on the shelves. In 2011, we acquired the first high-resolution 3D seismic cube (~3 m vertical and 6 m horizontal resolution) on the continental slope of the SW Barents Sea by use of a P-Cable 3D system, to study in detail the seismic stratigraphy and glacial depositional history of the Bear Island Trough Mouth Fan. This technology provides data with a resolution that, for the first time on the western Barents Sea slope, enables detailed mapping of deposits of different glacial cycles. The dataset provides entire spatially coverage, allowing us to reconcile multiple generations of glacigenic deposits and channel systems. High-resolution 3D seismic data is crucial to describe buried channels, glacial units, as well as low relief landforms such as sediment waves accurately. The 30 km^2 seismic cube is located at the southern flank of the Bear Island TMF at water depths from 592 to 660 m where sandwaves dominate the present seafloor. The data covers the glacially derived stratigraphy in the uppermost ~700 m below the seafloor. We establish a robust stratigraphic framework by interpreting seismic reflectors along 2D tie-in lines to previously well-constrained seismic and well data. We find that our data provide a record of progradation of glacigenic debris flows (GDFs) since MIS 12 (0.5 Ma) to present. Horizon slices reveal a range of gullies and channels at different depths overlying the GDFs. We describe the paleoenvironment and sedimentary processes throughout this time-span (that covers seven glacial cycles) and discuss the impact of the Barents Sea Ice Sheet waxing and waning on erosion, sedimentation, and deposition along the continental slope. Abundant buried gullies were hitherto unknown at the Bear Island TMF, with previous work describing this succession as a debris-flow dominated unit where meltwater-related features are lacking, and interpreting this to represent low average temperatures. By use of the relatively small high-resolution 3D seismic dataset, we provide new evidence for the presence of gullies and channels indicating that periods of ice sheet melting and meltwater runoff existed throughout the middle-late Pleistocene succession. The work offers new insight into the stratigraphic evolution of a continental margin dominated by GDFs and demonstrates the value of high-resolution seismic, such as the P-Cable system, in resolving important details of paleo-slope-environments.

1. Introduction

The Barents Sea is a shallow epicontinental sea with an average water depth of 280 m. Towards the North Atlantic Ocean, the western shelf edge can be up to 400 m deep extending from northern Norway to Svalbard (Fig. 1). Similar to other formerly glaciated passive continental margins, advance and retreat of ice sheets has controlled erosion, transport, and deposition of sediments from the shelf to the continental slope (Dowdeswell et al., 2016). Accordingly, shallow banks and deep troughs of glacial origin sculpture the Barents Sea continental shelf (Jakobsson et al., 2014).

The Bear Island Trough is the largest erosional feature, covering an area of about 100,000 km^2 with a trough length of > 100 km (Fig. 1) (Laberg and Vorren, 1995). Over the last 5 Ma, glaciations have been responsible for ~100 km westward advances of the Barents Sea margin (Vorren et al., 1989). Up to 2 km of predominantly glacially eroded sediments have been deposited on the slope, building the Bear Island Trough Mouth Fan (Bear Island TMF) during the Pleistocene glaciations

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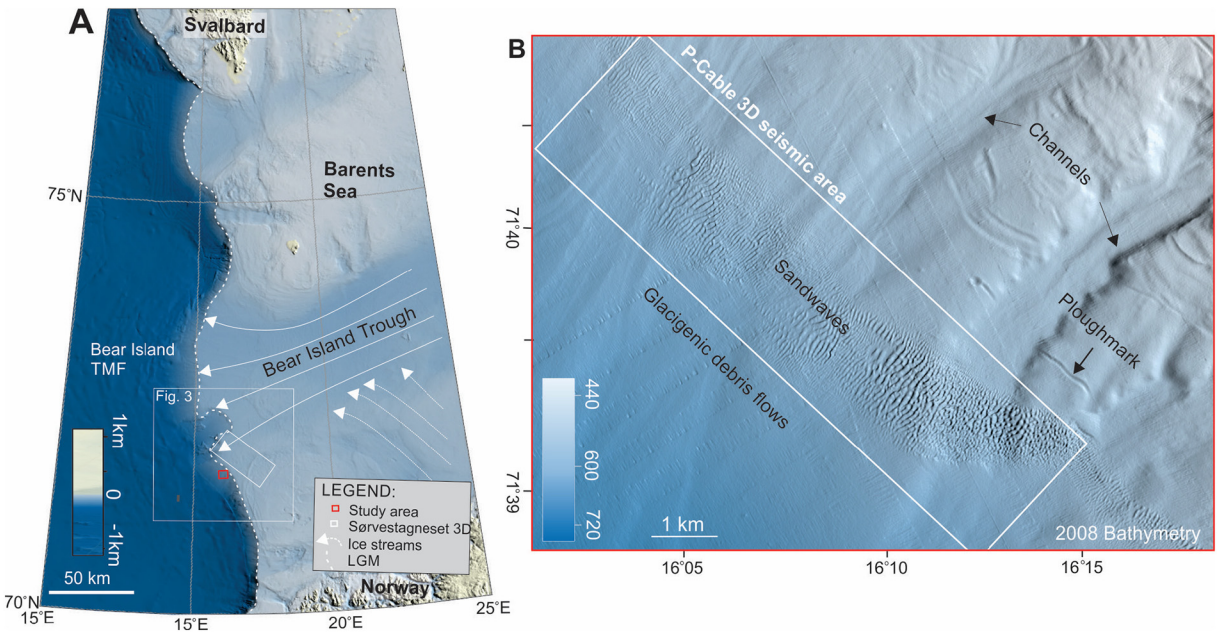

Fig. 1. Study Area. (A) Shaded relief map of the South Western Barents Sea with Last Glacial Maximum (LGM) and main ice stream directions indicated. The red square highlights the study area. The white square marks the location of the previously investigated Sørvestagneset 3D cube used for seismic correlation. (B) Bathymetry in the study area (red square in A) showing sandwaves, slope-channels, and glacigenic debris flows. Outline of the 3D seismic survey area is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

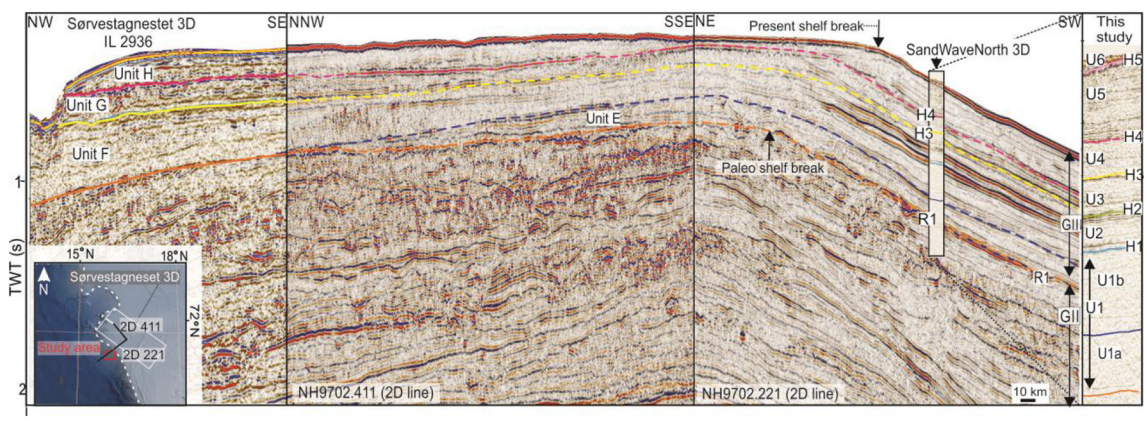

Fig. 2. Seismic correlation line from Sørvestagneset 3D (outer shelf) via 2D seismic lines (NH9702 survey) to study area (SandWaveNorth 3D) using Larsen et al. (2003) as a reference. The seismic boundaries between Larsen et al. (2003) units E to H can be traced from the Sørvestagneset 3D cube via 2D seismic lines. In this study, we identify six units named U1–U6, and six horizons; R1, and H1 to H5 within the regional unit GIII. Unit E and partly unit F appear to correlate with our unit U1–U3, unit G with our unit U4, and unit H with units U5 and U6. The panel in the lower left corner indicates the location of the correlation line.

(Vorren et al., 1989) (Figs. 1 and 2).

A variety of erosional landforms including chutes, channels, gullies, debris flows and ploughmarks, as well as intermittent contourite deposits reflect the slope-depositional environment of the TMF (Vorren et al., 1989; Laberg et al., 2012; Buhl-Mortensen et al., 2015; King et al., 2014; Bøe et al., 2015; Bellec et al., 2016). Similar to other TMF, the Bear Island TMF typically comprises glaciogenic, muddy debris flows enclosed between thin (< 10 m) units of well-sorted hemipelagic/glaciomarine mud (Vorren et al., 1989; Sættem et al., 1992). The debris flows are suggested to have been deposited when the ice sheet was close to or at the shelf edge (Vorren et al., 1989, Sættem et al., 1992). Seismic data commonly show characteristics of debris flow units as discontinuous, undulating to mounded reflectors alternating with semi-transparent intervals (Vorren et al., 1989; Sættem et al., 1992; Vorren and Laberg, 1997; Laberg and Vorren, 1996; Sættem et al., 1994).

When the shelf was deglaciated during interglacial periods, sediment supply from the shelf to the Barents Sea continental slope decreased significantly, and the depositional environment was mainly controlled by downslope transport driven by submarine slides or along-slope transport by ocean currents (Bryn et al., 2005). At present, the northward flowing North Atlantic Current has velocities of 0.2 to ~1 m/s along the upper slope (~500 to 800 m water depth) between ~71°N and 72°N (Poulain et al., 1996; Bøe et al., 2015; Skarðhamar et al., 2015). This current, together with internal waves, cause today's formation and migration of characteristic sandwaves on the seafloor (Kenyon, 1986; King et al., 2014).

In an extensive seismo-stratigraphic study following regional reflectors, Faleide et al. (1996) divided the Plio-Pleistocene succession (2.7 Ma to present) along the western Barents Sea slope into three regional seismo-stratigraphic units: GI, GII and GIII (Fig. 2). Combined with paleomagnetic, biostratigraphic and Sr-isotope analysis of borehole data from ODP site 986, Butt et al. (2000) revised a sparse existing chronology and suggested three phases of glaciation during this period. The third and last glacial phase started ~0.5 million years ago (Ma),

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