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A submarine fan in the Amundsen Basin, Arctic Ocean

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Abstract

Seismic reflection data from drifting ice stations and an icebreaker survey document the presence of a submarine fan along the east flank of the Lomonosov Ridge in the Amundsen Basin, Arctic Ocean. The fan extends from a source area at the North Greenland and Canadian Arctic continental margin to the North Pole. The fan probably developed in response to the combined effect of increased glacial sediment input during the Plio–Pleistocene and topographically confined transport of glacial debris in the deep sea passage between Lincoln Sea margin and the southern end of the Lomonosov Ridge.

Keywords: Arctic Ocean; Amundsen Basin; bottom features; submarine fan; glaci-marine sedimentation

1. Introduction

The deep basin between the North Pole and the Gakkel Ridge was outlined from spot soundings made by Russian scientists and appeared on a bathymetric chart of the Arctic Ocean published in 1954 (Burkhanov, 1957; Weber, 1983). Definition of distinct geomorphologic provinces became possible when continous echo soundings first were obtained over the interior of the polar basin by the nuclear submarines *Nautilus* and *Skate* in 1958 (Dietz and Shumway, 1961). They observed an abyssal plain between Lomonosov Ridge and Gakkel Ridge, but also noted a modern abyssal seafloor slope of 0.5 m/km from the North Pole towards the Gakkel Ridge and expressed their curiosity about the origin of such a slope in an abyssal setting. The first continuous multi-channel seismic reflection profile across the Amundsen Basin obtained by *Polarstern* in 1991 along a similar track enabled Jokat et al. (1995) to present a seismic stratigraphic cross section of the Amundsen Basin. These observations combined with the seismic reflection results from the Russian ice station ‘North Pole 28’ (NP-28) and the US ice station ‘Arctic Research Laboratory Ice Station–II’ (Arlis-II) in 1965 (Ostenso and Wold, 1977) reveal

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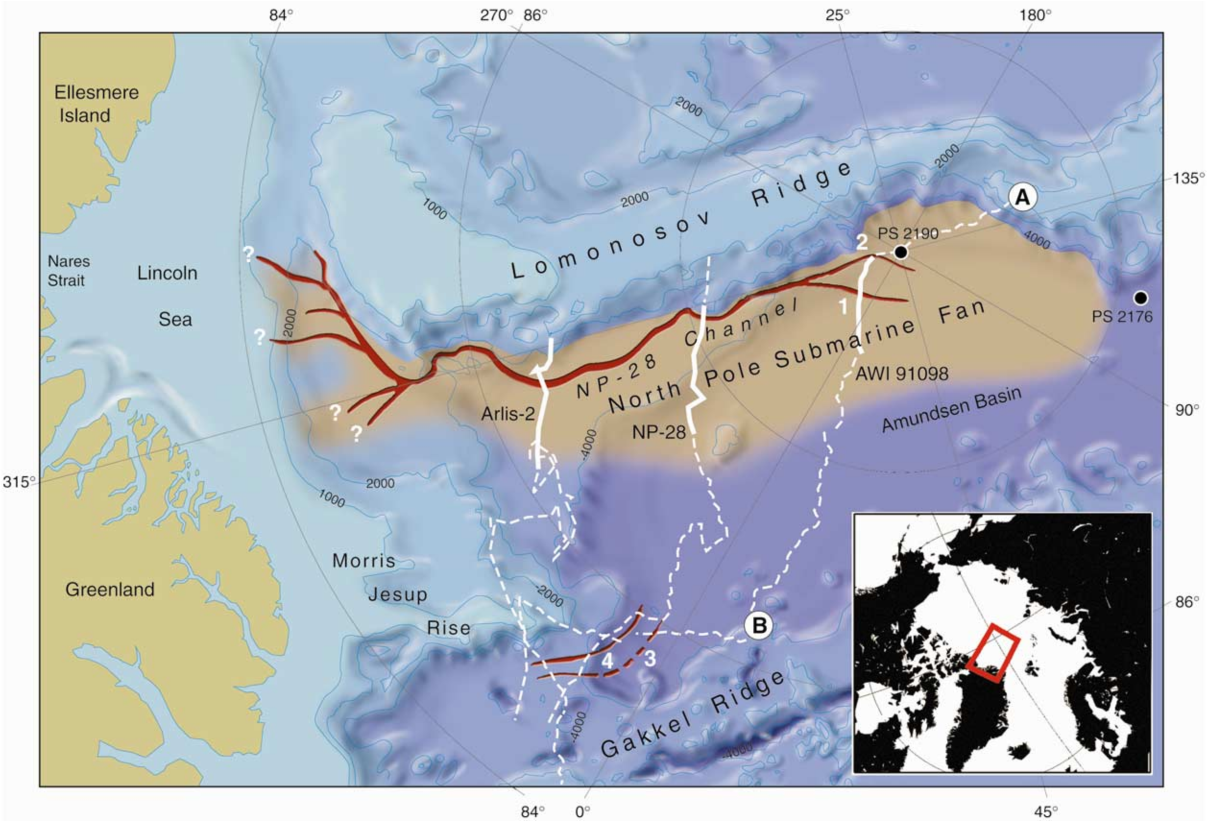

Fig. 1. Map of the Amundsen Basin with the locations of seismic profiles and observed crossings of submarine channels. Major sediment pathways indicated by a bold dark red line and the outline of the North Pole Submarine Fan by dark brown colour. Tributary paths from the Canadian–Greenland continental slope inferred from the position of bathymetric downslope depressions. Bathymetry from International Bathymetric Map of the Arctic Ocean (Jakobsson et al., 2001).

the existence of a submarine fan extending from a source area on the Lincoln Sea margin (Greenland–Canadian shelf) to the North Pole (Fig. 1). We propose to name this fan the North Pole Submarine Fan, and the main channel, the NP-28 Channel in recognition of the contribution of the Russian ice stations to exploration of the deep polar basin.

2. A submarine fan in the Amundsen Basin

We identify channel-levee complexes in all the three seismic reflection lines that presently exist of this area (Fig. 2): in the published line drawing of the data obtained by a sparker source and a single hydrophone during the drift of ice station Arlis-II (Ostenso and Wold, 1977), in the processed records from ice station NP-28 obtained with detonating caps and a geophone array on the ice, and in the multi-channel seismic records from *Polarstern* using a 24-l airgun array and a 300-m-long, 12-channel streamer (Fuetterer, 1992).

In the NP-28 crossing (Figs. 1 and 2), a single large channel, ca. 20 km wide and 120 m deep, is present at the foot of the Lomonosov Ridge. The elevated levee construction merges with the abyssal plain more than 100 km away from the channel. At least four relict channel positions are seen within the upper 500 milliseconds of levee stratigraphy and indicate that the channel has migrated westward towards the foot of Lomonosov Ridge. Along a parallel drift track ca. 150 km closer to Greenland (Fig. 1), ice station Arlis-II traversed

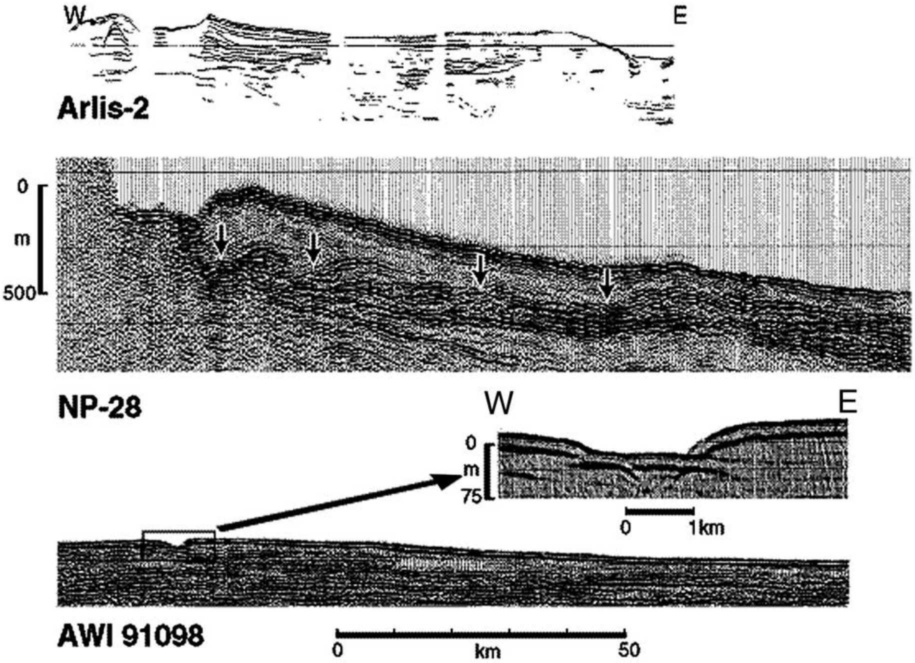

Fig. 2. Seismic reflection lines crossing the NP-28 Channel along the foot of the Lomonosov Ridge. Profile locations in Fig. 1 (bold white lines). Arrows on seismic section NP-28 indicate past locations of the channel axis.

and looped over seafloor morphology interpreted as a ca. 13-km-wide and more than 200-m-deep channel (Fig. 2). All channel crossings show a higher levee on the east side. The depth contours between 84°30′N and 89°N in the improved International Bathymetric Chart of the Arctic Ocean (Jakobsson et al., 2001) clearly express the path of the channel and its associated levee

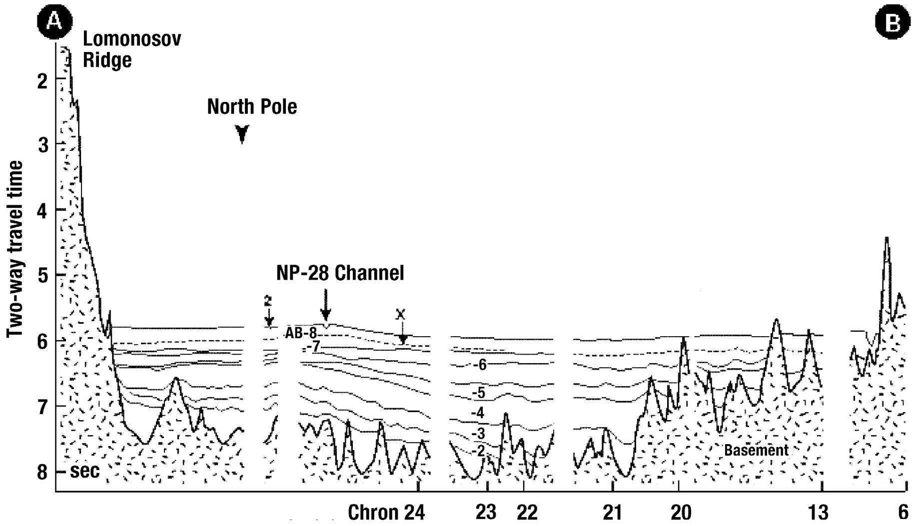

Fig. 3. Line drawing of a multichannel seismic section across Amundsen Basin. Sequence nomenclature from Jokat et al. (1995). Location of transect A-B shown in Fig. 1.

towards the margin of North Greenland–Canada. The main channel is likely to be fed by tributary channels on the continental slope of North Greenland inferred from bathymetric depressions (Fig. 1).

In the Amundsen Basin, sequences AB-7 and AB-8 (Jokat et al., 1995) exhibit upward convex internal horizons with maximum thickness near the North Pole (Fig. 3). Two submarine channels are present at the seafloor culmination. The position of the channels at the highest elevation of the abyssal plain and internal units of the sequence, particularly the lowermost one tapering off towards either side, suggests that sequences AB-7 and AB-8 represent the distal lobe of a submarine fan. The two channels at the seafloor are very different in size and cross section; the largest ones have a channel floor width of maximally 1.8 km, and a cross section with one levee higher (35 m) than the other. A width-to-depth ratio less than 40 is compatible with a location on the lower part of a fan (Clark and Pickering, 1996). The smaller channel is less than 0.4 km wide and the difference in levee height is 5 m (Fig. 4). Small bow-tie reflections within sequence AB-8 are interpreted as relict channels (for example channel X in Figs. 3 and 4). The low resolution in the data makes it difficult to assess the degree of vertical and lateral channel stacking in each case, apart from noting that the channels have occupied different positions during fan growth. Most likely the channels are to be classified as aggradational and a low gradient would also imply likely high sinuosity of the channel path (Clark et al., 1992). The low relief of the smaller modern channel near the base of the Lomonosov Ridge may reflect its relative youthfulness.

A 12.9-m-long sediment core (PS2190; Fuetterer, 1992) was recovered about 6.5 km north of the smaller channel (Figs. 1 and 3). This location is actually 3.3 km from the geographical North Pole. The upper 2 m of the core consist of clay with alternating layers of dark brown and olive colour interupted by two sandy layers between 50 cm and 90 cm depth. Below 2 m subbottom is a stack of silty sand layers, fining upwards. Most of the turbidite layers are 10 cm thick (maximally 20 cm), and separated by mottled intervals of similar thickness. The sediment stratigraphy shows that the coring site has received deposition of hemipelagic clays repeatedly interrupted by overbank flow from turbidity current events in the smaller channel. The sediments about 245 km farther into the abyssal plain along longitude 110°E (core PS2176; Fig. 1) consist of a 2-m-thick upper clay interval overlying alternating intervals of dark grey silt grading into clay, often laminated at the base. Clay intervals in this 14-m-long core are more dominant compared to the core (PS2190) from the fan lobe. The site of core PS2176 must be distal to any fan lobes extending from either the Greenland or Siberian continental margin (Fig. 1). The most important sediment transport in this part of the basin probably occurs in a near bottom nepheloid layer (Hunkins et al., 1969) and as the vertical flux from fallout of biogenic matter and ice transported lithic material (Clark and Hanson, 1983; Reimnitz et al., 1994).

3. Fan development and timing

Sequences AB-7 and AB-8 represent the emergence of a submarine fan lobe extending from the polar margin to the central part of the Amundsen Basin and mark a change in mode and flux of sediment input to the abyssal plain. The crest of the distal depositional lobe appears to have maintained its position through time (Fig. 3) while at least a section of the NP-28 Channel between 88°N and 89°N has migrated more than 50 km towards the foot of the Lomonosov Ridge (Fig. 2). We suggest that the key elements in development of the North Pole Submarine Fan are increased sediment input to the margin of Canada and North Greenland and topographic focussing of gravity driven flows. The east–west trending saddle between the southern end of the Lomonosov Ridge and the Lincoln Sea margin collects sediment input from a ca. 200-km-long section of the margin into the NP-28 Channel (Fig. 1). Apparent bathymetric indentations in the North Greenland continental margin west and east of Morris Jesup Rise may represent tributary pathways to the main trunk channel (Fig. 1). Turbidity currents in the NP-28 Channel subject to the

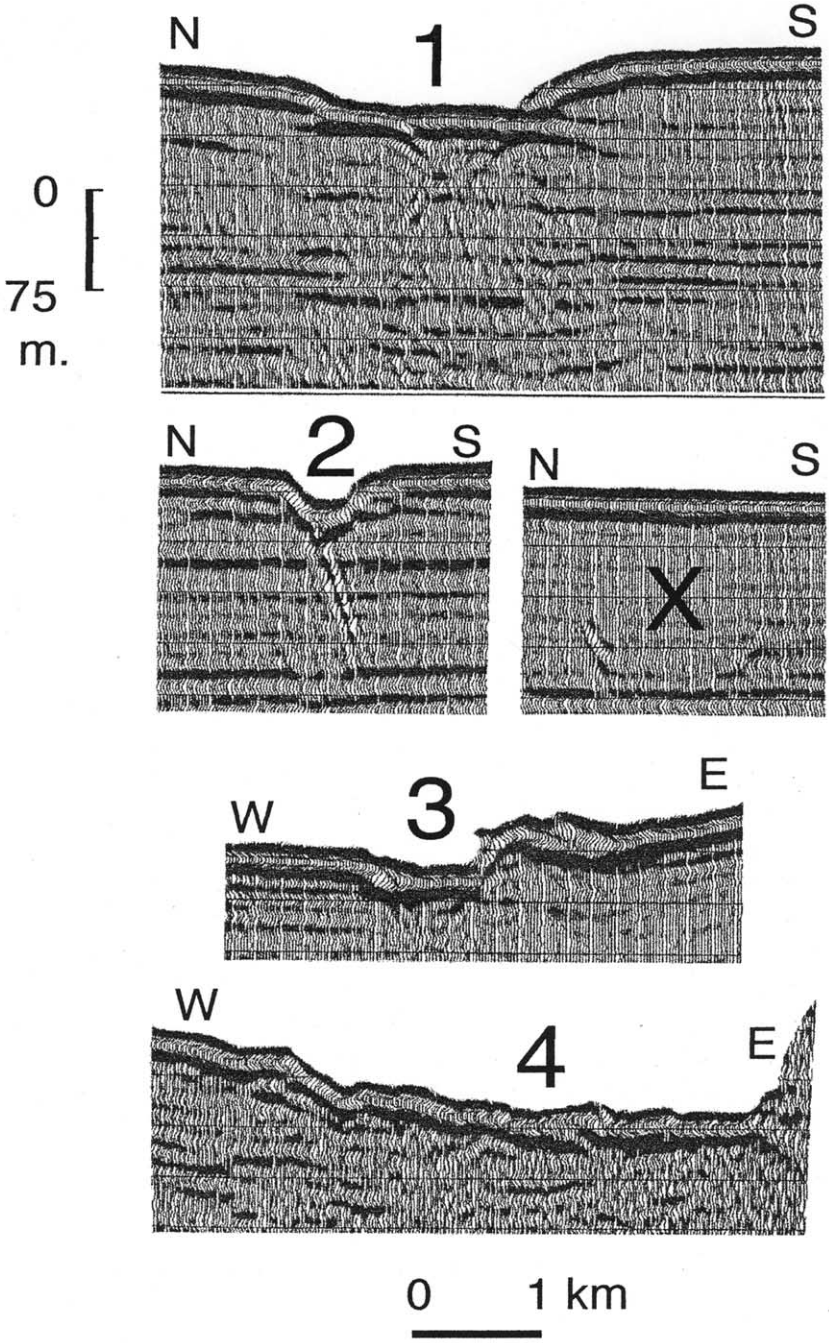

Fig. 4. Crossings of sediment pathways to the Amundsen Basin east of Morris Jesup Rise. Channel location numbers in Figs. 1 and 3.

Coriolis force would create the observed levee configuration by over-bank flow (Fig. 2).

We have sparse stratigraphic information for the sediments in the Amundsen Basin. The Holocene sedimentation rate at the location of core PS 2190 on the fan lobe (Fig. 1) is 1.4 cm/kyr or less (Gard, 1993). Schneider et al. (1996) attempted to date the same 12.9-m-long core by the palaeomagnetic method and concluded in spite of variable grouping of the inclinations that the sediments were probably deposited within the Brunhes normal geomagnetic polarity interval (i.e. sedimentation rate >1.7 cm/kyr).

The maximum sediment input to the Amundsen Basin must be related to glacial maxima or deglaciation events. Modeling suggest that the Arctic Ocean received about 15% of the total Northern Hemisphere iceberg flux during the Last Glacial Maximum, predominantly from North Canada (Bigg and Wadley, 2001). Field results demonstrate that the Nares Strait was completely filled with ice and transport from Greenland dominated the northern end of the strait where erratics were brought to more than 800 m above sea level, 5–10 km inland on the Ellesmere coast (England, 1999). Ice streams from this area must have entered the Lincoln Sea and brought sediments to the shelf edge where a depocentre is suggested by seaward convex bathymetric contours on the upper continental slope. Downslope gravity driven flows may have transported the material farther to the deep Amundsen Basin.

The earliest direct evidence of glaciation on the polar margin in the Southwest Canadian Arctic Archipelago on Banks Island postdates 1.77 Ma (Barendregt et al., 1998). Subsequently, at least two and possibly five full continental glaciations are recorded within the Matuyama reversed geomagnetic polarity interval and three glaciations within the Bruhnes normal zone (<0.78 Ma). Results of ODP drilling west of Svalbard date the first glacial advance to the shelf edge at ca. 1.6 Ma, associated with onset of frequent diamictic debris flow events (Forsberg et al., 1999). However, input of ice rafted detritus north of Svalbard increased dramatically at about 2.5 Ma (Thiede et al., 1995) and large glacial fans formed along the margin west of Svalbard (Faleide et al., 1996) and also along the East Greenland continental margin (Solheim et al., 1998). Intervals of debris flows at Site 987 off Scoresby Sound, East-Central Greenland, suggest that glaciers first extended to the shelf edge between 5 and 4.6 Ma, and later between 2.5–1.6 Ma (Channell et al., 1999; Solheim et al., 1998). Average sedimentation rates at these ice proximal sites (Site 986, water depth 2050 m; Site 987, water depth 1680 m) remained greater than 20 cm/kyr during the period 2.5–1 Ma (Channell et al., 1999). Although influx of glacial sediments to the Amundsen Basin from North Greenland and the Canadian Arctic may have started in the latest Miocene, we infer that deposition of most of sequences AB-7 and AB-8 is related to input from increased erosion during the full scale Northern Hemisphere glaciation after 2.5 Ma.

4. Discussion and conclusions

The Amundsen Basin is a closed elongated basin, and the principal terrestrial sediment input from the time of submergence of the Lomonosov Ridge must be from both ends of the basin; the margin north of the New Siberian Islands and the Greenland/Canadian Arctic continental margin. On the European polar margin, the evidence for a large Plio–Pleistocene sediment influx to the Nansen Basin from the Svalbard continental margin is fairly well established (Rasmussen and Fjeldskaar, 1996; Vågnes, 1996; Thiede et al., 1995). A number of glacial through-mouth fans formed on the circum-arctic continental margin, but it is presently not known if any developed into submarine fans with a channel/levee system which extended far into the adjacent abyssal plain. Three seismic transects demonstrate that the gentle continental slope north of Greenland adjacent to the Lomonosov Ridge is constructed by levee deposits from the main channel of a submarine fan which extends beyond the North Pole in the Amundsen Basin. We suggest that the existence of the North Pole Fan is partly due to the presence of the elevated southern end of Lomonosov Ridge which formed a sediment trap to downslope glacial debris flows for a distance of

200 km along the Lincoln Sea margin. Large amounts of glacial debris accumulated in the deepest passage for further gravity driven transport into the abyssal realm through the NP-28 Channel. During pre-glacial times, the continental margins would have shed siliclastic debris into the Amundsen Basin during sea-level lowstands and the total sediment input would have been substantially lower.

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This paper is dedicated to the memory of Mikhail Y. Sorokin who was suddenly taken away by a tragic event. We thank the crews of ice stations Arlis-II and NP-28, and the officers and crew of icebreakers *Polarstern* and *Oden* for their effort in collecting the data. The Russian ice station NP-28 operated from 25 February 1987 until 17 January 1989 and drifted ca. 2800 km during that period.

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