Divergent flow of the West Antarctic Ice Sheet on the outer continental shelf of the Amundsen Sea during the late Quaternary

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Summary Understanding the past glacial history of regions undergoing potential rapid deglaciation is essential in order to estimate the possible threat of sea level rise. Recently acquired data have given new images of mega-scale glacial lineations on the sea floor of the Amundsen Sea, which provide us a new understanding of the direction of glacial flow on the continental shelf of the Amundsen Sea region. Two adjacent areas of seafloor on the outer shelf of the Amundsen Sea embayment exhibit remarkably different styles of glacial lineations, and allow the interpretation of a divergent glacial trough for the Pine Island Glacier during the last glacial maximum, whereas ice flow from the Abbot Ice Shelf probably converged with that from the Pine Island Glacier to the north of a grounding zone wedge.

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Introduction

There has been much work in recent years on the dynamics and stability of the West Antarctic Ice Sheet (WAIS), in order to gain an increased understanding of the potential threat of sea level rise through rapid deglaciation. While few consider an imminent collapse of the WAIS likely, some of the highest rates of thinning affect the glaciers which currently flow into the Amundsen Sea (Thomas et al., 2004). This highlights a need for increased understanding of the ice sheet dynamics since the Last Glacial Maximum (LGM).

Despite the fact that approximately one-third of the outflow from the WAIS drains into the Amundsen Sea, relatively little is known about the history of the major glacial systems in this area. Two recent collaborative research cruises led by the British Antarctic Survey and Alfred Wegener Institute for Polar Research (Graham et al., 2007) to the Amundsen Sea acquired new marine geology and geophysics data to address the need for information on the late Quaternary history of the WAIS. This data has provided new information about the late Quaternary glacial flow directions in previously unsurveyed areas, such as the part of the outer continental shelf to the west of Thurston Island, in the eastern Amundsen Sea (Figure 1).

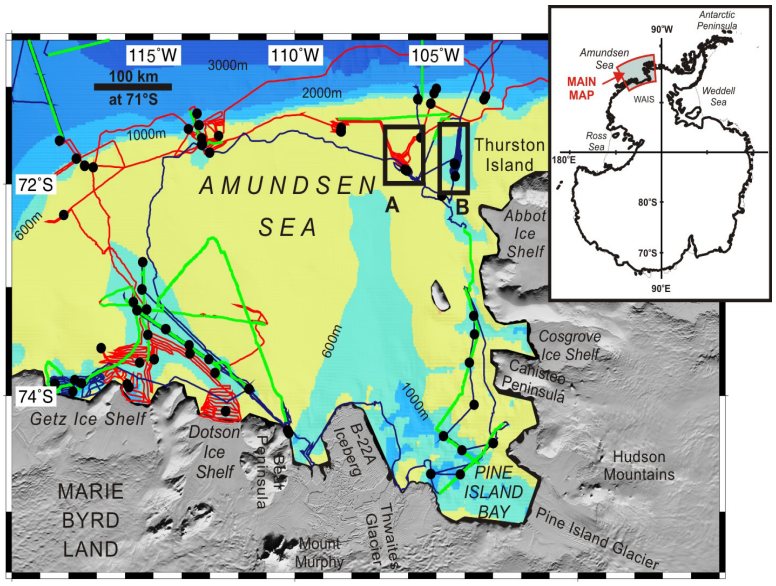

Figure 1. Location map of the Amundsen Sea, indicating its relative position to the Antarctic continent, and the locations of swath tracks and seismic lines from the JR141 (red, swath; green, seismic) and ANT-XXIII/4 (blue, swath and green, seismic) cruises. Black dots indicate sediment core locations. Regional bathymetry compiled from echo-sounding data by F. Nitsche (Nitsche et al., 2006). The location for Figure 2 is indicated (Box A). Box B indicates an area of north-south lineations.

Past work

Despite the major influence of drainage from the WAIS into the Amundsen Sea, relatively little work has been done in this region in the past. Few vessels visit the area because of its remoteness and persistent sea ice cover. Multibeam echo-sounding data collected on the only research cruise to the region in the five years before the 2006 expeditions revealed streamlined subglacial bedforms within a bathymetric trough on the continental shelf at 114°W, suggesting that the WAIS grounding line advanced to the shelf edge in the western Amundsen Sea during the last glaciation (Evans et al., 2006), and that the general motion of the glacial ice stream from the Pine Island Glacier (PIG) was to the northwest.

A cruise undertaken on the RV *Nathaniel B. Palmer* during 1999 established that grounded ice developed similar bedforms and

extended at least as far as the continental shelf during the LGM, flowing along a cross-shelf trough between 107°W and 108°W, and extending at least as far north as 72°S (Lowe and Anderson, 2002). The relationship between the troughs remains unclear (Larter et al., 2007).

New data and preliminary results

In early 2006, successive research cruises on the RRS *James Clark Ross* (Cruise JR141, January-February) and the R/V *Polarstern* (expedition ANTXXIII/4, February-April) visited the Amundsen Sea embayment. The two cruises were able to double the existing area surveyed by multibeam swath bathymetry. While ice conditions were difficult in the Pine Island Bay (PIB) region, areas of the PIB outer shelf were accessible, which allowed mapping of the outer PIB trough to be undertaken.

The main direction of motion for ice movement from the Pine Island Glacier (PIG) along the eastern edge of the trough is generally to the north-west. The recently acquired data over the eastern Amundsen Sea outer continental shelf mostly show randomly oriented trails produced by iceberg keels ploughing through shelf sediments. However, bedforms of likely subglacial origin, exhibiting a strong preferential alignment in a north-east direction, were observed in two previously unmapped locations on the eastern part of the outer shelf (Figure 2), and are interpreted to mark the eastern boundary of the spreading drainage trough for the PIG. These bedforms have remained relatively unscoured by iceberg keels presumably because of their relative depth.

Just to the east of Figure 2 (Figure 1), bedforms exhibit a strong preferential alignment in a more north-south direction. The change in direction could reflect a different timing of the formation of the lineations and therefore a temporal change in glacial flow. If the bedforms developed contemporaneously, they could represent a spatial difference in flow regime which would have implications for models of the flow of PIG.

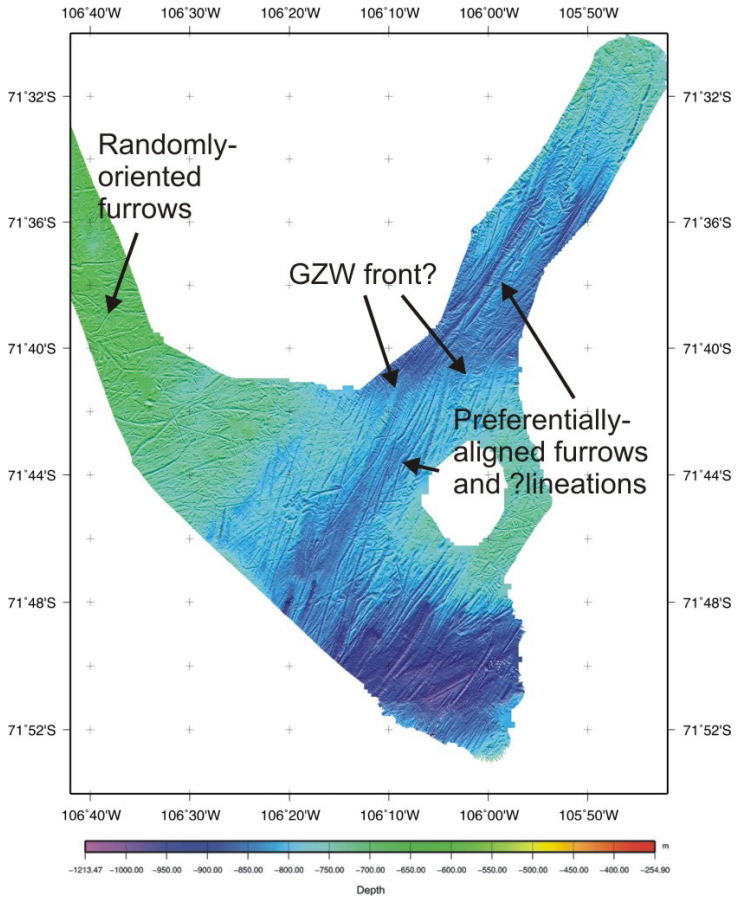

Figure 2. Swath multi-beam bathymetry data from the outer shelf of the Amundsen Sea (location in Figure 1), indicating random grooves created by iceberg ploughs and glacial lineations which have a preferential flow direction to the north-east.

Discussion

Mega-scale glacial lineations have been observed in glacial regions around the world (i.e., Clark et al., 2003), and are a reliable indicator of former glacial ice stream activity. Observations of the general trend of ice flow in the trough draining the PIG during the LGM indicate flow to the north-west in the central Amundsen Sea and to the north-east in the eastern Amundsen Sea. This suggests that the ice stream diverged with increasing distance from the present-day shoreline during the LGM. Breaks in the lineations are interpreted as grounding lines, and may indicate the site of a grounding zone wedge (GZW). The size of the trough mouth (approximately 400 km wide) implies a large capacity for ice drainage during the LGM. The additional indicator of north-south glacial flow to the east of the trough margin (Box B, Figure 1) suggests that a different glacial flow regime prevailed outside the immediate trough. The controlling influence on glacial flow in Box B is not yet clear. It is probable that these bedforms record the dynamics of ice flow from Thurston Island and the Abbot Ice Shelf, and that the two ice streams may have converged to the north of this location, providing the two events were contemporaneous. Questions yet to be answered include: Were the two events contemporaneous? Was there any interaction between the two ice streams? Were the deglaciations of the two ice streams linked or independent? Further investigation of sediment cores and seismic data taken in the region (Figure 1) may shed light on these questions.

Summary

The acquisition of new data sets in the Amundsen Sea region have provided a wealth of information with which to improve the understanding of the glacial flow regimes during the LGM. Multibeam swath bathymetry data acquired on the outer continental shelf of the eastern Amundsen Sea has indicated that the late Quaternary PIB glacial trough identified in previous work is divergent with increasing distance from the present-day shoreline, and that the glacial flow regime to the east of the trough was probably controlled by ice flowing from Thurston Island and the Abbot Ice Shelf. Understanding this motion better enables us to comprehend the glacial dynamics of the PIG during the LGM.

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