Late Quaternary ice sheet dynamics and deglaciation history of the West Antarctic Ice Sheet in the Amundsen Sea Embayment: Preliminary results from recent research cruises

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Summary The threat, in terms of sea level rise, posed by the potential rapid deglaciation of West Antarctica means there is an urgent need to know more about the speed and style of marine ice sheet retreat. Quaternary deglacial events recorded in marine sediments provide an opportunity to understand the future of the modern day ice sheet. In this context, we examine the glacial history of a particularly poorly understood sector of the West Antarctic continental shelf – the Amundsen Sea Embayment –using new data from two recent research cruises. This extended abstract describes how marine geological and geophysical data are being used alongside terrestrial dating methods to understand the full extents, dynamics and retreat pattern of the West Antarctic Ice Sheet in the Amundsen Sea region during the last glacial cycle. These data hold significance for understanding and accurately modelling the stability and climate sensitivity of the West Antarctic Ice Sheet.

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Introduction

An important motivation for current studies of the dynamics and stability of the West Antarctic Ice Sheet (WAIS) is the threat of sea level rise through rapid deglaciation ("collapse"). The potential contribution to eustacy from a complete collapse of the WAIS is estimated at 5-6 metres (Vaughan, 2007); enough to devastate large areas of agricultural land (e.g., Southeast Asia), and to increase the risk of major flooding in key low-lying cities (e.g., London and New York).

Whilst many consider an imminent total collapse of the WAIS unlikely, the Amundsen Sea has been identified as a probable area for initiation of collapse in the past (e.g., Hughes 1981). Modern rates of thinning and grounding line retreat are most pronounced in the glaciers which currently flow into the Amundsen Sea (Thomas et al., 2004). Melting of ice shelves via warmer Circumpolar Deep Water intrusion onto the continental shelf may be responsible for these changes (Jacobs et al., 1996; Shepherd et al., 2004).

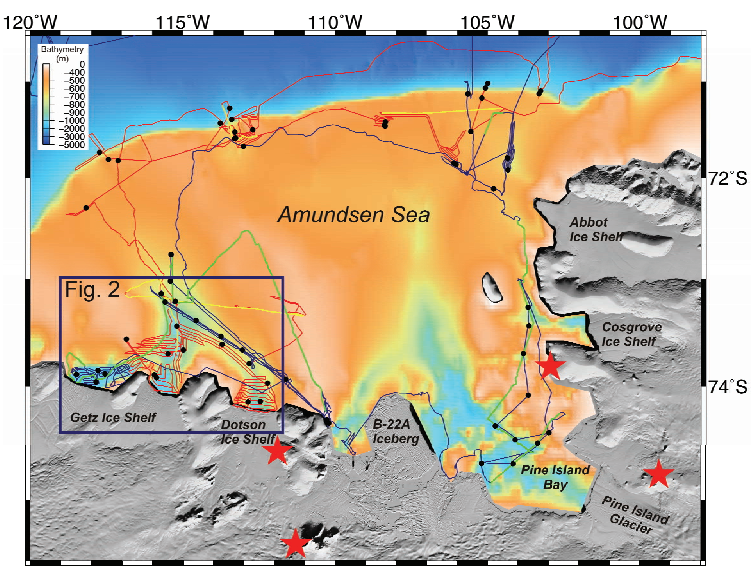

Figure 1. Location map showing swath tracks and seismic lines from the JR141 (Red, swath; Yellow, seismic) and ANT-XXIII/4 (Blue, swath; Green, seismic) cruises. Cores (dots) and sites sampled for exposure dating (stars) also shown. Regional bathymetry compiled from echo-sounding data by F. Nitsche (Nitsche et al., 2006).

Interest in the stability of the modern WAIS has highlighted a need to determine how large the last ice sheet was at its maximum extent (e.g. Anderson et al., 2002). Similar studies have also considered whether the timing and magnitude of earlier Quaternary deglaciations could give insight into how the contemporary WAIS might respond to changes in the future. Marine and terrestrial records of Quaternary change are thus key to understanding the stability of both the past and present-day ice sheets. Their improved understanding is required for testing and refining Antarctic ice sheet models, which can be used to better predict future climate sensitivity and sea level contributions from the ice sheet.

With these requisites in mind, two collaborative research cruises to the Amundsen Sea Embayment (ASE) in early 2006 collected extensive new data on the late Quaternary history of the WAIS (Larter et al., 2007). Preliminary results from the British Antarctic Survey-led JR141 (aboard the RRS *James Clark Ross*; JCR) and Alfred Wegener Institute-led

ANT-XXIII/4 (RV *Polarstern*) cruises are presented in this extended abstract.

Background and New Data

Due to its remoteness and persistent sea-ice cover the ASE has received relatively little past scientific attention, despite the sector draining up to a third of the modern WAIS. As a result, knowledge of its glacial geology and history is sparse. Recent offshore geophysical data obtained from an area to the north of Pine Island Bay (Fig. 1) have revealed sedimentary and landform evidence in support of an ice sheet extending to the shelf edge during the last glacial maximum (LGM; Evans et al., 2006). However, ice flow dynamics over sizable areas of the shelf remain unresolved. Subsequent ice recession is also poorly known, with patterns of retreat constrained by only a handful of radiometric dates, some of which possess large uncertainties (Lowe and Anderson, 2002). Given the paucity of information, the joint aims of the new research cruises were to determine:

- *the maximum extent of the WAIS during the last glacial period in the ASE.*
- *the extent of fast ice flow in the area.*
- *controls on the shelf geomorphology, including possible locations of ice stream onset zones.*
- *an age-constrained retreat history for the LGM ice sheet.*

To address these aims, multibeam swath bathymetry, sub-bottom acoustic profiles, single and multi-channel seismic data, vibrocores, gravity cores and boxcores were collected from the ASE. Ice-free sites onshore were also visited to collect samples from bedrock and erratics for surface exposure age dating, which will provide the first constraints on elevation changes in this sector of the WAIS during the various stages of deglaciation.

Preliminary results

Swath bathymetry

Extensive multibeam swath bathymetric data were collected from ice-free polynyas in the Pine Island Bay area and in front of the Dotson-Getz Ice Shelves during the 2006 cruises, more than doubling the seafloor coverage in the ASE to ~20,000 km^2 (Fig. 2). The spatial coverage and quality of the resulting dataset is unrivalled for the West Antarctic shelf. Numerous glacial geomorphological features have been identified on the new bathymetric dataset, including tunnel valleys, subglacial meltwater channels, p-forms and bedrock grooves, drumlins and attenuated drumlinoid ridges, mega-scale glacial lineations, and iceberg ploughmarks.

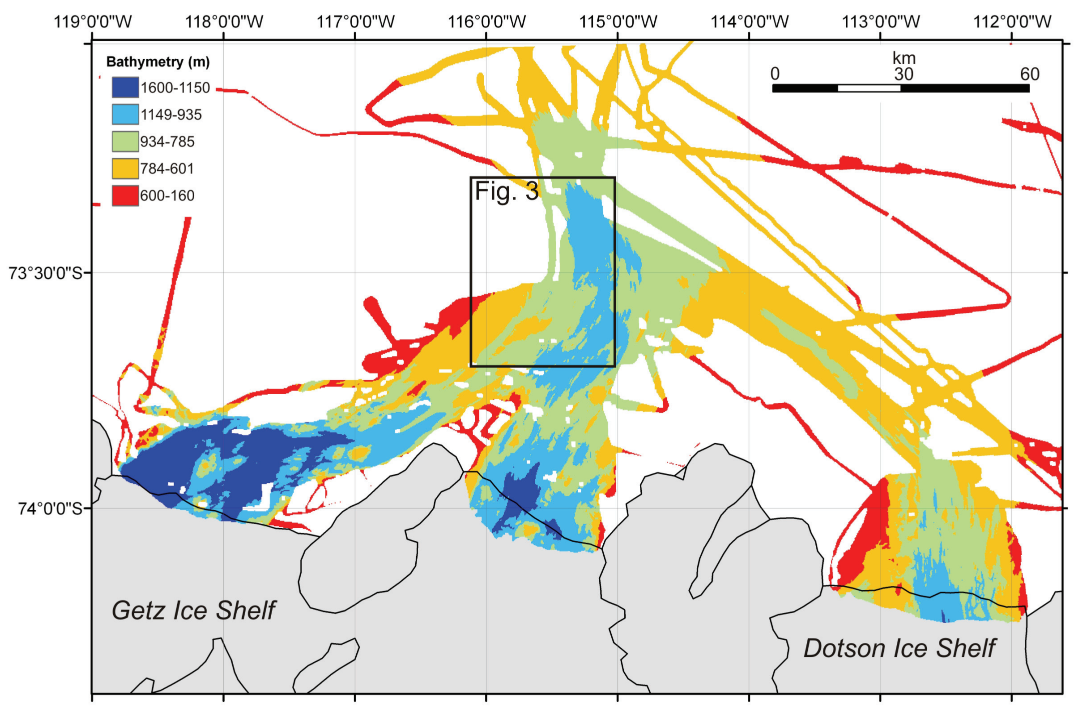

Figure 2. Simplified block-contour bathymetric map derived from new multibeam swath bathymetry data for the ASE. Figure illustrates coverage of the new dataset in addition to the main ice stream trough, tributaries and deep inner-shelf basins. Collated from new *JCR*/*Polarstern* data and existing *Nathaniel B. Palmer* swath tracks. Grid cell size 200 m.

Abrupt spatial variations in seafloor morphology occur on the inner shelf. Of the features that cover the seabed, streamlined subglacial bedforms are most prominent, indicating that fast-flow formed a major component of paleo-ice sheets that covered the region. A major cross-shelf trough in which these features formed shoals seaward and extends to the outer shelf. It is identified on the new data as a probable paleo-drainage pathway (fast-flowing ice stream) of the former ice sheet (Figs. 1 & 2). The data collected to the north of the Dotson and Getz ice shelves indicate that this trough was also fed initially by three separate ice stream tributaries which then converged on the middle shelf to flow in a northwest direction toward the outer shelf.

At the head of each of the ice stream tributaries, the bathymetry data also reveals areas of overdeepened seafloor extending to depths of up to 1600 metres below sea level (Fig. 2). These are the deepest inner shelf basins yet to be found anywhere on the West Antarctic continental shelf. The largest of the three basins, at the front of the Getz Ice Shelf, contains abundant morphological evidence for erosion in the form of large-scale networks of slightly sinuous to straight channels with undulating long-axis profiles. Similar morphologies are interpreted elsewhere on the Antarctic shelf as subglacial meltwater features (e.g., Lowe and Anderson, 2003).

Further investigation of the swath bathymetry will determine the true extents of the LGM WAIS and allow reconstruction of former flow patterns and ice sheet dynamics on the continental shelf.

JCR seismic reflection profiles

530 line-km of high-resolution single-channel seismic lines were obtained from the inner to outer shelf areas of the ASE on the JR141 cruise (Fig. 1, yellow). Additional multi-channel seismic profiles, collected on RV *Polarstern*, are being used to assess ice sheet behavior in Pine Island Bay during the last deglaciation (see Uenzelmann-Neben et al., this volume).

Data collected along the major cross-shelf trough in the ASE show a clear transition from acoustic basement (bedrock) nearshore to undeformed sedimentary strata shelfward, which correlate with a transition from drumlins to highly-attenuated streamlined bedforms on the swath data (Fig. 3). Ties to regional seismic lines collected during previous surveys (e.g. NBP9902; Lowe and Anderson, 2002) have allowed us to begin mapping out the boundary between sedimentary and bedrock substrate. Combined with the morphological information from swath mapping, the data will be used to test the hypothesis that substrate is an important control on flow dynamics, and hence on the downstream evolution and style of seafloor morphological features (e.g., Wellner et al., 2001).

Seismic lines obtained along the strike of the outer shelf will also be valuable in identifying buried paleo-ice stream troughs. These data can be used additionally to analyse the sedimentary architecture of ancient glaciations and reveal information on the glacial evolution of this part of the Antarctic shelf.

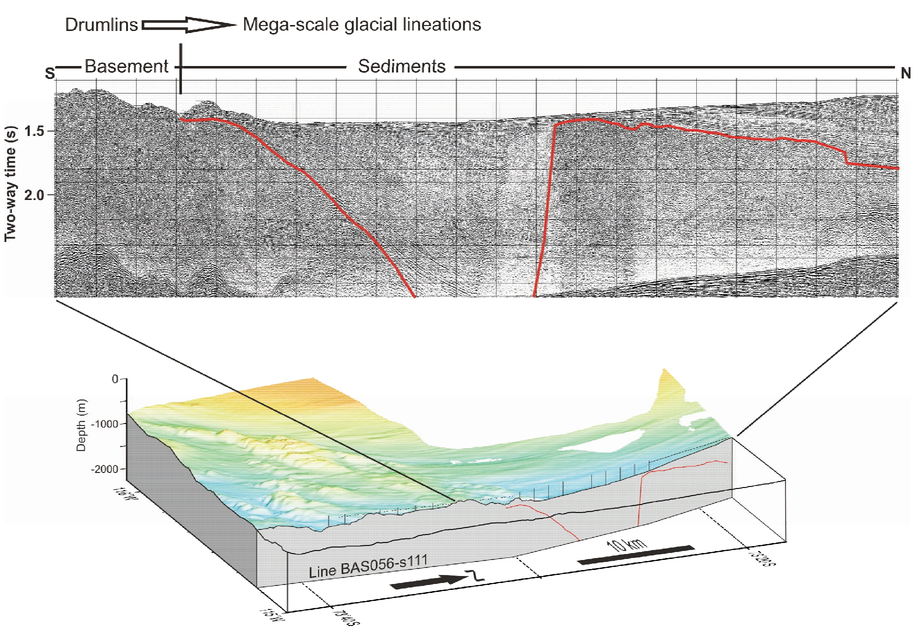

Figure 3. Seismic reflection profile illustrating the transition from acoustic basement to sedimentary substrate on the middle Amundsen Sea shelf (top of basement in red). Note change in seafloor morphology on corresponding swath data.

Dating the deglaciation from JCR Vibrocores

In order to reconstruct the deglaciation of the western ASE, a transect of vibrocores from the inner to outer shelf were obtained. Sedimentary cores typically contain a threefold sequence comprising soft, massive subglacial diamicton at their base, overlain by gravelly to sandy deglacial muds and capped by bioturbated Holocene muds with an upward-increasing contents of planktonic foraminifera (on the outer shelf) and diatoms (on the inner shelf). The timing of deglaciation is being investigated prinicipally with radiocarbon techniques, dating the interface between subglacial deformation till and glacimarine sediments in the cores. Initial results comprising several dozen ^{14}C dates reveal a sequence of ice retreat, and build upon previous data which suggest that deglaciation of the shelf was initiated sometime after ~16 ka B.P (Lowe and Anderson, 2002).

Terrestrial age constraints on deglaciation

A small suite of glacially-derived boulders (mostly granites and granitoids) were collected for cosmogenic isotope analysis from four sites surrounding Pine Island Bay (Fig. 1). ^{10}Be and ^{26}Al exposure ages from these samples are being used to assess the post-glacial thinning rate of glaciers in the region, and will complement the offshore record of deglaciation. They help to put the very rapid recently-observed thinning rates in the ASE (Thomas et al., 2004) into a longer-term context. Further more-detailed sampling will take place in the Hudson Mountains during the forthcoming 2007/2008 field season.

Discussion and summary

Marine geophysical and geological data combined with terrestrial age data are being used to investigate the extent, thickness, former flow pattern, and deglacial history of the late Quaternary WAIS in the ASE.

Survey of the continental shelf between the modern-day ice front and the Amundsen Sea outer shelf has revealed that the ice sheet grounding line probably extended to the shelf break at the LGM, and that this ice sheet included fast-flowing ice streams. Initial interpretation of new marine geophysical data indicates that the main ice stream trunk formed a significant artery of the LGM ice sheet.

The swath data reveal considerable spatial variability of morphological features, which leads to questions concerning ice sheet dynamics on the inner to outer shelf. The variety of features may be indicative of differing ice flow velocities and subglacial conditions in the former ice sheet through the last glacial cycle; seismic profiles along the ice stream trough suggest that substrate has been a particularly key control over seafloor morphology. Subglacial meltwater features which are found on the inner shelf will be the focus of future work concerning the role of meltwater in deglaciation and the implications of such features for developing ice sheet reconstructions in Antarctic shelf areas.

A well-preserved record of deglaciation is found in sedimentary sequences from numerous shelf cores in the ASE. Radiocarbon ages from these deposits will allow patterns of deglaciation to be determined for the central Amundsen Sea shelf and Pine Island Bay regions. New data should provide the most robust and complete understanding of late Quaternary deglaciation in the ASE to-date.

Integrating these data with results of ongoing surface exposure dating onshore will lead to a more complete picture of the LGM ice sheet extent, configuration and retreat history in the ASE. It is hoped that a synthesis of these data, in time, can be used to more accurately model the former ice sheet and therefore assess the potential for future change in its modern counter-part.

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