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Sediments collected from beneath the Amery Ice Shelf, East Antarctica, document sub-ice-shelf circulation of water and sediments throughout the Holocene.

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Introduction

Sediments collected from beneath and adjacent to the front of the Amery Ice Shelf are described. These include a 144cm gravity core collected from beneath the ice shelf containing a 0.5 m thick Holocene age surface layer of siliceous mud and diatom ooze of marine origin, which provides evidence for the landward transport of marine sediments beneath a major embayed ice shelf. The surface sediment distribution and its relation to sub-ice-shelf circulation patterns is also presented.

Sediment Collection

The AMISOR hot-water drill was used to access the ocean cavity beneath the Amery Ice Shelf at two sites (Fig. 1); AM02 (69°42.8′S, 72°38.4′E), located ∼ 80 km south of the floating ice shelf edge, where the seafloor at the site is 843 m below the ice shelf surface and the ice shelf is 373 m thick; and AM01 (69°26.5′S, 71°25.0′E), located ∼ 50 km west of AM02, and ∼ 100 km from the open water of Prydz Bay. At AM01, the ice shelf is 479 m thick, the lower ∼ 200 m of which is marine ice (Fricker et al., 2001), and the seafloor is 840 m below the sea surface. On the basis of numerical ocean model results (Hunter et al., 2003), the AM02 site is thought to be in a region of inflow and basal melt, and AM01 is thought to be in a region of outflow and basal freeze.

At both sites AM01 and AM02, a 150-cm-long, 10-cm diameter gravity corer was lowered to the seafloor by winch. A 144-cm core was collected at site AM02, and a surface sediment grab sample was obtained at site AM01.

In addition to the sub-ice-shelf sediments, 23 Shipek surface sediment grabs were taken from immediately adjacent to the calving ice front of the Amery Ice Shelf. Eleven of these were collected from the RSV Aurora Australis during the 2000/2001 AMISOR voyage 6 (au0106), and the remaining 12 grabs were collected during the following season (2001/2002) AMISOR voyage 7 (au0207). The location of the 23 ice front grab locations are also shown in Figure 1.

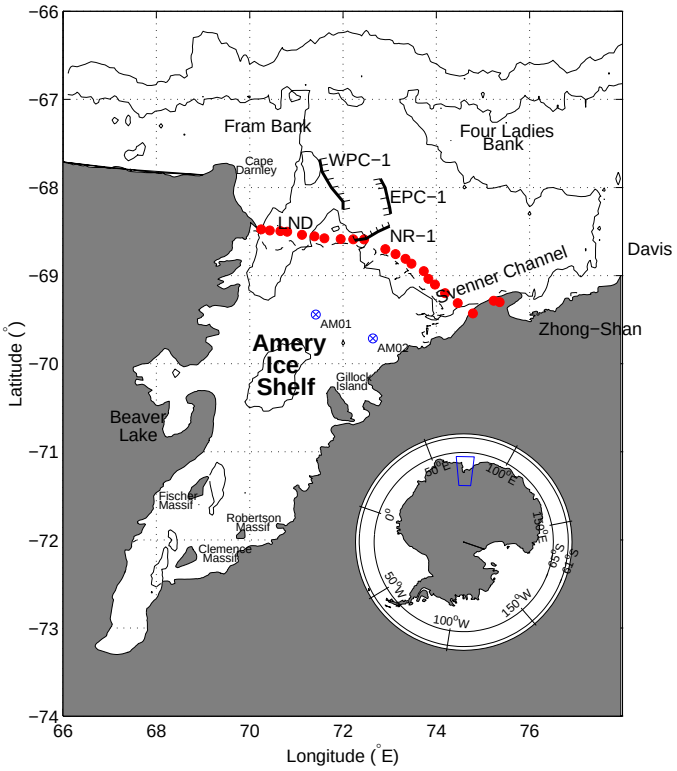

Figure 1: The location of the sub-ice-shelf core sites AM01 and AM02 (open circles with x), and the location of the 23 surface grabs from adjacent to the ice shelf front (solid circles). Major grounding line positions as determined by seismic reflection (Domack et al., 1998) are indicated. Grounding line "moraines" are named geographically and are the Eastern Prydz Channel 1 (EPC-1), Nella Rim 1 (NR-1) and Western Prydz Channel 1 (WPC-1). Hachures mark the steep, seaward slope of the grounding line "moraines".

AM02 Core Log Description

The AM02 core contains a full continuous record of glacial retreat. The core log is described by Figure 2, and outlined in more detail by Hemer and Harris (2003). The surface unit of AM02 consists of a 0.5 m thick Holocene age layer of siliceous mud and diatom ooze (SMO) of marine origin. This overlays a rapidly lain diamicton and waterlain till. The presence of the upper SMO units in the sub-ice-shelf core, although deposited at a slower rate (0.03 mma^{-1}) than in the open waters in front of the ice shelf (0.08-0.16 mma^{-1}, Franklin (1997)), provides clear evidence of Holocene deposition beneath the floating ice shelf, and consequently, transport of marine sediments landwards beneath the ice-shelf.

Surface Sediment Distribution

Figure 3 shows the surface distribution of grain-size, biogenic opal, and Total Organic Carbon (TOC) obtained from the surface grabs collected adjacent to the calving ice front. Part (d) displays the horizontal transport (in Sv) perpendicular to the ice front, determined from the CTD data collected during voyage au0106 along the ice shelf front.

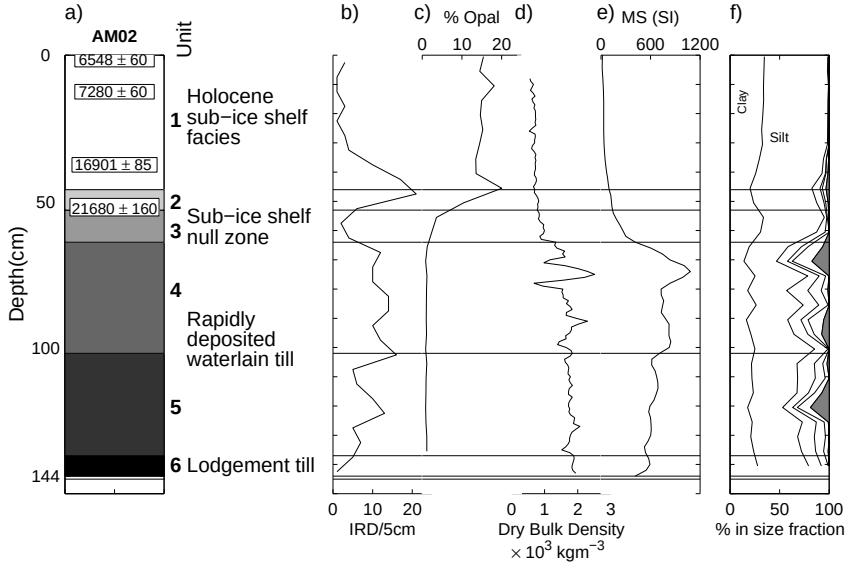

Figure 2: Visual AM02 corelog and down core profiles. (a) Visual core log showing facies succession. Numbers shown are uncorrected radiocarbon dates (with error limits), obtained on bulk organic carbon (with dilute HCl pre-treatment). The laboratory reference numbers from the New Zealand Institute of Geological and Nuclear Sciences, Rafter Radiocarbon Laboratory, Lower Hutt (NZA) are NZA 13747 (0-1 cm), NZA 15924 (12 cm), NZA 15925 (37 cm) and NZA 13748 (51-52 cm). (b) Ice-rafted (gravel) debris (IRD) count per 5 cm counted from X-yar radiographs. (c) Percentage biogenic opal per dry weight sediment, measured at 5 cm intervals using the method outlined in Mortlock and Froelich (1989). (d) Dry Bulk Density (kgm^{-3}) measured at 1 cm. intervals using the GEOTEK MS-2 multisensor core-logger. (e) Magnetic Susceptibility (MS), measured at 1 cm intervals using the GEOTEK core-logger, and (f) Grain-size distibution of the mud and sand fraction (up to 2 mm diameter), measured at 5cm intervals using a Malvern Mastersizer 2000 laser particle sizer. Contours are at 3.9, 62.5, 125, 250 and 500 μm. The component larger than $500\mu m$ is shaded. The core contains six units as indicated, the uppermost being siliceous mud and ooze of Holocene age.

From Figure 3d, it is seen that on the eastern side of the cavity, a large inflow to the east of longitude $74°E$ exists, and a return outflow between longitudes $72.8°E$ and $74°E$. On the western side of the ice front, a broader inflow of smaller magnitude between $71°E$ and $72.8°E$, and a larger outflow to the west of $71°E$ are observed. Sediment properties also display two peaks in biogenic fines. The peak on the eastern side of the ice shelf front is centred at $73.5°E$, and the peak on the western side is at $71°E$. It appears that associated with the inflow, the sediments with decreased mean grain size, and an increase in TOC and biogenic opal (up to 29%[1]) are found. Associated with the outflow are regions of coarser sediments, with reduced TOC and biogenic opal content.

At the site of the warm water inflow, AM02, surface sediments have a higher biogenic opal content (15.4 %) than at the site of Ice Shelf Water outflow, AM01 (3.6 %). Also, the surface age at AM01, dated at $11,722 \pm 60$ yr BP (laboratory reference

[1]The grab taken at longitude 74.5° indicates 50% biogenic opal, however this grab was taken further from the ice front, on the eastern side, than other grabs

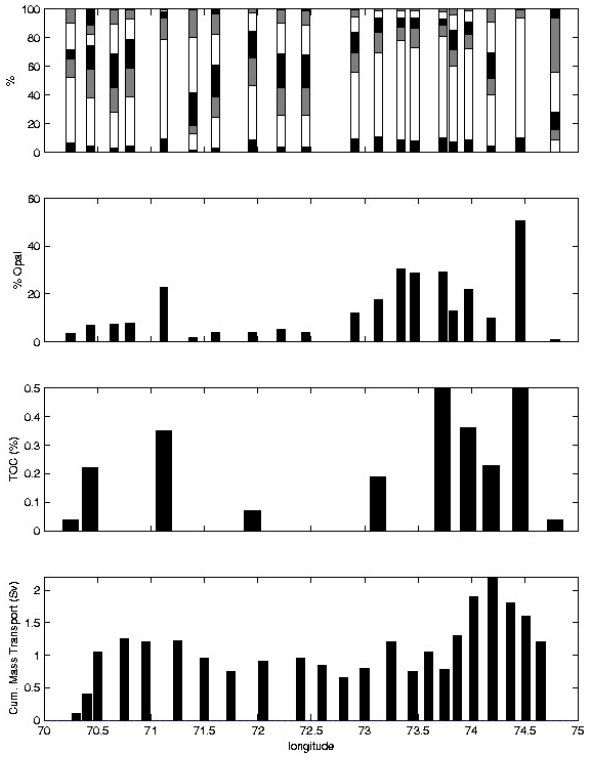

Figure 3: Sediment properties across the Amery Ice Shelf calving front as a function of longitude. (a) Grain-size distibution of the mud and sand component (up to 2 mm) measured using a Malvern Mastersizer 2000 laser particle sizer. Black at the bottom is the fraction finer that $20\mu m$. The lowest white area is the $20-63\mu m$ fraction, the lower grey section is the $63-125\mu m$, the middle black section is the $125-250\mu m$ fraction, the upper white section is the $250-500\mu m$ fraction, the upper grey section represents the $500\mu m - 1mm$ fraction, and the upper black represents the $1-2mm$ fraction. (b) The percent biogenic opal per dry weight sediment, measured using the method outlined by Mortlock and Froelich, 1989. (c) The percent Total Organic Carbon per dry weight sediment of the grabs collected from voyage au0106, and (d) The cumulative mass transport, in Sv, out of the cavity. An eastwards increase relates to outflow, an eastwards decrease relates to inflow.

NZA 15923), is significantly older than the AM02 surface age, dated at 6548 ± 60 yr BP (laboratory reference NZA 13747). The older surface age, and reduced marine influence, suggest the AM01 site has been starved of sediment during the Holocene. These results support predictions from the sub-Amery Ice Shelf baroclinic 3-D circulation model, which predict that site AM02 is a region of oceanic water inflow, and site AM01 lies in a region of ice shelf water outflow.

Figure 4 details the diatom assemblages for the AM02 core, the AM01 surface sample, and a sample of the sediments taken from the ice front. It is observed that with increasing transport distance beneath the ice shelf, from the ice front to AM02, to AM01, a decrease in Absolute Diatom Abundance is accompanied by a decrease in the dominance of sea-ice associated species, *Fragilariopsis curta* and *F. cylindrus* and an increase in relative abundance of the slightly more heavily silicified *Thalassiosira antarctica*.

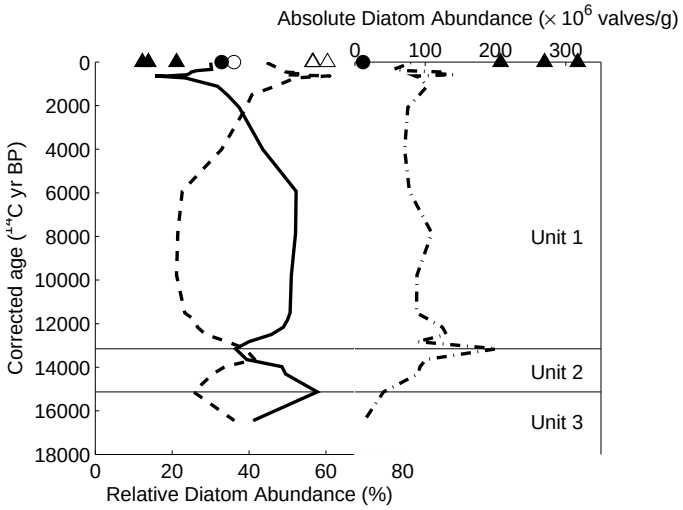

Figure 4: Diatom assemblages were studied using a variant of the method of Armand (1997). Left side x-axis: Distribution of *Fragilariopsis curta* (dashed line) and *Thalassiosira antarctica* (solid line) relative abundance throughout Units 1 and 2 of the AM02 core, sampled at 1 or 5 cm intervals. AM01 values are marked by circles, and ice shelf front values are marked by triangles. Solid markers represent *T. antarctica*, Unfilled markers represent *F.curta*. Right side x-axis: dash-dot line; Distribution of Absolute Diatom Abundance (in valves per gram of dry weight sediment). AM01 values are marked by circles, and ice shelf front values are marked by triangles. The y-axis is corrected age in ^{14}C yr BP. The boundary between Units 1, 2 and 3 are shown.

Down AM02 core, two periods at 1-5.7 kyr and 13-14 kyr of increased *F. curta* abundance and biogenic silica content are observed (Fig. 4), and are possible indicators of greater marine influence at the AM02 core site. This suggests a major retreat of the Amery Ice Shelf, or an increased sub-ice-shelf circulation, occurred at these times. Both scenarios are a predicted response of the baroclinic circulation model to increased ocean temperatures (Hunter et al., 2003).

Conclusions and Future Work

The study has shown evidence for the landward transport of marine sediments beneath a major embayed ice shelf. This advancement is important for the interpretation of marine sediment cores from the Antarctic continental shelf, where previously, researchers have defined open water conditions to have begun as soon as marine sediments were evident in the sediment record. Results here show that after lift-off of an advanced ice sheet during periods of warming, marine sediment may be transported beneath the floating ice shelf, and not represent open water conditions.

Extra hot-water drill sites are proposed for the Amery Ice Shelf. Attempts to retrieve sub-ice-shelf sediments will continue at these sites with the aim to advance knowledge of sub-ice-shelf sedimentation processes, and for validation of modelling activities.

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