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# PRE-CRUISE REPORT - PRYDZ BAY - MACROBERTSON SHELF & KERGUELEN PLATEAU, FEBRUARY-APRIL 1995

## AGSO CRUISE 149, R.V. *AURORA AUSTRALIS*

*BY*

*P.E. O'BRIEN, P.T. HARRIS, P. WELLS, E.L. SIKES & F. TAYLOR*

## RECORD 1995/28





AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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AGSO Cruise 149, R.V. *Aurora Australis*

by


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**ISSN: 1039-0073**
**ISBN: 0 642 22349 1**

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## INTRODUCTION

This record describes the background, aims and methods to be employed in the second AGSO/Antarctic Co-operative Research Centre/ANARE marine geoscience program in Prydz Bay and the Mac. Robertson Shelf. The cruise program consists of activities aimed at understanding modern sedimentary processes on the Antarctic margin, understanding the Plio-Pleistocene environmental history of the region and obtaining samples from the Kerguelen Plateau to illuminate the history of water mass reorganisation in the Southern Ocean during Quaternary climate change episodes.

The cruise will address goals set by the Antarctic CRC Natural Variability (sediments) sub-program, which are to promote a better understanding of global climate change by providing statements of the Antarctic and Southern Ocean palaeoenvironments over the following time intervals:
(A) 0-10,000 years (post-glacial warming)
(B) 0-160,000 years (last glacial cycle)
(C) 0-5,000,000 years (Pliocene "warming" of Antarctica)
These goals will be achieved by studying the Antarctic and Southern Ocean sedimentary record for evidence of Antarctic ice sheet and Southern Ocean circulation changes.

The development of accurate predictive models of climate change requires an understanding of the behaviour and interaction of components of global climate systems. The East Antarctic Ice Sheet is one such major component so that the study of its behaviour during past climatic fluctuations should provide key guidelines for climatic modelling. Sediments deposited in Prydz Bay contain a record of ice sheet fluctuations because this area is located at the downstream end of the largest outlet glacier flowing from the East Antarctic Ice Sheet, the Lambert Glacier-Amery Ice shelf.

Another major component of the global climate system is the Southern Ocean. Water masses of the Southern Ocean play a pivotal role in world climate by absorbing, transporting and releasing heat and by transferring oxygen, nutrients and $CO_2$ to and from the deep ocean. In this context, the Kerguelen Plateau has accumulated sedimentary sequences that will contain records of how the polar front and its associated water masses have varied between glacial and interglacial periods.

The three geographical features targeted for study during the cruise are: (A) the trough-mouth fan deposits adjacent to Prydz Bay; (B) sediment traps associated with deep, shelf-basins on the Mac.

Robertson Shelf; and (C) depositional basins on the Kerguelen Plateau. In the following sections the existing data bases for these areas are discussed and the objectives for the 1995 cruise of Aurora Australis are presented.

## REGIONAL SETTING OF PRYDZ BAY

Prydz Bay is a re-entrant in the Antarctic coastline that overlies a sedimentary basin, the Prydz Bay Basin (Fig. 1; Stagg, 1985). A fault bounded structure, the Lambert Graben extends about 600 km inland from Prydz Bay to the Prince Charles Mountains (Fedorov *et al.*, 1982, Stagg, 1985). This structure is occupied by the Amery Ice Shelf - Lambert Glacier ice drainage system, which drains up to 1.09 million km or about 22% of the East Antarctic ice sheet (Allison, 1979). The efficiency of this system has produced a large depression in the ice cap and exposure of the Prince Charles Mountains.

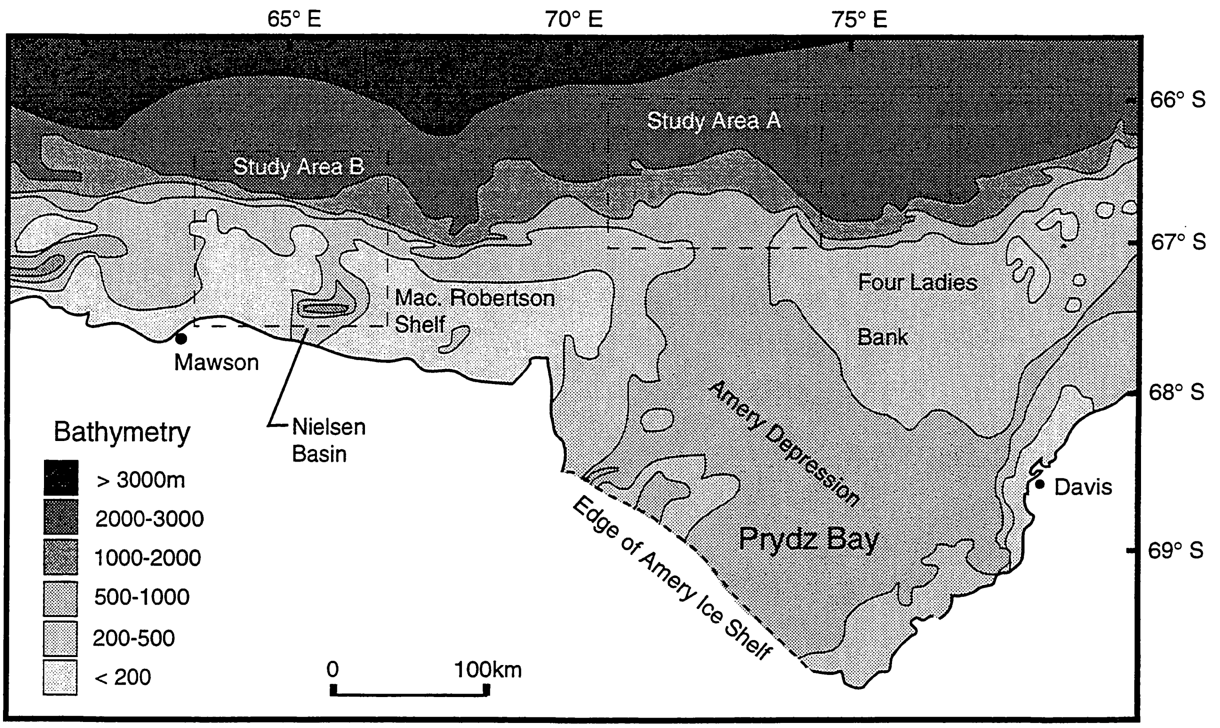



Figure 1. Regional bathymetry and location of study areas: (A) on the trough mouth fan adjacent to the Amery Ice Shelf, Prydz Bay; and (B) on the Mac. Robertson shelf.

Major fluctuations of the East Antarctic ice sheet should be reflected in glacial geological features on these bedrock features and sedimentary or morphological evidence at the downstream end of the Lambert Glacier-Amery Ice Shelf system in Prydz Bay. During Cainozoic glacial episodes, the Amery Ice Shelf probably advanced across Prydz Bay to the shelf edge (Cooper *et al.*, 1991, Hambrey *et al.*, 1991).

Prydz Bay is occupied mostly by a broad topographic basin, the Amery Depression. As with much of the Antarctic continental shelf, the deepest part of the Amery Depression is near-shore (Anderson *et al.*, 1983, Vanney & Johnson, 1985). Depressions up to 1000 m deep are found in the south-western corner of the Bay (the Lambert and Nanok Deeps) and running parallel to the Ingrid Christensen Coast is an elongate trough up to 1000 m deep called the Svenner Channel. Another elongate deep, the Prydz Channel, runs along the western edge of the Amery Depression, extending to the continental shelf edge. Prydz Channel resembles shelf-crossing valleys seen in the Weddell and Ross Seas in being quite broad with low banks flanking it (Fig. 1).

Offshore from the Amery Depression, the shelf shallows to be less than 200 m deep along the shelf edge, forming the Four Ladies Bank, on the eastern side of the Prydz Channel and Framm Bank on the western side (Fig. 6). The topography of Prydz Bay is rugged along its southeastern flanks between the edge of the Svenner Channel and the present coast. Large U-shaped valleys extend northwest from the termini of the Sorsdal, Ranvick and Polar Record Glaciers. Sea floor topography is also rugged close to the present position of the Amery Ice Shelf front.

The continental slope beyond Prydz Bay consists of two areas of different morphology. The western side features a large, smooth-surfaced fan offshore from the Prydz Channel. The fan extends 50 km seaward and is 100 km across with a surface slope of 2°. It lacks submarine canyons. The eastern side is steeper (4°) with several submarine canyons that start as dendritic tributaries on the upper slope that join in the mid-slope (Vanney & Johnson, 1985). These canyons are not as steep sided as those further west on the Mac. Robertson Land continental slope.

## Existing Data

### *Seismic Data*

Prydz Bay has received relatively more attention than other parts of the East Antarctic continental shelf and slope. A marine geoscience cruise by Australian National Antarctic Research Expeditions (ANARE) and the Australian Bureau of Mineral Resources (BMR) on the M.V. Nella Dan in 1982 acquired 5000 km of multichannel seismic reflection data and 8 - 10 000 km of 3.5 kHz echo sounder data along straight tracks (Stagg, 1985). Russian and Japanese expeditions have also obtained multichannel seismic data in the area (Kuvaas & Leitchenkov, 1992; Mizukoshi et al., 1986). An additional line was shot by the Ocean Drilling Program (ODP) in 1988 to aid siting of ODP holes 739 to 743 that were situated on line PB-021 of the ANARE/BMR survey (Barron et al., 1989). This seismic line shows prograding foreset bedded units that have been related to episodes of glacial advance to the shelf break (Fig. 2)

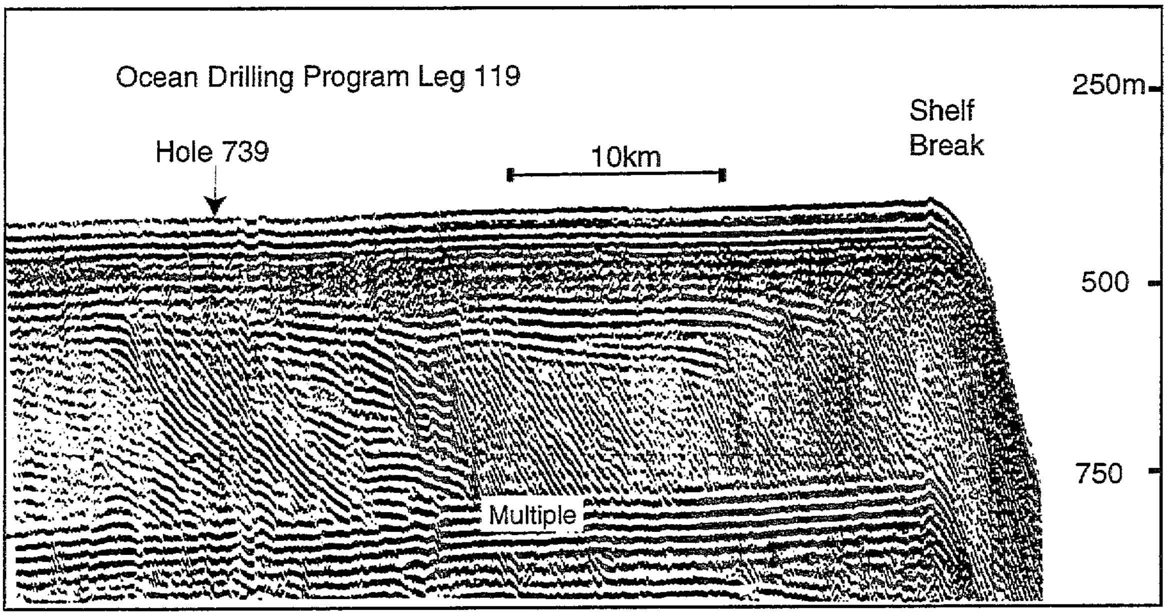



Figure 2. Seismic reflection profile (after Cooper et al, 1991) showing the location of ODP site 739 and progradational foreset beds in Prydz Bay.

Since 1990, ANARE cruises by the R.S.V. Aurora Australis have collected 12, 35 and 120 kHz echo sounder records. These data were also used to select sites for grab and gravity coring during January and February 1993 (O'Brien et al., 1993).

*Sediment Samples*

Sediment samples were first collected from the region by H.M.S. Challenger in 1873 (Murray & Renard, 1891), then by the Soviet Marine Antarctic Expedition commencing in 1955 (Lisitzin, 1960). McLeod et al., (1966) describe a few samples from the approaches to Mawson Station. The 1982 ANARE cruise obtained 37 bottom sediment samples using dredges, grabs and small gravity cores from locations scattered widely across Prydz Bay and the Mac. Robertson shelf (Fig. 3; Quilty, 1985). Ocean Drilling Program Leg 119 drilled five holes up to 486m deep in a transect across Prydz Bay (Fig. 3). These holes were drilled using conventional rotary techniques because the ODP piston coring equipment could not penetrate the glaciomarine diamictites encountered. Consequently, the Quaternary sediments obtained were badly disturbed by drilling (Barron et al., 1991). Since then, the 1991 summer cruise by the R.S.V. Aurora Australis obtained 17 bottom samples by shallow gravity corer (up to 50 cm) and by accidental dredging by trawl nets (Franklin, 1991). Antarctic Division has also collected sea bottom photographs from 17 locations in Prydz Bay.

Of particular importance is the Holocene section cored by ODP Hole 740A. Domack et al. (1991) identified a silt interval interbedded with diatomaceous ooze. They interpreted the silt as representing deposition beneath the Amery Ice Shelf when it extended much further seaward than at present. They argue from C-14 dates that this took place during the Holocene warm phase around 7000 yrs BP. Similar stratigraphy in continental shelf deposits around East Antarctica led Domack et al. (1992) to conclude that east Antarctic outlet glaciers expanded during past warm periods.

One gravity core obtained on the slope in 1993 (KROCK139GC09; located at 66°20'S, 71°59'E in 1,879m water depth), is a 326cm sequence of foraminiferal, diatomaceous fine sand to ooze. Planktonic foraminifera are abundant in the top 130cm, and this interval is being dated by C-14 and analysed for oxygen isotope trends. The occurrence of foraminifera in this core together with the prospect of high sedimentation rates associated with the fan deposit have encouraged us to study this area in more detail.

## SEISMIC STRATIGRAPHY OF THE PRYDZ CHANNEL TROUGH MOUTH FAN

### Area

The Prydz Channel Trough Mouth Fan is a semicircular wedge of sediment 200 km in radius on the continental slope between 70° 45' E and 74° E (Fig. 1). It is situated at the seaward end of a broad cross-shelf channel, the Prydz Channel, that extends from the Amery Depression. At the shelf edge, the channel floor is 600 m deep and the toe of the fan is indicated by a bulge in the 2600 m contour.

### Objectives

1. To map seismic sequences in the trough mouth fan built by advances of the Lambert Glacier-Amery Ice Shelf from the Pliocene to the present.
2. Obtain cores that will give records of Holocene and Pleistocene environmental changes on the continental slope on the western side of Prydz Bay and a sample of the sedimentary facies of the fan.
3. Interpret the history of ice advances to the shelf edge by sampling any seismic sequences that crop out on the sea floor and by tying to ODP Site 739.
4. Investigate the modern sedimentary environment of the Prydz Channel Trough Mouth Fan to understand fan modification during

interglacials and the present oceanographic conditions in the region.

**Justification**

The Antarctic Ice Sheet is a key component of the world's climatic system and has a major influence on global sea levels. To test models of its behaviour it is necessary to examine its fluctuations during episodes of climate change. There is only a small amount of data pertaining to whether the current ice sheet will grow or diminish with global warming (Domack *et. al.*, 1991) and there is controversy over the stability of the East Antarctic Ice Sheet, particularly during the Pliocene (Webb *et al.*, 1984; Sugden *et. al.*, 1993). The continental shelf and slope are the major repositories of information on ice sheet behaviour, in the form of deposits laid down by the ice and from the water column. Erosional glacial landforms occur where the ice has advanced across the shelf and depositional landforms are usually formed during ice retreat (Cooper *et al.*, 1991; Anderson *et al.*, 1994).

Seismic stratigraphic studies of the Antarctic and other glaciated shelves reveal the presence of both aggradational and progradational sequences deposited by ice with significant hiatuses representing episodes of erosion (Fig. 2, Cooper *et al.*, 1991). Erosion surfaces of glacial origin slope shoreward (Anderson *et al.*, 1994). Other meso-scale landforms on the shelf have potential to provide details on ice behaviour (O'Brien, 1994). Multi-channel seismic data show that the Plio-Pleistocene sequences around the Antarctic margin tend to be thinner than older glacial sequences, probably because of higher frequency sea-level change (Anderson *et al.*, 1994). Therefore, to understand Plio-Pleistocene climates in Antarctica, it will be necessary to find areas that accumulate sediment throughout the glacial-interglacial cycle and are not vulnerable to subglacial erosion and to image them with higher-resolution tools.

The most complete records of glacial history are probably contained in trough mouth fans built on the continental slope by large ice streams (Boulton, 1990; Larter & Cunningham, 1993) because these fans are built of sediment eroded from the shelf during major ice advances. The adjacent shelves preserve only hiatuses and over-compacted sediment from these periods. During interglacials, trough mouth fans are subjected to normal slope processes so they may be sediment starved, reworked by oceanic currents (Boulton, 1990) or ice shelf water (Kuvaas & Kristoffersen, 1991) and slumping (De Batist *et al.*, 1994). In the case of the Prydz Channel Trough Mouth Fan, existing multichannel seismic (Stagg, 1985, Kuvvas & Leitchenkov, 1992) shows little evidence of large-scale sediment gravity flows seen in similar fans

(Bart *et al.*, 1994; Hiscott & Aksu, 1994) and 3.5 kHz profiles show only small scale slump-scars near the shelf edge (O'Brien, 1994). A gravity core collected from the Prydz Channel Fan (Fig. 3; O'Brien *et al.*, 1993) contains beds of sediment with diatoms and planktonic foraminifera suggesting that this fan receives a drape of biogenic sediment during interglacials. If this is the case, the Prydz Channel fan could contain the most complete sedimentary record of any trough mouth fan on the Antarctic margin. This record will be of particular significance because the Lambert Glacier drains a large proportion of East Antarctica (Allison, 1979).

## Research Design

### *Seismic*

The seismic grid will consist of about 940 km of single-fold intermediate to high resolution data acquired with a GI gun source and four-channel, high resolution streamer. The 150 cubic inch GI gun source has been shown to provide an appropriate balance of frequency content and penetration for imaging glacially-deposited sequences on various parts of the Antarctic shelf (Anderson *et al.*, 1994). The dip lines will run normal to fan contours, radiating from the mouth of the Prydz Channel (Fig. 3). Tie lines will be shot approximately normal to

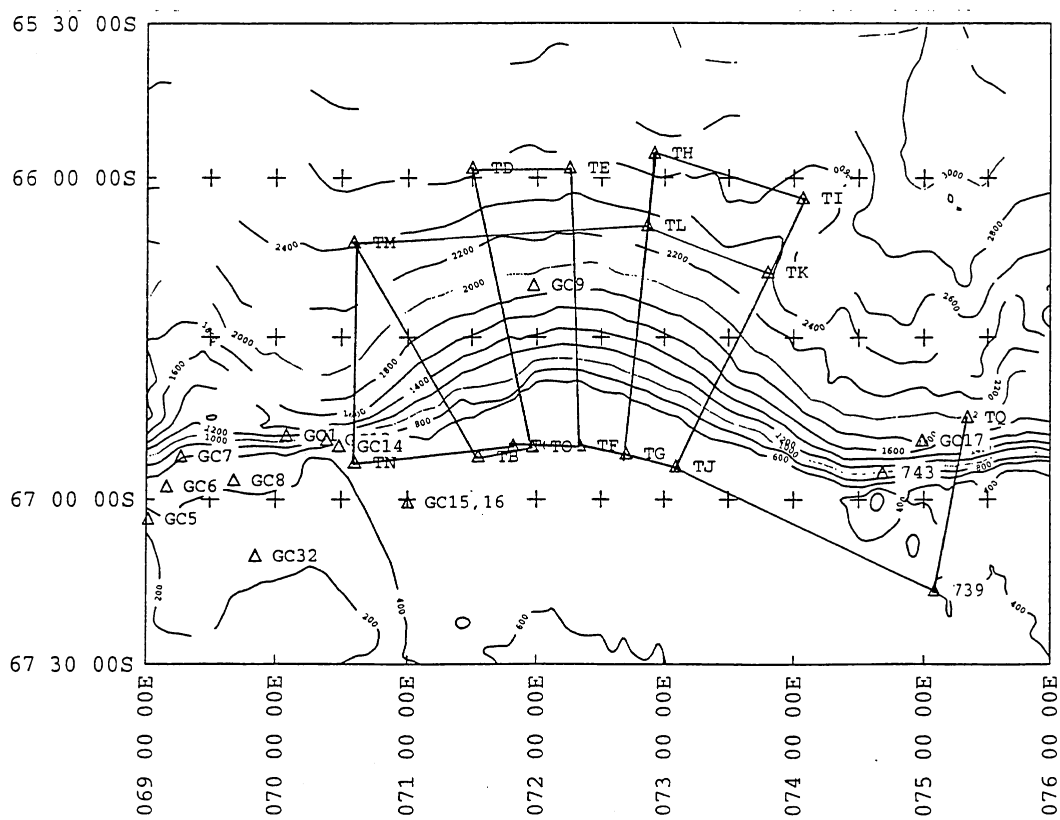



Figure 3. Bathymetry of the Prydz Channel tough mouth fan located on the Prydz Bay continental slope. The location of previous core sites and of seismic survey track lines planned for the present study are indicated.

the dip lines on both the lower fan and the shelf. An along-strike line will be shot across the shelf from the grid to ODP Site 739, the only ODP site in the region that was geophysically logged. Re-interpretation of ODP 739 is being done by AGSO (geophysical logs) in collaboration with University of Nebraska (palaeontology) and Liverpool John Moores University (sedimentology).

*Sampling*

Twenty-five stations will be sampled, time permitting, at which a gravity core, grab, CTD and bottom photograph will be taken. Preliminary locations used for planning are tabulated in Appendix A. Final sites will be chosen from seismic data collected on the cruise with the aims of sampling major seismic facies, Holocene sediments and any Plio-Pleistocene sequences cropping out on the fan surface. CTDs will be collected with similar aims to those on the Mac. Robertson Shelf.

**Late Quaternary diatom palaeoecology and biostratigraphy**

Surface sediment samples contain modern planktonic diatom assemblages, which coincide with the present-day oceanographic conditions of the area. The distribution of modern diatom assemblages, combined with environmental data, will form the basis for a model that will be used to interpret past oceanographic conditions. This can be detected from changes in diatom assemblages down sediment cores.

The analysis of surface samples will also allow for the documentation of planktonic diatom species in Prydz Bay and their distribution and potentially for the identification of previously undescribed species. The samples will also allow for the characterisation of community assemblages (e.g. dominant species, diversity) and for assemblage distribution within the area. Variations in down-core diatom assemblages will allow the interpretation of climatic and oceanographic features, such as: circulation patterns; sea ice extent; open water primary production; depositional processes; and local biostratigraphy.

Sediment for this work to date has come from grab and core samples collected during the 1993 ANARE KROCK (krill and rock) marine geoscience cruise to Prydz Bay and the Mac. Robertson Shelf. Preliminary diatom work from these samples has shown at least three diatom assemblages to be present in Prydz Bay. These are associated with the:

1. Amery Ice Shelf front

2. Ranvick Glacier edge
3. Continental shelf break (i.e. offshore)

Thirty-one sites have been proposed for sediment collection, in priority order (Table 1), during the present voyage 6 of Aurora Australis. These sites are generally situated on the area north and east of the Prydz Bay continental shelf break, where sediment has not been previously collected. It is anticipated that at the majority of sites grab samples will be sufficient; sediment cores will be collected at selected sites if possible.

The samples should more fully document the regional circulation patterns in Prydz Bay. The distinction between planktonic diatom assemblages associated with open water primary production will be made from those associated with sea ice and ice edge communities. From this, general circulation patterns and water mass conditions (e.g. salinity, ice-coverage, temperature, depth) can be determined.

*Dating of sediment cores*

The use of diatoms as biostratigraphic markers will enable sediment cores collected during the voyage to be dated. Dating of the cores will be based on the diatom biostratigraphic zonations of Harwood & Maruyama (1992; Table 1). These zones may be further extended pending the results of this project.

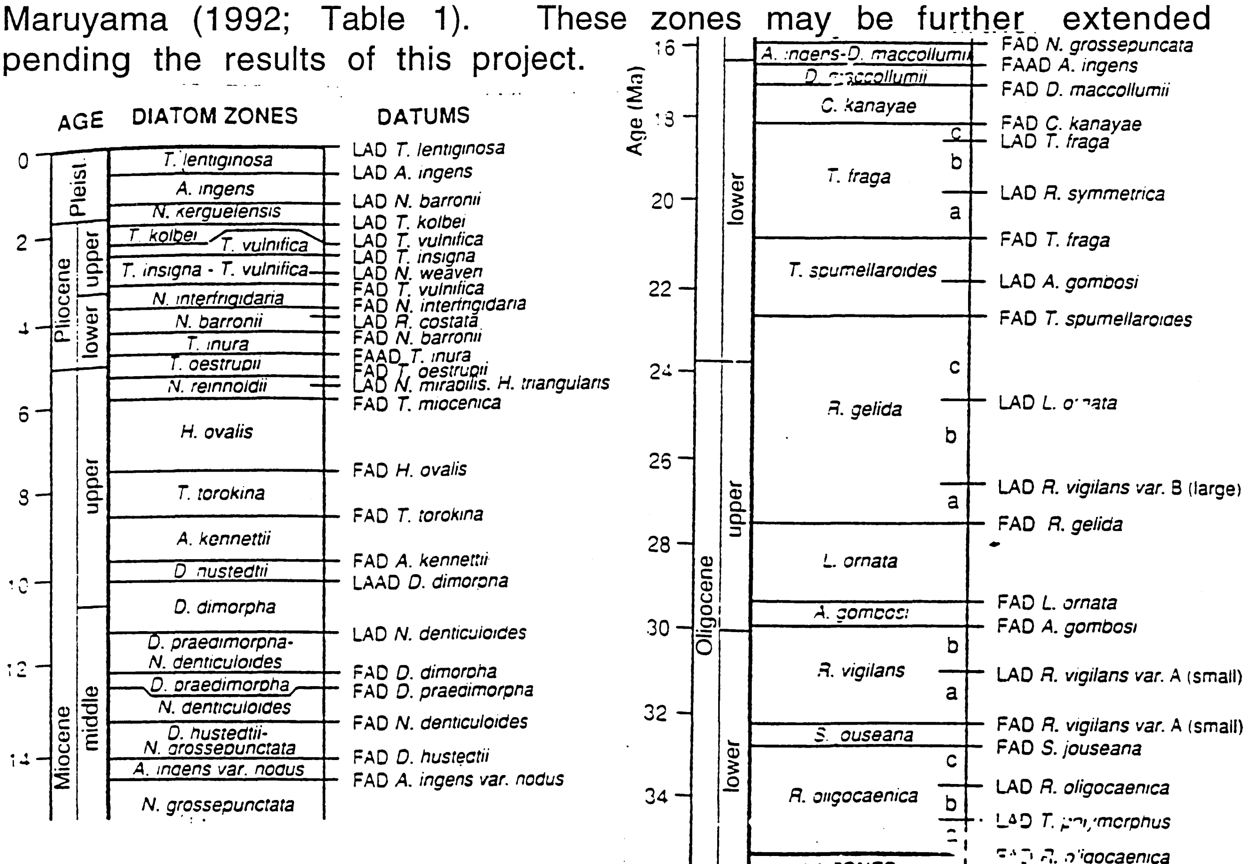



Table 1. Middle Eocene to Pleistocene diatom biostratigraphy of Southern Ocean sediments from the Kerguelen Plateau (from Harwood and Maruyama, 1992).

# SEDIMENTATION ON THE MAC. ROBERTSON SHELF

## Area

The Mac. Robertson Shelf extends for about 400km west from Prydz Bay and adjacent to Mac. Robertson Land on the continental shelf of East Antarctica (Fig. 1). Shelf width is typically 90km and the depth of the shelf break averages about 400m. The shelf contains relatively shallow banks (<200m depth) located on the mid- to outer shelf and deep shelf basins, notably the Nielsen Basin, which is more than 1,200m in depth (Fig. 4). In general, the geomorphology of this shelf region represents the major part of Antarctica's shelf, away from the broad shelf seas (Weddell Sea, Ross Sea and Prydz Bay). In comparison with the shelves of other continents (eg. generally defined as being less than 200m deep), Antarctica's shelf is much deeper; shelf processes in Antarctica differ from those on other continental shelves around the world (Dunbar et al., 1985; Jacobs, 1989).

The Mac. Robertson shelf area is effected by a strong, westward-flowing shelf current associated with the East Wind Drift (Smith et al, 1984). Coastal polynyas coincide with shelf basins that are over 1,200m in depth, locally (eg. the Nielsen Basin). Winter sea ice formation and the production of dense, cold and saline shelf water may produce across-shelf, near-bottom density currents.

These, and other oceanographic processes give rise to a facies succession, in which coarse-grained relict deposits are found on the shelf edge, where erosional bottom currents are strongest, with fine-grained sediment deposition occurring in adjacent, lower-energy environments in the shelf basins and on the slope. As pointed out by Jacobs (1989), however, the direct measurements of shelf-edge currents presently available are insufficient to substantiate that hypothesis. It is evident that further measurements of shelf and slope current regimes are required.

## Objectives

1. To quantify the physical processes controlling sediment deposition on the shelf and slope off the Mac. Robertson shelf of East Antarctica.
2. To relate the history of sedimentation to processes active at the present time by correlation of facies successions.
3. To locate deposits suitable for obtaining high-resolution sedimentary records of late Quaternary environmental change.

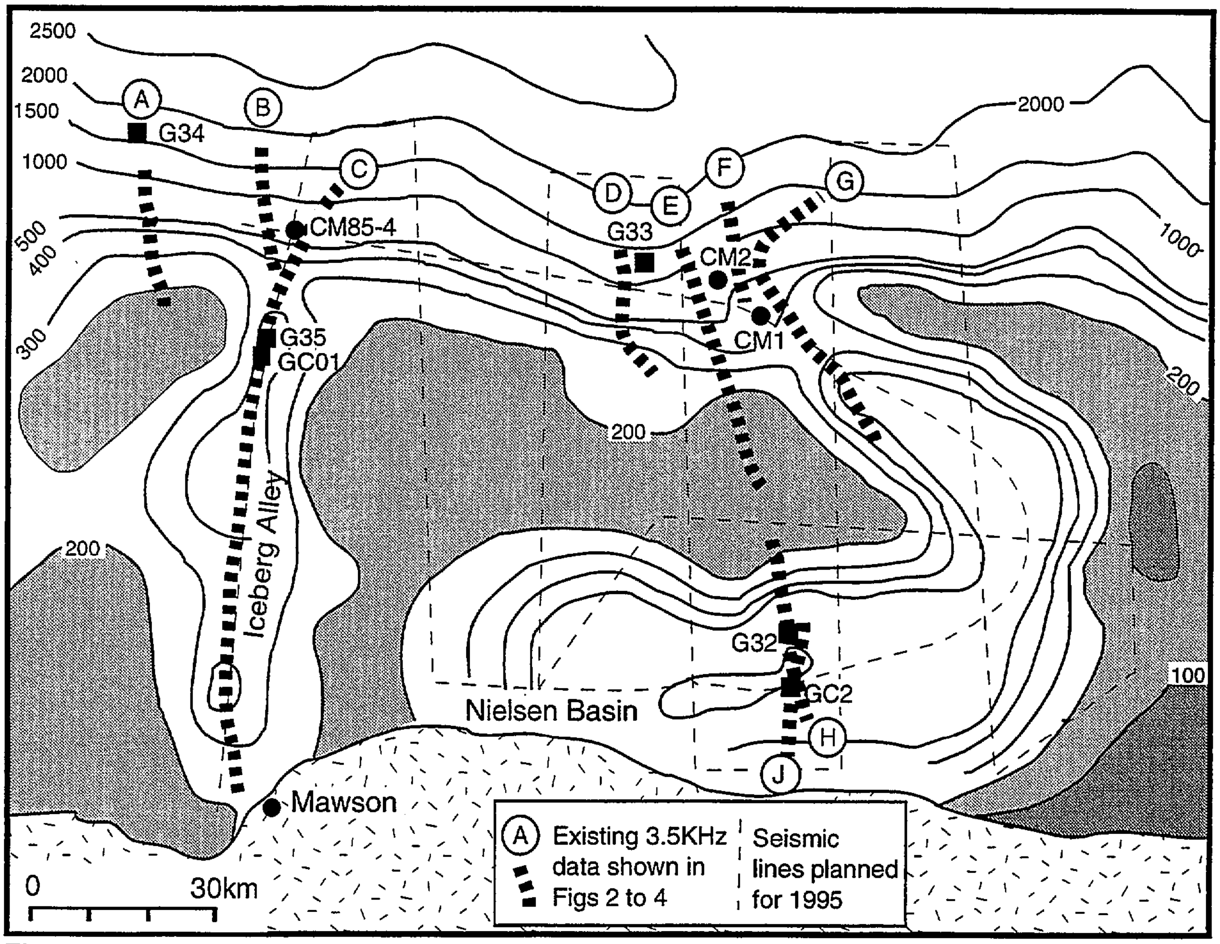



Figure 4. Map showing the location cores, grabs, current meter stations and of 3.5KHz sections from the Mac. Robertson Shelf. Seismic survey lines planned for 1995 are also indicated.

## Existing Data

### *Bathymetry and 3.5KHz Profiles*

Available 3.5KHz pinger-seismic data show that the shelf comprises several geomorphic zones. Profiles oriented across the shelf indicate that the inner shelf is characterised by rough, high-relief ridges/pinnacles and valleys/depressions (Figs. 5 and 6). The shelf edge is often "rimmed" with a ridge that rises >150m above the level of the outer shelf (i.e. line C in Fig. 5 and lines E, F & G in Fig. 6).

On the mid- to outer-shelf centred on Iceberg Alley (Fig. 4), large basins infilled with layered sediments are evident in the 3.5KHz records (Fig. 7). These basins are of particular interest, as the sediments deposited here appear to be undisturbed by glacial ploughing and mixing; hence they may contain useful records of late Quaternary environmental changes in the area. The Nielsen Basin has been singled out for attention for this reason, i.e. that it might contain undisturbed deposits of use in palaeoenvironmental studies. However, the few

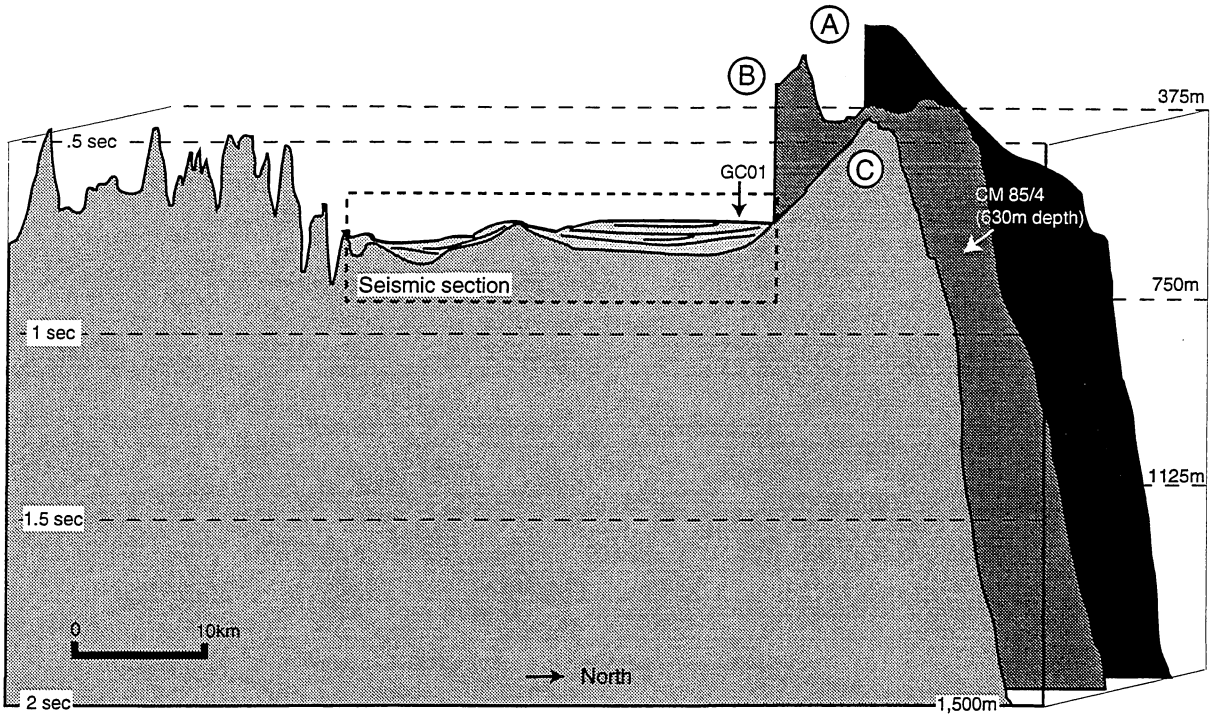



Figure 5A. Bathymetric profiles based on 3.5KHz records (see Fig. 4 for location of track lines). The seismic section indicated in the smaller box is shown in Fig. 5B.

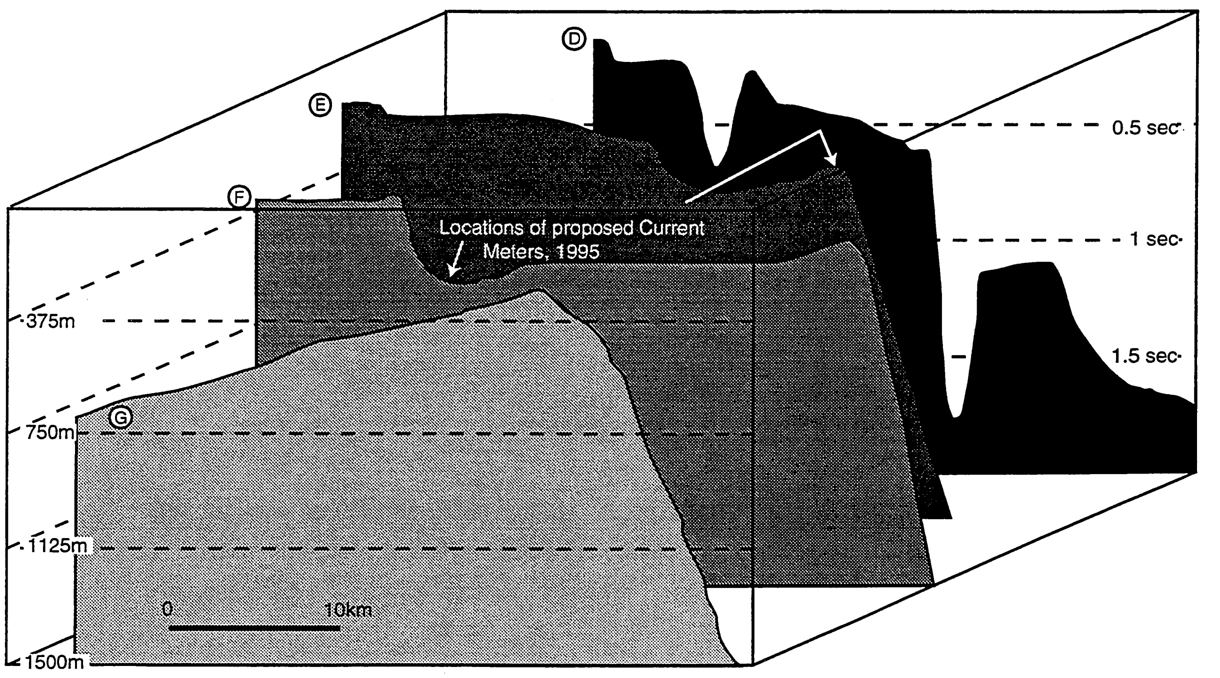



Figure 6. Bathymetric profiles based on 3.5KHz records (see Fig. 4 for location of track lines).

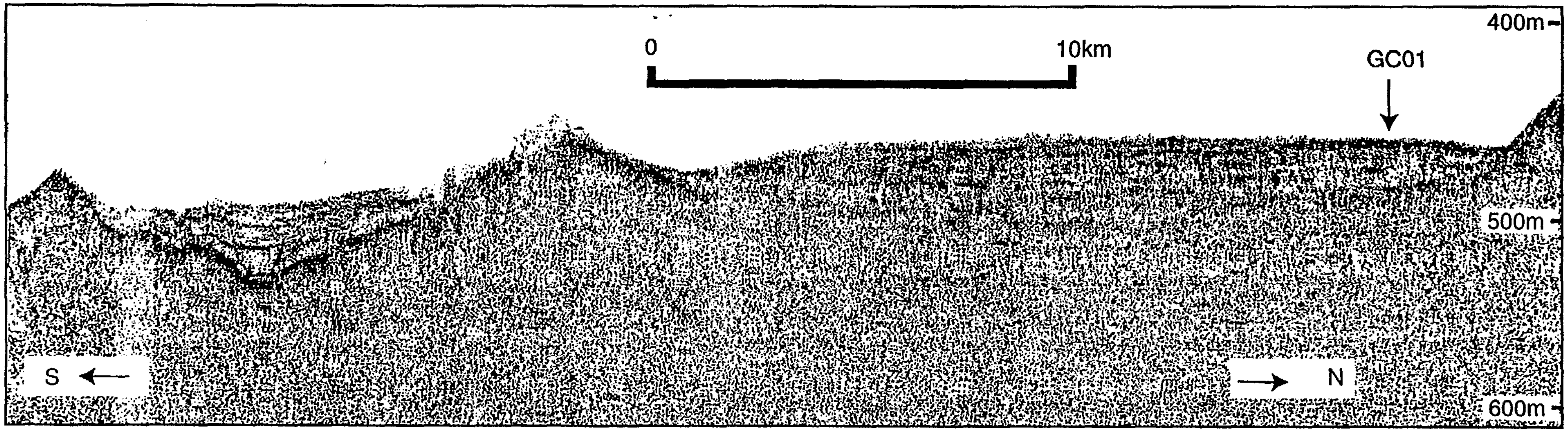



Figure 5B. Example of 3.5 KHz record showing bedded sediments infilling depressions on the outer shelf, Iceberg Alley. The location of core GC01 is shown.

3.5KHz records obtained from this basin do not exhibit any obvious layered sediments as are found in the Iceberg Alley area (Fig. 5).

The continental slope in this area is generally steep (6° locally) and exhibits re-entrants, probably associated with submarine canyon heads (eg. the deep valley in line D, Fig. 6). The slope also exhibits notches or nick-points at about 600m depth at the location of the current meter site 85/4 (Fig. 6). These may have formed by erosional processes associated with strong, contour-currents that flow along the upper slope in this region (see discussion of current meter data below).

Based on the above assessment, the Mac. Robertson shelf and slope may be divided into 4 geomorphic zones: (1) steep continental slope; (2) high-relief, ridge & valley topography; (3) smooth sea floors associated with depositional basins; and (4) low-relief, planated bank-tops. The spatial distribution of these zones are depicted in Figure 8, and are similar to those described by Barnes (1987) for the Wilkes Land shelf.

Seismic lines planned for the 1995 cruise of Aurora Australis will provide the first systematic coverage of the region, allowing a more accurate assessment of the distribution of geomorphic zones. In particular, areas of net sediment accumulation will be mapped in more

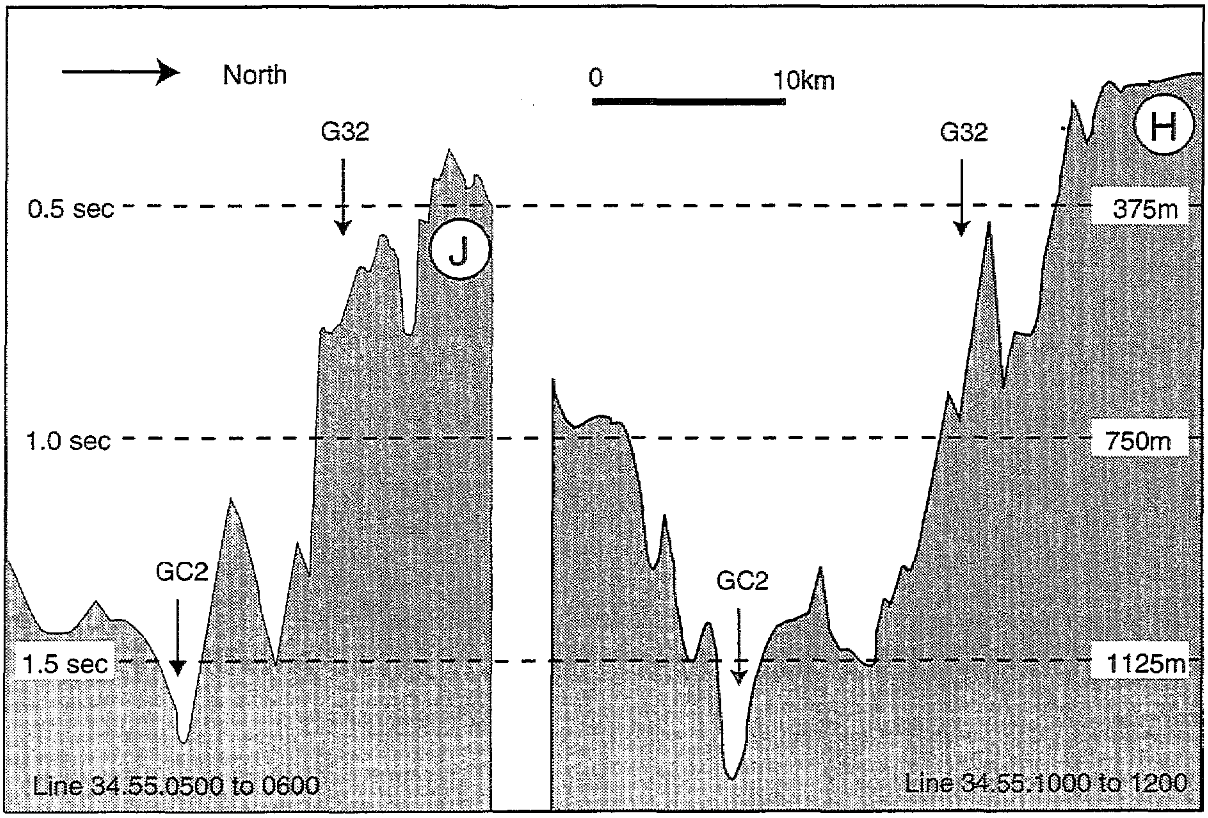


Figure 7. Bathymetric profiles based on 3.5KHz records (see Fig. 4 for location of track lines).

detail, providing the basis for locating core sites. Sidescan sonar data will elucidate the nature of the high relief geomorphic zone (pinnacles? ridges?) and the extent of iceberg ploughing on the more shallow banks. The seismic lines shown in Figure 4 represent approximately 580 nautical mile of track which will require about 116 hours (4 days & 20hrs) to complete at a ships speed of 5 knots. Proposed positions of way points for the survey are given in Appendix A.

*Core and Surficial Grab Data*

Surficial sediments on the Mac.Robertson shelf have been described by Quilty (1985) based on 18 pipe-dredge samples. These samples included one from Nielsen Basin (Station 28) in 1,250m water depth and another from 415m water depth located about 10km offshore from Mawson Base (Station 47). These two stations comprised a "dominantly mud with diverse siliceous skeletal component" association. The other 16 samples were located on the upper continental slope and on low relief bank tops in depths of from 71 to 1,166m and comprised a "coarse sediment (biogenic and terrigenous)" association (Quilty, 1985).

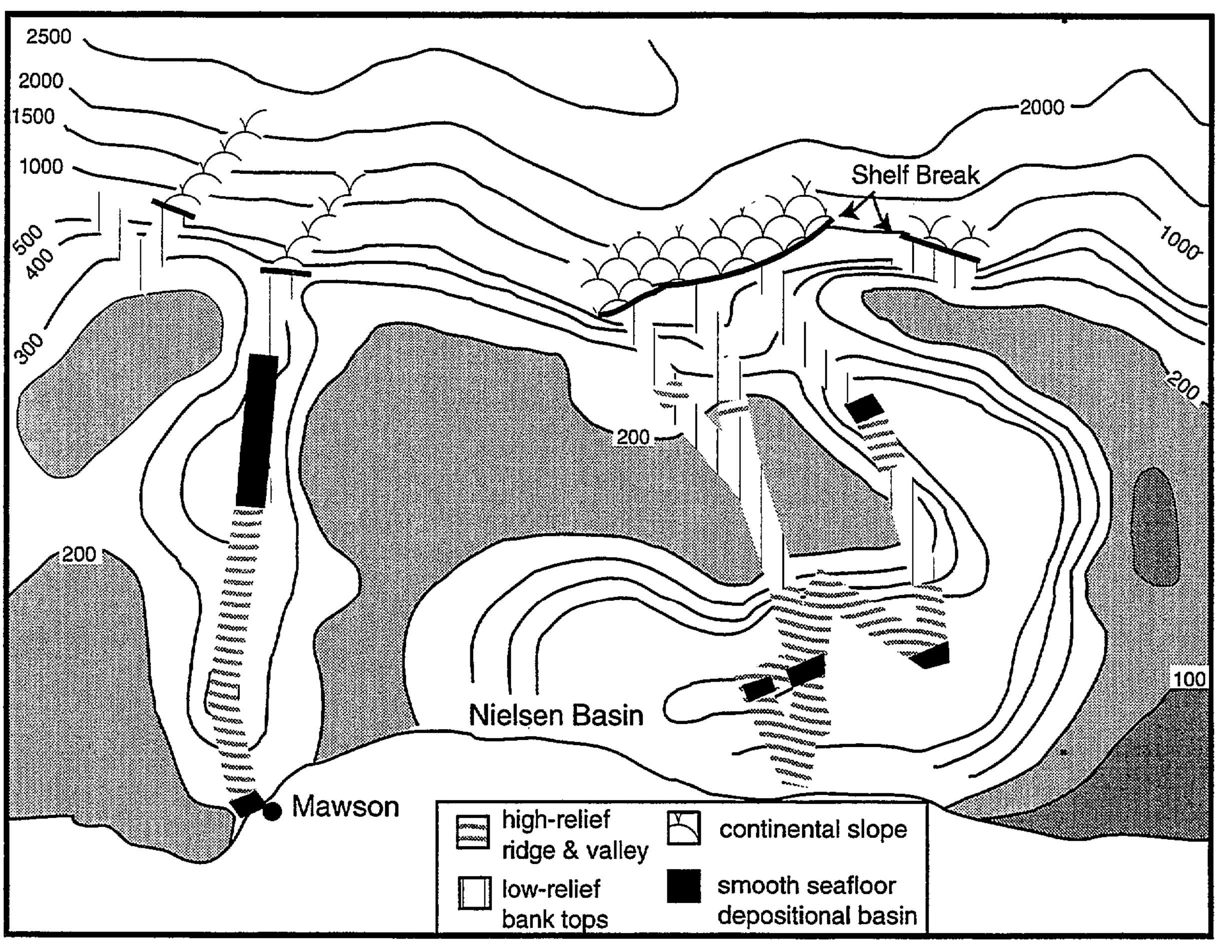



Figure 8. Geomorphic zones defined on the basis of available 3.5KHz profiles.

In addition to Quilty's (1985) samples, three cores and 5 surficial grab samples were obtained during the 1993 expedition of Aurora Australis (see Fig. 4 for locations). Core GC01, obtained in 478m water depth is a muddy, biosiliceous ooze, containing interbedded light/dark layers. The core was $^{14}C$-dated at its base at 12,250±110 years, which gives a sedimnetation rate of 16cm/kyr. The darker layers contain about 10% very fine grained quartz sand and diatoms, whereas the lighter layers are composed almost exclusively of diatoms. Figure 5 shows the layered sediments infilling a shelf-edge basin at the site of core GCO1. Analyses carried out by Dr. L. Dowling at AGSO's organic geochemistry laboratory indicate that samples from this core contain between 0.24 and 1.08% total organic carbon with a mean of 0.69% and no apparent down-core trends and $\delta^{13}C$ ranges between -24.64 and -26.75 with a mean of -25.28 and a trend towards increasing values with depth.

Core GC02, obtained in 1,091m water depth from Nielsen Basin (Fig. 4), has been $^{14}C$-dated at its base at 6,701±70 years BP; this gives a sedimentation rate of 44 cm/kyr (3 times that of GC01). Analyses indicate that samples from this core contain between 0.61 and 1.83% total organic carbon with a mean of 1.41% and no apparent down-core trends and $\delta^{13}C$ ranges between -24.42 and -23.84 with a mean of -24.09 and a trend towards slightly increasing values with depth. The core exhibits a colour variation between light to dark olive grey, which correlates with an increased terrigenous component. It is tempting to speculate that the increased terrigenous content below 100cm depth in the core is related to the 4 - 7 kyr BP hypsithermal event (Domack et al., 1991); further analyses on this core will determine whether such is the case.

Of the 3 cores available from this region, only GC3, located on a shallow bank-top in 134m water depth (67° 16'S, 65° 25'E) contains sufficient calcium carbonate for conventional isotope analyses. Radiocarbon dates on planktonic foraminifera (N. pachyderma) indicate an age of 4314 ±96 years BP at 15cm, and 8030 ±110 years BP at 55-57cm. Planktonic foraminifera are currently being analysed for oxygen isotopes and benthic foraminifera for carbon isotopes (P. Wells, work in progress). The sediments in this 57cm core are uniform, shelly foraminiferal diatomaceous fine to medium sands. The core is richly fossiliferous, and contains Mollusca, Bryozoa, Brachiopoda, Ostracoda, Foraminifera, diatoms and sponge spicules. The Bryozoan and Mollusca are currently being analysed for isotope and trace-element composition (P. Rao, Geology, Uni. Tas., work in progress)

Grab samples collected in 1993 from the Mac. Robertson shelf are described by O'Brien et al (1993). These include 1 sample from the

Nielsen Basin (G32) which contained a fine-grained anoxic ooze. The 2 samples from the slope (G33 and G34) contained coarse, bioclastic gravel, living sponges, polychaetes, brittle stars and gastropods. One sample collected from the sediment-filled basin of Iceberg Alley (G35) contained fine-grained sandy mud, with foraminifers, diatoms and sponge spicules. Grab sample G31 was obtained at the same site as core GC3 and had a composition similar to the core (described above).

Core stations planned for the 1995 cruise of Aurora Australis will provide the first systematic coverage of the region, allowing a more accurate assessment of the distribution of depositional environments. In particular, areas of net sediment accumulation will be sampled in more detail. A total of 30 stations are proposed in water depths of 100 to 2,200m for the Mac. Robertson Shelf (see Appendix A for locations) and 4 days have been allocated to this sampling program.

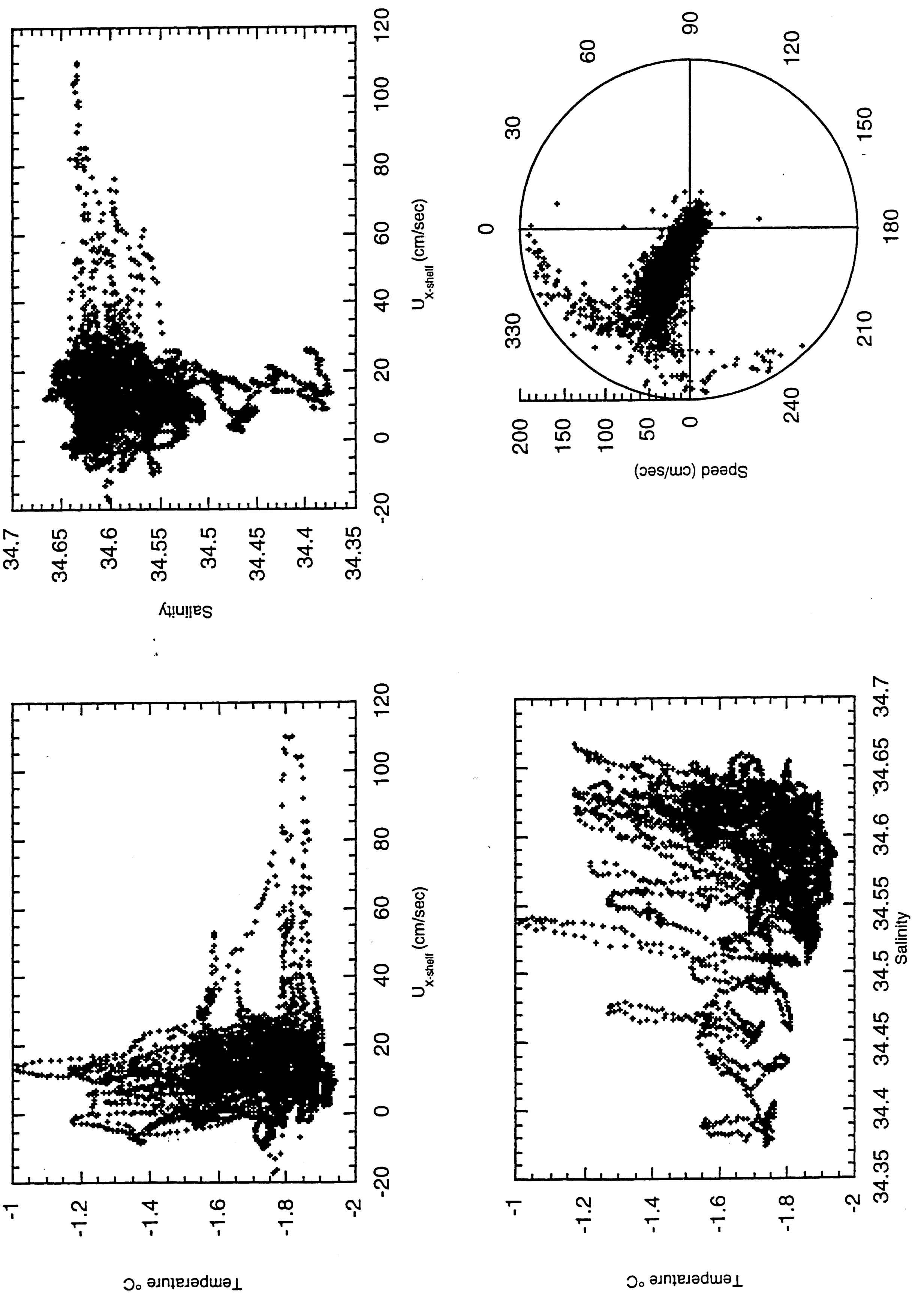
*Physical Oceanographic Data*

The Mac. Robertson Shelf is subject to strong, westward flowing shelf currents associated with the East Wind Drift. A weaker, cyclonic gyre system in Prydz Bay (Nunes Vaz and Lennon, 1993) is transformed into this swift boundary current, probably due to geographic constriction of the flow as it exits the bay. This swift current decouples primary production in surface waters from the underlying sediments, as material falling through the water column will be transported a distance before being deposited.

Current meter data obtained in 630m water off Iceberg Alley (Fig. 4), was moored at 10m elevation above the bed and collected data over a 10 month period in 1985. Current speeds of up to 192 cm/sec were recorded, flowing mainly parallel to the shelf edge (Fig. 10). Current speeds exceeding 150 cm/sec appear to coincide with an increased scatter of current direction, whereas currents less than 150 cm/sec are restricted to a direction between 260° and 300° (Fig. 10). Resolving the currents into along-shelf and across-shelf components (Fig. 11) shows that maximum speeds occur in bursts lasting for several days, followed by periods of lower speeds. The mean current speed over the 300 days of data was 47.3 cm/sec. The time-series of current speed-data exhibits an episode of prolonged weak currents, about 40 days in duration during July-August. Higher current speeds occurred during May-June and September-November (when the maximum current speed was recorded).

Temperature and conductivity data obtained by this mooring permit an analysis of the correlation of these properties with current speed. If the current maxima were produced by density currents, driven by winter sea-ice production, for example, one might expect a correlation to exist between these variables. In fact, peak across-shelf current speeds are associated with the lowest temperature (-1.8°C) and higher salinity (34.65$^{o}$/oo) water types (Fig. 10). The time-series of temperature, salinity and density demonstrates a change in regime over the 10 month period. Between May-August, temperatures were steady between -1.5 to -1.8 and salinity ranged between 34.5 and 34.6. During September to December, however, temperature oscillated at a frequency of several days, between about -0.8 to -1.8 and salinity showed a steady decline from >34.6 in October to less than 34.4 in December. This decline in salinity with contemporaneous oscillations in temperature correlates with the largest across-shelf current speeds and with the period of rapid seasonal melting of sea ice (Fig. 11). The current regime and water properties observed at this time are thus consistent with the sinking of shelf surface water masses and their flow down-slope as density currents.

Figure 10. Plots of across-shelf current speed versus temperature and salinity, plot of temperature versus salinity and plot of current speed versus direction from CM85-4 (see Fig. 4 for location).



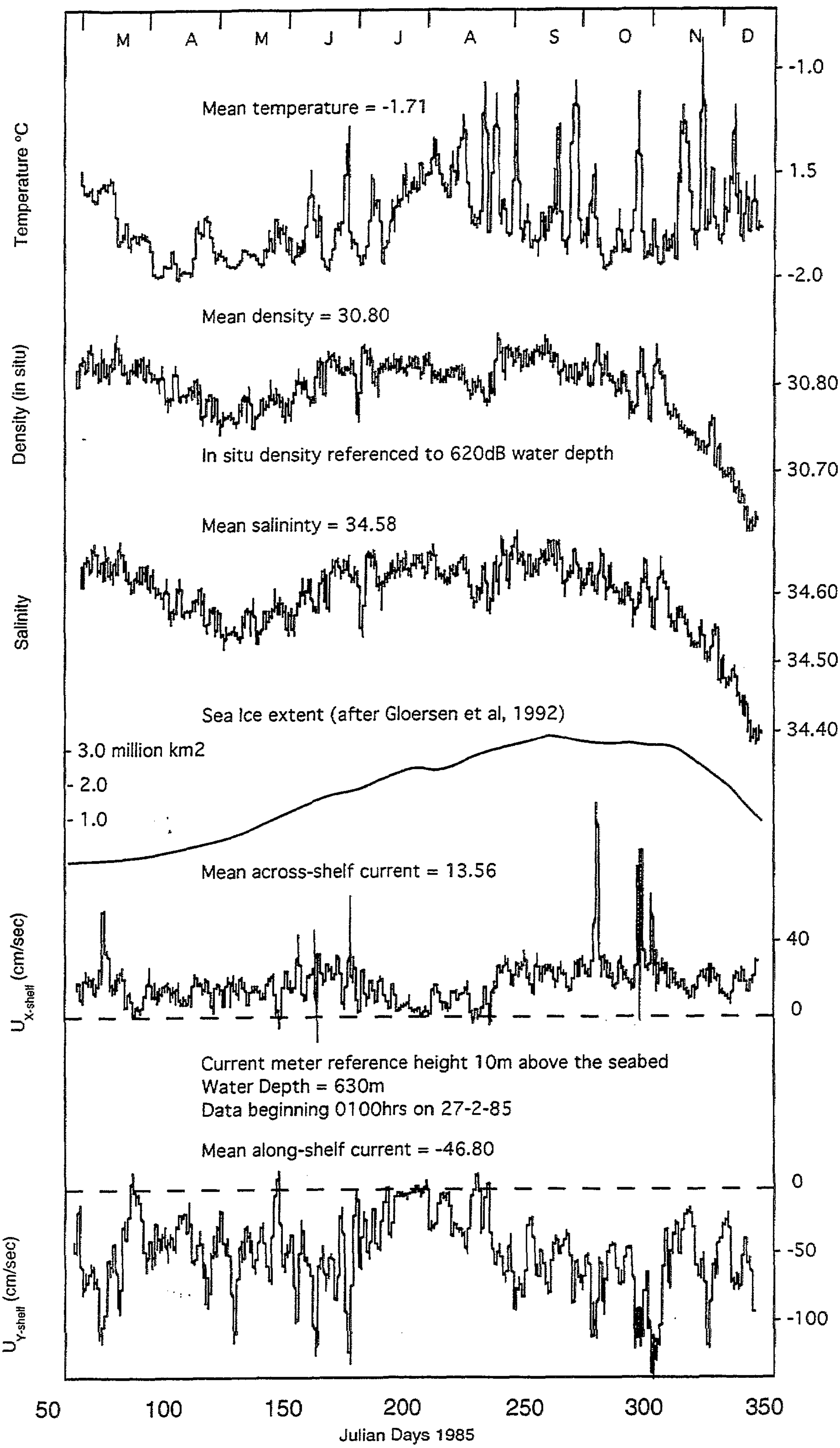



Figure 11. Time series plots showing data obtained from current meter CM85-4 (see Fig. 4 for location of the current meter). The curve showing the extent of sea-ice cover during 1985 was abstracted from Gloersen *et al.* (1992).

If the production of bottom water is occurring in this area, then current meters placed in the bottom of shelf valleys, connecting the deep shelf basins to the continental slope canyons, should record the episodic passage of cold, salty water. If the strong current events described above are associated with the export of bottom water, it is likely that they play a significant role in the redistribution of sediments on the shelf and in the organisation of sedimentary facies. To test this hypothesis, we propose to place 2 Aanderaa current meters on the bottom of the shelf valley which connects the Nielsen Basin with the continental slope (Fig. 4; see Appendix A for exact coordinates). Also, in order to relate the structure of the water column present on the shelf during the summer to observed currents, we will collect CTD profiles at each of the 30 core stations mentioned above.

*Suspended Sediments*

No previous observations of suspended sediments or of sediment dynamics are available from the Mac. Robertson shelf. However, studies carried out in other parts of Antarctica may give an indication of the concentrations and factors controlling sediment suspension.

Elverhoi and Roaldset (1983) collected and filtered seawater from 16 sites in the Weddell Sea to determine suspended sediment concentrations and characteristics. A total of 30 samples were obtained in water depths of 180 to 1,800m, within 250km of the eastern Weddell Sea ice shelf (off Dronning Maud Land), at 1m and other various heights above the seabed. Concentrations of suspended sediments were from 2.2 to 0.2 mg/l, with the highest concentrations being obtained at 1m above the bed. The material in suspension was classified into three categories: (1) biogenic; (2) detrital clastic; and (3) authigenic. Clastic material was dominant at 21 out of 30 samples, biogenic sediments dominated at 5 out of 30 samples and authigenic sediments dominated at 4 out of the 30 samples. The clastic material is composed of: (i) glacial detritus, 15 to 70µm in size; and (ii) aeolian silicates with traces of cosmic/volcanic metalliferous grains, <5 to 10µm in size. Biogenic grains are mostly diatoms, 20 to 17µm in size, with occasional threadlike spicules up to 300µm in length. Biogenic faecal pellets are also an important component. Authigenic grains identified are iron-silicate aggregates.

Carter et al. (1981) collected and filtered seawater from 7 stations in the Ross Sea, from under the ice shelf, to determine suspended sediment concentrations and characteristics. Samples were collected at 4-hourly intervals over a 24 hour period at each station, in water depths of 138 to 620m. Between 4 and 6 samples were collected during each cast, equally spaced through the water column, starting above the seabed. Current speed and water temperature and salinity were also measured. Concentrations of suspended sediment ranged typically between 2 to 4 mg/l with a maximum value of 8.7 mg/l. The highest concentrations were observed at mid-depth, rather than directly above the seabed, suggesting that lateral transport rather than direction erosion and resuspension of bed material was the major source of the suspended particulate material. Mean current speeds ($\bar{u}$) were 5 to 15 cm/sec and the highest speed measured was 33 cm/sec. Speeds exhibited a semidiurnal tidal oscillation and the highest values were recorded at mid-depth, probably due to the boundary shear of the sea ice above and the seabed below the moving water mass. Integration of the suspended sediment concentration (C) through the water column (Z) was combined with current speed data in order to estimate sediment flux ($F = \bar{u}\ C\ Z$). The net flux was found to be landward, under the Ross Ice Shelf. The character of the suspended samples analysed by Carter et al (1981) was found to be similar to that of the samples described by Elverhoi and Roaldset (1983), above, i.e. terrigenous glacial detritus comprised most of the material in suspension.

During voyage 6 of Aurora Australis, it is planned to obtain near-surface and near-bed water samples for filtration and determination of suspended sediment concentration and character. These will be used to calibrate an optical backscatter sensor (OBS) that will be deployed as an attachment to a Neil Brown CTD. The CTD will be deployed at each core station (see Appendix A). Furthermore, time-series of suspended sediment will be recorded by transmissometers attached to current meters that are planned for deployment at 2 locations in the shelf valley that joins the Nielsen Basin to the shelf break. These current meters will be moored with their rotors (and the transmissometer) located 150cm above the seabed and left in situ for 1-year. These measurements will be used to estimate the annual across-shelf flux of suspended particulate matter and to investigate the influence of bottom-water formation on near-bed currents in the area.

## KERGUELEN PLATEAU

This part of the cruise is part of a study targeting transects of the Southern Ocean between 60°E and 180°E that potentially preserve sediments deposited in contact with major water masses and beneath zones in which the major fronts have moved. Other regions being examined are the South Tasman Rise and the Chatham Rise.

The Kerguelen Plateau is a NNW-trending ridge 2100km long between 45°S, 65oE and 63oS, 83oE. It is about 500 km across and rises 3 to 4 km above the surrounding ocean floor (Fig. 12). Kerguelen, Heard and McDonald Islands are peaks on the northern half of the plateau. Water depths on the southern half are as shallow as 700 m but are mostly between 1500 m and 2500 m (Fig. 12).

### Previous Work

Geophysical surveys carried out on the Kerguelen Plateau up until 1983 are summarised by Ramsay *et al.* (1986). Since then, AGSO conducted multi-channel seismic surveys (Ramsay *et al.*, 1986) and French institutions have conducted seismic reflection and sampling programs using N/O Marion Dufresne; these programs are reviewed and summarised by Schlich, Wise *et al.* (1989). Piston cores were collected from the region by Eltanin cruises, mostly in deep basins next to the plateau, by the Robert Conrad (Fig. 12), and by the Marion Dufresne (Schlich, Wise *et al.*, 1992). ODP leg 119 (Barron, Larson *et al.*, 1989, 1991) and leg 120 (Schlich, Wise *et al.*, 1989, 1992) drilled 11 holes on the Plateau. The most recent activity consists of seismic reflection surveys by the Research Institute for the Geology and Mineral Resources of the World Ocean (Leitchenkov, pers. comm., 1994) and the collection of one gravity core by AGSO in 1993 (O'Brien *et al.*, 1993).

### Objectives

1. To reconstruct the structure and the carbon and nutrient chemistry of the deep water masses in the Southern Ocean.
2. To establish the location and movements of the surface water mass fronts of the Southern Ocean over glacial/interglacial cycles.
3. To determine the influence of the Southern Ocean chemistry and structure (as above) on global climate change on Milankovitch time scales.

### Justification

The Southern Ocean plays a key role in the circulation of the world's oceans and global climate. Sea surface temperature patterns are a major determinant of global climate and the Southern Ocean is a region where major deep and intermediate water masses are generated. These water masses are important in the interchange of Carbon dioxide between the atmosphere and the ocean, with the Southern Ocean thought to be one of the major sinks for $CO_2$. The Southern Ocean features several major hydrological boundaries between water masses. The Sub-Tropical Convergence and the Polar Front are the two most important, across which marked surface water temperature gradients occur. The Polar Frontal Zone is also the site of formation of an important water mass, Antarctic Intermediate Water (Tchernia, 1980).

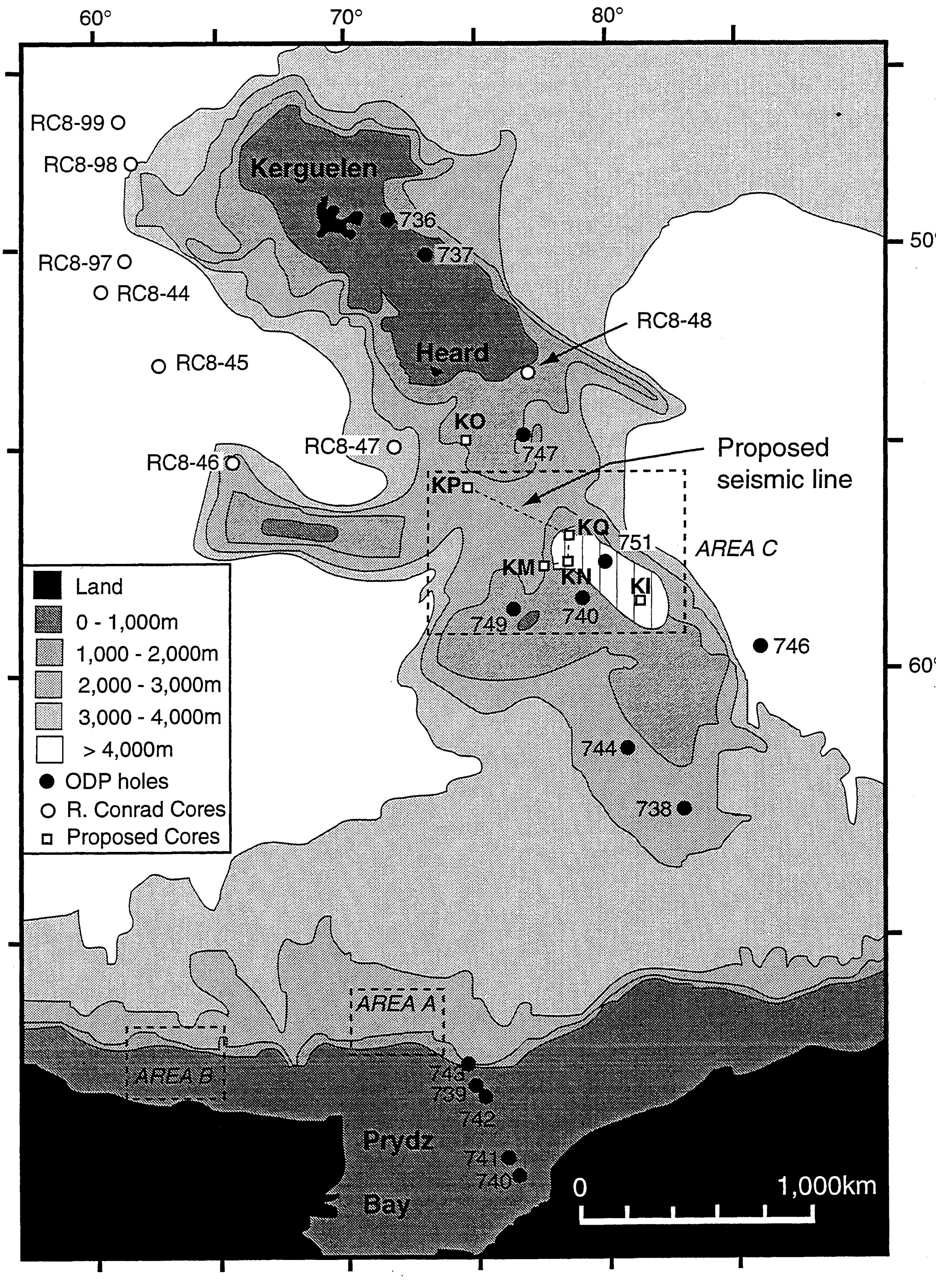



Figure 12. Bathymetry of the Kerguelen Plateau region, showing the location of Ocean Drilling Program holes, core sites occupied by the Robert Conrad and proposed cores sites of the present study. The location of thick Quaternary sediments as interpreted from existing seismic and core data are indicated by vertical shading.

During episodes of varying climate, these major hydrological fronts of the Southern Ocean are thought to change their position, moving north during glacials and southward during interglacials in many places (Howard & Prell, 1992). Processes of deep and intermediate water mass formation may have changed as well, with reduced North Atlantic Deep Water formation during glacial periods enhancing the role of the Southern Ocean (Charles & Fairbanks, 1992). Importantly, Boyle (1988) and Broecker & Peng (1989) proposed that a shift of the Southern Ocean nutrient sink from intermediate water in the interglacial ocean to deep waters in the glacial ocean can explain the 30 percent change in atmospheric $CO_2$ observed between glacial and interglacial episodes. Thus, tracing the changes in sea surface temperature, primary production and deep and intermediate water mass formation during the Quaternary would provide significant tests of models of Antarctic and global climatic change.

## Research Design

The major challenge in Quaternary palaeoceanography of the Kerguelen Plateau is obtaining continuous cores of Quaternary sediment from the depths of interest on the plateau. Rig Seismic and Eltanin seismic lines have been used to identify the distribution of sediments and have been compared to the core top ages of ODP holes and published ages for piston cores in order to understand patterns of erosion and deposition. The results of this exercise indicate that Quaternary sediments more than a few centimetres thick are found only on the crest of the plateau and possibly in locations where the sea floor is protected by topography from erosive ocean currents (Fig. 12). These areas will be crossed by short seismic lines before sampling, weather permitting. This will identify the best sediment accumulations for sampling and better identify areas of erosion at the sea floor.

The main sampling tool will be gravity coring with some grab sampling and CTD water sampling. Cores will be logged for sedimentological characteristics and their chronostratigraphy developed using $^{14}$C. dating. Analyses on core samples will include stable isotopes of foraminifera, particularly (18O for estimating palaeotemperatures and chronostratigraphy and ($^{13}$C of benthic foraminifera for trace the flow of nutrients in water masses in contact with the sea floor. Biomarker compounds from the extractable lipids will be used as additional sea surface temperature indicators (alkenone instauration ratio, Uk'37) and (13C of individual alkenones will be measured as a proxy for past atmospheric CO2 content. Foraminiferal and coccolithophorid assemblages will be used as indicators of sea surface temperatures and palaeoproductivity.

## TRENDS IN MODERN AND HOLOCENE CARBON ISOTOPE SIGNALS AND ASSEMBLAGES OF DEEP SEA BENTHIC FORAMINIFERA: RELATION TO DEEP WATER $\delta^{13}C$ SIGNALS

Southern Ocean benthic foraminifera in the vicinity of oceanic fronts (Kerguelen Plateau), and at the potential site of Antarctic bottom water formation (Prydz Bay) are little understood at present. Modern analogues can provide the key to sensible interpretation of down-core trends in benthic foraminifera. The $\delta^{13}C$ characteristics of modern deep-water masses and living benthic foraminifera on the Prydz Bay (Antarctica) and Kerguelen Plateau areas, will be examined to (1) determine the modern regional variation in the $\delta^{13}C$ signal and to assess the extent of decoupling of the water-benthic signals in relation to localised changes in nutrient level/productivity and (2) determination of suitable Antarctic epifaunal benthic forams that can be used as a proxy for $\delta^{13}C$ signals, to determine the modern $\delta^{13}C$ characterise of bottom waters in Prydz Bay and its paleosignal in fossil sequences.

The $\delta^{13}C$ record of the benthic foraminifera *C. wuellerstorfi* is commonly used as an indicator of changes in Late Quaternary paleoproductivity and deepwater circulation, since it is generally accepted that this species secretes its test in equilibrium with the carbon isotopes of the carbon dioxide dissolved in the ambient sea water. However, recent work in the eastern Atlantic sector of the Southern Ocean (Mackensen et al, 1994) has indicated that the $\delta^{13}C$ of *C. wuellerstorfi* can differ significantly from the mean deep-ocean values in areas of high productivity, associated with major oceanographic fronts. This has important implications in interpreting the past history of ocean circulation, since the paleo-$\delta^{13}C$ signal of *C. wuellerstorfi* can be erroneously attributed to glacial/interglacial shifts in mean ocean circulation patterns when they should more correctly be attributed to shifts in the geographic position (i.e. 'localised effects') of the Polar Front Zone.

The Kerguelen Plateau region is located between the Subtropical Convergence and Polar Front Zone, and is a major $CO_2$ sink in summer, when maximum phytoplankton activity occurs. The resultant increase in surface productivity results in a high influx of $^{12}C$ depleted organic matter to the deep-sea floor, in turn resulting in a release of $^{12}C$ at the sediment-water interface which is recorded in depleted $\delta^{13}C$ in *C. wuellerstorfi*. This facet of the $\delta^{13}C$ record in the Australian sector of the Southern Ocean needs to be investigated. The regional circulation in this area is complex, and individual sites are expected to show differing degrees of coupling or decoupling in the modern bottom water *C. wuellerstorfi* $\delta^{13}C$ signal, but this must be understood before down-core interpretations can be made.

In addition, population compositions of deep-sea benthic foraminifera of the Atlantic sector of the Southern Ocean (35°S to 57°S) have been shown to have a distinct character that is associated with different, deep-sea, water masses (Mackensen et al., 1993; Mackensen et al., 1990). Voyage 6 of Aurora Australis will provide an opportunity to determine the character of the benthic foraminiferal populations in the Kerguelen Plateau area and establish their relationships to oceanographic parameters, especially the deep-water mass in which they are immersed. Once the association between benthic foraminifera and key deep-water masses is established, it will be applied to selected down-core sequences, enabling interpretation of the lateral and vertical movement of deep-water masses over the Kerguelen Plateau during the Late Quaternary.

Different taxa of deep sea benthic foraminifera live at specific depths within the sediment to depths of 20 cm: this vertical structuring is dynamic and varies with changes in nutrient availability and/or changing environmental conditions. Changes in the population structure of deep sea benthic foraminifera will be examined for indications of past changes in surface productivity.

The expected outcomes from this study are determination of: (1) deep and intermediate water characteristics; (2) the localised deviation of the C. wuellerstorfi dC13 record from that of the dC13 of ambient bottom waters, and (3) study of the population characteristics and vertical habitat structure of living benthic foraminiferal assemblages on the Antarctic continental margin. The latter will provide a modern analogue, which when coupled with the $\delta^{13}C$ information from surface-dwelling benthics, can be applied to deduce past changes in surface productivity and deep water circulation in selected down-core sequences. Shipek grabs will be deployed at a number of stations on the Prydz Bay Fan and Neilsen Basin and Kerguelen Plateau. Samples will be processed in the manner outlined in McCorkle et al. (1990). Niskin bottles will be deployed to collect water above the sediment/water interface.

## NANNOPLANKTON DISTRIBUTION IN SOUTHERN OCEAN WATERS AND SEDIMENT AND THEIR USE IN PALAEOCEANOGRAPHIC RECONSTRUCTIONS.

Calcareous nannoplankton in deep-sea sediment can be used as useful Palaeoclimate indicators to supplement information from other microfossil groups. In particular their biostratigraphic trends can be used to subdivide the Plio-Pleistocene at a very high resolution. In addition, floral trends have been linked variation in to surface productivity (Okada and Wells, submitted), and to changes in the vertical structure of the ocean (Molfino and McIntyre, 1990). Nannofossils are preserved in deep-sea sediment of the Southern Ocean particularly north of the Polar Front (Nishida, 1986), but little is known of the modern (living) floral composition of the Indian Ocean at the high latitudes of the Kerguelen Plateau and further south, or of the links between living nannoplankton distribution and associated preservation on the modern sea-floor.

This study aims to provide some of this information, and to apply observed trends to selected core sequences, in order to establish the Late Quaternary paleo-record of: (a) changes in the vertical structure of the water column; (b) interpretation of major changes in past ocean-circulation (in particular migration of major hydrological fronts in the Southern Ocean). This will be achieved through examination of living and fossil nannoplankton south of and adjacent to the Polar Front and the Subtropical Convergence fronts in the Kerguelen Plateau region, and at higher latitudes.

Calcareous nannoplankton are generally sparse or absent at high latitudes in the Southern Ocean (including the southern Kerguelen Plateau), but occasional incursions of *E. huxleyi* are known (Wei and Thierstein, 1991; Wei and Wise, 1992). Further south, calcareous nanoplankton have been found in the Ross Sea (Thomson et. al., 1988), and the Weddell Sea. Research to date (Findlay, 1994a,b) has identified similar taxa in water samples of the Southern Ocean between approximately 50°S to 63°S, and observed that these species have a considerable degree of calcification, suggesting that they may be preservable in the sediment, and useful in palaeoceanographic reconstructions.

Currently, trends in the modern distribution of nannoplankton in the Southern Ocean are being determined from filtered water samples (WOCE material transect along ~ 140°E: C. Findlay PhD thesis, in prep.) and from modern sediment samples (cores from the cruises of *Eltanin* and *Sonne*). To supplement those studies, additional ~2 litre water samples (5 levels down to 250 m water-depth on the Kerguelen Plateau), and underlying sea-floor sediments, will be collected on Voyage 6.

## References

Allison, I., (1979) The mass budget of the Lambert Glacier drainage basin, Antarctica. *Journal of Glaciology*, 22:223-237.

Anderson, J. B., Brake, C. F., & Myers, N. C. (1984) Sedimentation on the Ross Sea continental shelf, Antarctica. *Marine Geology*, 57:295-333.

Anderson, J.B., Banfield, L., Bart, P., Bartek, L., De Santis, L., & Shipp, S. (1994) Seismic expression of glaciation on the Antarctic Continental Shelf. In: Cooper, A.K., Barker, P.F., Webb, P-N., & Brancolini, G. (editors) The Antarctic continental margin: geophysical and geological stratigraphic records of Cenozoic glaciation, paleoenvironments and sea-level change. *Terra Antarctica*, 1(2):411-412.

Barron, J., Larson, B., et al., (1989) Proceedings ODP Initl. Repts., 119, College Station, Texas, 1003 pp.

Bart, P., De Batist, M., & Miller, H. (1994) Neogene collapse of glacially-deposited, shelf-edge deltas in the Weddell Sea: relationship between deposition during glacial periods and sub-marine fan development. In Cooper, A.K., Barker, P.F., Webb, P-N., & Brancolini, G. (editors) The Antarctic continental margin: geophysical and geological stratigraphic records of Cenozoic glaciation, paleoenvironments and sea-level change. *Terra Antarctica*, 1(2):317-318.

Boulton, G.S., (1990) Sedimentary and sea level changes during glacial cycles and their control on glacimarine facies architecture. In: Dowdeswell, J.A. & Scourse, J.D. (editors) *Glacimarine environments: processes and sediments*. Geological Society Special Publication, 53, 15-52.

Boyle, E. A. (1988) The role of verticle chemical fractionation in controling late Quaternary atmospheric carbon dioxide, *Jour. Geophys. Res.*, 93:15701-15714.

Broecker, W. S., & Peng, T-H. (1989) The cause of the glacial to interglacial atmospheric co change: A polar alkalinity hypothesis. *Global Biogeochemical Cycles*, 3:215-239.

Carter, L., Mitchell, J. S., & Day, N. J. (1981). Suspended sediment beneath permanent and seasonal ice, Ross Ice Shelf, Antarctica. *New Zealand Journal of Geology and Geophysics*, 24:249-262.

Charles, C. D. & Fairbanks, R. G. (1992) Evidence from Southern Ocean sediments for the effect of North Atlantic deep water flux on Climate, *Nature*, 335, 416-419.

Cooper, A.K., Barrett,P.J., Hinz, K., Traube, V., Leitchenkov, G. & Stagg, H.M.J. (1991) Cenozoic prograding sequences of the Antarctic continental margin: a record of glacio-eustatic and tectonic events. *Marine Geology*, 102, 175-213.

Cooper, A., Stagg, H., and Geist, E. (1991) Seismic stratigraphy of Prydz Bay, Antarctica: implications from leg 119 drilling. In: Barron, J., Larson, B., et al., *Proceedings ODP Sci. Results*, vol. 119, 5-25.

De Batist, M., Bart, P., Kuvaas, B., Moons, A., & Miller, H. (1994) Detailed seismic stratigraphy of the Crary Fan. In Cooper, A.K., Barker, P.F., Webb, P-N., & Brancolini, G. (editors) The Antarctic continental margin: geophysical and geological stratigraphic records of Cenozoic glaciation, paleoenvironments and sea-level change. *Terra Antarctica*, 1(2):321-323.

Domack, E.W., Jull, A.J.T. & Nakao, S. (1991) Advance of East Antarctic outlet glaciers during the Hypsithermal: implications for the volume state of the Antarctic ice sheet under global warming. Geology, 19, 1059-1062.

Domack, E. W., Jull, A. J. T., & Donahue, D. J. (1992). Holocene chronology for the unconsolidated sediments at Site 740A. In: Barron, J., Larson, B., et al. (eds) *Proceedings ODP Sci. Results*,, 119, College Station, Texas.

Dunbar, R. B., Anderson, J. B., Domack, E. W. and Jacobs, S. S. (1985) Oceanographic influences on sedimentation along the Antarctic continental shelf. In: Jacobs, S.S. (editor) Oceanology of the Antarctic continental shelf. American Geophysical Union Antarctic Research Series, 43, pp. 291-312.

Elverhoi, A., & Roaldset, E. (1983). Glaciomarine sediments and suspended particulate matter, Weddell Sea, Antarctica. *Polar Research*, 1:1-21.

Federov, L.V., Grikurov, G.E., Kurinin, R.G. & Masolov, V.N. (1982) Crustal structure of the Lambert Glacier area from geophysical data. In: Craddock, C., (editor) *Antarctic Geoscience*, University of Wisconsin Press, Madison, pp. 931-936.

Findlay, C., (1994) Floral assemblage of calcareous nannoplankton from the water column of the Southern Ocean and their biostratigraphic distribution. Abstract. Workshop *Late Quaternary history of the oceans in the Australasian region* Australian National University. November, 1994.

Findlay, C., (1994). The identification of three morphotypes of *Emiliania huxleyi* in the water column of the Southern Ocean and their biogeographic distribution. Abstract. Workshop *Calcareous nannoplankton- applications to Quaternary paleoceanography* Workshop. University of Tasmania. November, 1994.

Franklin, D. (1991) *The marine environment of Prydz Bay, Antarctica: microbiota and facies distribution*. Unpublished Honours Thesis, Australian National University.

Hambrey, M.J., Ehrmann, W.U., & Larsen, B. (1991) Cenozoic glacial record of the Prydz Bay continental shelf, East Antarctica. In. Barron, J., Larson, B., et al. Proceedings of the Ocean Drilling Program Scientific Results, 119, 77-132.

Harwood, D.M. and Maruyama, T. (1992) In: Wise, S.W., Schlich, R., et al., (editors) *Proceedings of the Ocean Drilling Program, Scientific Results*, 120, p. 683 - 733.

Hiscott, R. N. & Aksu, A. E., (1994) Submarine debris flows and continental slope evolution in front of Quaternary Ice Sheets, Bafin Bay, Canadian Arctic. *American Association of Petroleum Geologists Bulletin*, 78(3):445-460.

Howard, W. R. & Prell, W. L. (1992) Late Quatemary surface circulation of the southern Indian Ocean and its relationship to orbital variations, *Paleoceanography*, 7, 79-117.

Jacobs, S. S. (1989). Marine controls on modern sedimentation on the Antarctic continental shelf. *Marine Geology*, 85:121-153.

Kuvaas, B. & Kristoffersen, Y. (1991) The Crary Fan: a trough-mouth fan on the Weddell Sea continental margin, Antarctica. *Marine Geology*, 97, 345-362.

Kuvvas, B. & Leitchenkov, G. (1992) Glaciomarine turbidite and current controlled deposits in Prydz Bay, Antarctica. *Marine Geology*, 108, 365-381.

Larter, R. D. & Cunningham, A. P. (1993) The depositional pattern and distribution of glacial-interglacial sequences on the Antarctic Peninsula Pacific margin. *Marine Geology*, 109, 203-219.

Lisitzin, A.P., 1960 - Bottom sediments of the eastern Antarctic and the southern Indian Ocean. Deep Sea Research, 7, 89-99.

Mackensen, A. et al. (1993). Benthic foraminiferal assemblages from the eastern South Atlantic Polar Front region between 35° and 57°S: distribution, ecology and fossilisation potential. *Mar. Micropal.*, 22:33-69.

Mackensen, A., et al. (1990). Benthic foraminiferal assemblages from the Eastern Weddell Sea between 68° and 73°S: distribution, ecology and fossilisation potential. *Mar. Micropal.*, 16: 421-283.

Mackensen et al., (1994). $\partial^{13}C$ in benthic foraminiferal tests of Fontbotia wuellerstorfi (Schwager) relative to $\partial^{13}C$ of dissolved inorganic carbon in Southern Ocean deep water: implications for glacial ocean circulation models. *Paleoceanography*.

Mcleod, I.R., Trail, D.S., Cook, P.J., & Wallis, G.R., 1966 Geological work in Antarctica, January to March, 1965. Bureau of Mineral Resources, Australia, Record, 1966/9.

McCorkle, D.C., Keigwin, L.D., Corliss, B.H. and Emerson, S.R., (1990). The influence of microhabitats on the carbon isotopic composition of deep-sea benthic foraminifera. *Paleoceanography*. 5(2) : 161-185.

Mizukoshi, T., Sunouchi, H., Saki, T., & Tanahshi, M. (1986) Preliminary report of the geological and geophysical surveys of Amery Ice

Shelf, East Antarctica. *Memoirs of the National Institute of Polar Research*, Japan, Special Issue, 43, 48-62.

Molfino, B. and McIntyre, A., (1990). Nutricline variation in the equatorial Atlantic coincidental with the Younger Dryas. *Paleoceanography*, 5(6) : 9971

Murray, J., & Renard, A. (1891) Report on deep-sea deposits based on specimens collected during the voyage of H.M.S. Challenger in the years 1872 to 1876. *Challenger Reports*, 821 pp.

Nishida, S. (1986) Nannoplankton flora in the Southern Ocean, with special reference to siliceous varieties. *Memoir of the National Institute of Polar Research*, Special Issue, 40 : 56-68.

O'Brien, P.E. (1994) Morphology and Late Glacial history of Prydz bay, Antarctica, based on echo sounder data. In Cooper, A.K., Barker, P.F., Webb, P-N., & Brancolini, G. (editors) The Antarctic continental margin: geophysical and geological stratigraphic records of Cenozoic glaciation, paleoenvironments and sea-level change. *Terra Antarctica*, 1(2), 403-405.

O'Brien, P. E., Franklin, D., & O'Loughlin, M. (1993). Post Cruise Report - Prydz Bay and Mac. Robertson shelf, Antarctica , January - March, 1993. Australian Geological Survey Organisation, Record No. 1993/78, 39 pp.

Quilty, P. (1985). Distribution of foraminiferids in sediments of Prydz Bay. *South Australian Department of Mines and Energy Special Publication*, **5**, 329-340.

Ramsay, D.C., Colwell, J.B., et al. (1986) *Rig Seismic research cruise 2: Kerguelen Plateau initial report*. Bureau of Mineral Resources, Australia, Report, 270, 41 pp.

Stagg, H.M.J. (1985) The structure and origin of Prydz Bay and Mac. Robertson Shelf, East Antarctica. *Tectonophysics*, 114, 315-340.

Schlich, R., Wise, S.W., et al. (1989) *Proceedings of the Ocean Drilling Program Initial Report*, 120, 648 pp.

Sugden, D.E., Marchant, D.R., & Denton, G.H. (editors) (1993) The case for a stable East Antarctic Ice Sheet. *Geografiska Annaler*, 75A, 151-351.

Tchernia, P. (1980) *Descriptive regional oceanography*. Pergamon Press, 252 pp.

Thompson, H.A, Buck, K.R., Coale, S.L., Garrison, D.L. and Gowing, M.M., (1988). Nanoplanktonic coccolithophorids (Prymnesiophyceae, Haptophyceae) from the Weddel Sea, *Antarctica. Nord. J. Bot.* 8(4) : 419-436.

Vanney, J.R. & Johnson, G.L., 1985 - GEBCO Bathymetric Sheet 5.18 (Circum-Antarctic) In. Jacobs, S.S. (editor) Oceanology of the Antarctic continental shelf. American Geophysical Union Antarctic Research Series, 43, 1-4.

Webb, P-N., Harwood, D.M., McKelvey, B.C., Mercer, J.H. & Stott, L.D., (1984) Cenozoic marine sedimentation and ice-volume variation on the East Antarctic Craton. *Geology*, 12, 287-291.

Wei, W and Thierstein, H.R., (1991). Upper Cretaceous and Cenozoic calcareous nannofossils of the Kerguelen Plateau (southern Indian Ocean) and Prydz Bay (East Antarctica). In : Barron, J., Larsen, B., et al. (Eds), *Proceedings of the Ocean Drilling Project*, Scientific Results, 119: 467-493.

Wei, W. and Wise, S.W., Jr., (1992). Oligocene-Pleistocene calcareous nannofossils from Southern Ocean Sites 747, 748, 751. In : Wise, S.W. Jr., Schlich, R., et al., (eds) *Proceedings of the Ocean Drilling Program Scientific Results*, vol 120.

Wise, S.W., Schlich, R., et al., 1992 - *Proceedings of the Ocean Drilling Program Scientific Results*, 120, 448 pp.

# APPENDIX A

## Proposed Geophysical Survey Way-Points and Coring Sites

**Area A**: *Prydz Bay Seismic/Side-scan sonar Survey and Core Sites*

| Point | Latitude | Longitude |
|---|---|---|
| TA | 66° 5'S | 070°42'E |
| TB | 66°52'71"S | 071°33'E |
| TC | 66°50'S | 071°49'E |
| TD | 65°58'S | 071°30'E |
| TE | 65°58'S | 072°15'E |
| TF | 66°50'S | 072°20'E |
| TG | 66°50'S | 072°42'E |
| TH | 65°55'S | 072°55'E |
| TI | 66°10'S | 074°10'E |
| TJ | 66°55'S | 073°07'E |
| TK | 66°23'S | 073°48'E |
| TL | 66°10'S | 072°52'E |
| TM | 66°12'S | 070°36'E |
| TN | 66°53'S | 070°36'E |
| TO | 66°48'S | 072°00'E |
| ODP739 | 67°16.5'S | 075°04.5'E |

**Area B**: *Mac. Robertson Shelf Seismic/Side-scan sonar Survey*.

| Point | Latitude | Longitude |
|---|---|---|
| A | 67° 35'S | 62° 45'E |
| B | 67° 00'S | 63° 05'E |

crossing over sites GC1 @ 66° 53.95'S 63° 09.26E 478m depth and current meter 85-4 @ 66° 44'S 63° 17'E 630m depth

| Point | Latitude | Longitude |
|---|---|---|
| C | 66° 35'S | 63° 25'E |
| D | 66° 35'S | 63° 50'E |
| E | 67° 27'S | 63° 40'E |
| F | 67° 28'S | 64° 05'E |
| G | 66° 41'S | 64° 20'E |
| H | 66° 42'S | 64° 50'E |
| I | 67° 37'S | 64° 42'E |

| | | |
|---|---|---|
| J | 67° 37'S | 65° 15'E |
| K | 66° 41'S | 65° 25'E |
| L | 66° 42'S | 65° 55'E |
| M | 67° 40'S | 65° 55'E |
| N | 67° 32'S | 66° 30'E |
| O | 67° 20'S | 66° 30'E |

crossing over site GC3 @ 67° 16.18'S 65° 25.07E 134m depth

| | | |
|---|---|---|
| P | 67° 13'S | 64° 38'E |
| Q | 67° 28'S | 64° 05'E |

follow deepest "curved" course along basin thalweg
passing over site of GC2 @ 67° 28.46'S 64° 58.36'E 1091m depth

| | | |
|---|---|---|
| R | 66° 54'S | 65° 00'E |
| S | 66° 54'S | 63° 00'E |

580 nautical mile of track = 116 hours (4 days & 20hrs) @ 5 knots

*Current Meter Moorings and Core/Camera/Grab Sites*

| | | | |
|---|---|---|---|
| CM1 | 66° 55'S | 65° 12'E | 350m water depth |
| CM2 | 66° 53'S | 65° 00'E | 550m water depth |

Note: core sample, deep-sea photograph and bottom water sample (10 litres) to be obtained at each current meter site prior to deployment. The 30 core sites nominated below may be relocated on the basis of seismic data obtained. 4 days time to be allowed for current meter deployments, coring, deep sea camera and grab sampling in this area.

*Mac. Robertson Shelf Core Sites*

| Station | Latitude | Longitude | Depth (m) |
|---|---|---|---|
| 1 | 67° 08'S | 63° 00'E | 500 |
| 2 | 67° 04'S | 63° 03'E | 500 |
| 3 | 66° 57'S | 63° 08'E | 400 |
| 4 | 66° 44'S | 63° 19'E | 300 |
| 5 | 66° 39'S | 63° 14'E | 300 |
| 6 | 66° 44'S | 63° 17'E | 630 CM85/4 |
| 7 | 66° 49'S | 63° 48'E | 800 |
| 8 | 67° 00'S | 63° 45'E | 200 |
| 9 | 67° 14'S | 64° 42'E | 100 |
| 10 | 67° 27'S | 63° 52'E | 100 |
| 11 | 67° 28'S | 64° 53'E | 1,100 |
| 12 | 67° 28'S | 65° 13'E | 1,000 |
| 13 | 67° 28'S | 65° 41'E | 1,000 |

| | | | |
|---|---|---|---|
| 14 | 67° 24'S | 66° 00'E | 500 |
| 15 | 67° 12'S | 66° 00'E | 800 |
| 16 | 67° 05'S | 65° 30'E | 600 |
| 17 | 66° 55'S | 65° 12'E | 350 CM1 |
| 18 | 66° 53'S | 65° 00'E | 550 CM2 |
| 19 | 66° 57'S | 65° 00'E | 600 |
| 20 | 66° 41'S | 65° 40'E | 2,200 |
| 21 | 67° 05'S | 64° 35'E | 2,200 |
| 22 | 66° 35'S | 63° 40'E | 2,200 |
| 23 | 66° 54'S | 64° 16'E | 300 |
| 24 | 67° 07'S | 64° 11'E | 150 |
| 25 | 67° 15'S | 64° 45'E | 100 |
| 26 | 67° 35'S | 62° 45'E | 500 |
| 27 | 67° 19'S | 62° 54'E | 300 |
| 28 | 67° 37'S | 66° 10'E | 100 |
| 29 | 67° 07'S | 65° 43'E | 650 |
| 30 | 67° 23'S | 66° 30'E | 100 |

**Area C:** *Kerguelen Plateau Seismic Survey Way Points & Core Sites*

| Station | Latitude | Longitude | Depth (m) |
|---|---|---|---|
| KI | 58° 31.01'S | 81° 13.15'E | |
| KM | 57° 45.06'S | 77° 32.05'E | |
| KN | 57° 36.25'S | 78° 18.17'E | |
| KO | 57° 07.15'S | 78° 26.93'E | |
| KP | 56°16.00'S | 74° 41.29'E | |
| KQ | 54° 52.79'S | 74° 30.98'E | |

*Supplementary sampling sites for biostratigraphy - Prydz Bay*

| Sample No. | Latitude °S | Longitude °E | Depth (m) | Priority |
|---|---|---|---|---|
| 1 | 67° 40' | 80° 00' | 300 | * * * |
| 2 | 67° 12' | 79° 20' | 1000 | * * * |
| 5 | 68° 15' | 77° 50' | 500 | * * * |
| 8 | 67° 40' | 76° 30' | 350 | * * * |
| 9 | 68° 20' | 76° 35' | 550 | * * * |
| 11 | 69° 23' | 75° 00' | 700 | * * * |
| 15† | 68° 10' | 74° 00' | 650 | * * * |
| 16† | 68° 05' | 75° 00' | 550 | * * * |
| 17† | 67° 40' | 74° 00' | 550 | * * * |
| 18† | 67° 25' | 75° 00' | 450 | * * * |
| 20 | 67° 20' | 73° 30' | 550 | * * * |
| 21 | 67° 42' | 72° 30' | 650 | * * * |
| 23 | 68° 00' | 70° 00' | 300 | * * * |
| 25 | 67° 15' | 72° 00' | 550 | * * * |
| 29 | 67° 35' | 69° 30' | 200 | * * * |
| | | | | |
| 3 | 66° 40' | 79° 20' | 1150 | * * |
| 4† | 68° 00' | 79° 00' | 200 | * * |
| 6† | 67° 20' | 78° 00' | 250 | * * |
| 10 | 69° 05' | 76° 30' | 500 | * * |
| 12 | 69° 10' | 74° 00' | 700 | * * |
| 13† | 68° 35' | 72° 50' | 650 | * * |
| 14† | 68° 40' | 75° 20' | 650 | * * |
| 19† | 67° 00 | 74° 50' | 400 | * * |
| 22 | 68° 15' | 71° 10' | 600 | * * |
| 24 | 67° 40' | 71° 00 | 450 | * * |
| 28 | 67° 15' | 70° 35' | 300 | * * |
| 30 | 67° 40' | 67° 25' | 500 | * * |
| 31 | 67° 15' | 67° 00 | 100 | * * |
| | | | | |
| 7 | 66° 40' | 76° 50' | 2250 | * |
| 26 | 66° 40' | 73° 50' | 2000 | * |
| 27 | 66° 35' | 70° 40' | 2000 | * |

Sample priority: *** (essential), ** (important), * collect only if shipping schedule permits. † Core if possible.