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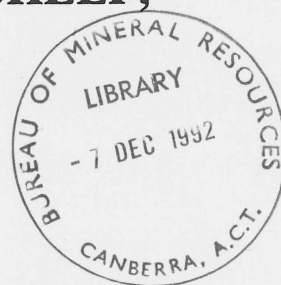
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CRUISE PREVIEW REPORT

PRYDZ BAY & MAC. ROBERTSON SHELF,

ANTARCTICA,

JANUARY - MARCH 1993



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by

P.E.O'Brien,

Onshore Sedimentary and Petroleum Geology Branch

Australian Geological Survey Organisation &

Co-operative Research Centre for Antarctic and Southern Ocean Environments



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SUMMARY

The Natural Variability and Past Environmental change Sub-program of the Co-operative Research Centre for Antarctic and Southern Ocean Environments aims to use the records contained in ice and sediments to understand past environmental change to calibrate climatic models. The marine geoscience program for Voyage 7 consists of a sea bed sampling program designed to

- . Elucidate sedimentation processes on the Antarctic shelf and slope.
- . Provide sediment cores from the Antarctic shelf and slope for the study of Quaternary environmental change.

Sampling is proposed for Prydz Bay and the adjoining Mac. Robertson Shelf. Prydz Bay is an important site for studying the past behaviour of the Lambert Glacier-Amery Ice Shelf system which is the largest ice stream draining the East Antarctic Ice Sheet. The adjacent but contrasting Mac. Robertson Shelf may not have experienced the same style of glaciation during the Quaternary and has accumulated biogenic sediments in places. Bathymetry and 3.5 kHz echo sounder data from Prydz Bay reveal features formed by erosion and deposition beneath the Amery Ice Shelf. The extent of post-glaciation iceberg gouging can also be inferred. On the Mac. Robertson Shelf, sediment accumulations suitable for coring can also be interpreted from the 3.5 kHz records. Fifteen gravity cores at sites selected to help interpret the Late Quaternary history of Prydz Bay and the Mac. Robertson Shelf will be collected on Voyage 7 of the 1992/93 Antarctic Division shipping season, on the R.V. Aurora Australis. An additional core from BANZARE Bank, the southern-most extension of the Kerguelen Plateau will be collected for palaeotemperature studies at the Co-operative Research Centre for Antarctic and Southern Ocean Environments. Grab samples will also be collected to

elucidate modern sediment types in Prydz Bay and the Mac. Robertson Shelf.

INTRODUCTION

The Natural Variability Sub-program of the Co-operative Centre for the Antarctic and Southern Ocean Environments (CRC), of which AGSO is a part will, study palaeoenvironmental change over timescales that include the last 10,000, 160,000 and 5 million years. Towards this aim, a sampling cruise by the R.V. Aurora Australis in the Summer of 1993 will target the Antarctic continental shelf and slope between Mawson and Davis Stations. This report presents the cruise scientific background and sampling strategy.

Study Area

The choice of Prydz Bay and the Mac. Robertsonland continental shelf for this first stage of CRC Antarctic marine geoscience activities stems from:

- (i) the proximity to the Amery Ice Shelf.
- (ii) the presence of deep basins nearshore on the Mac. Robertson Shelf.
- (iii) the availability of an extensive data set that defines suitable successful sampling sites on the shelf and upper slope.

Prydz Bay is a re-entrant in the Antarctic coastline that overlies a sedimentary basin, the Prydz Bay Basin (Fig. 1; Stagg, 1985). This structure is occupied by the Amery Ice Shelf - Lambert Glacier ice drainage system, which drains up to 1.09 million km², 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. 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 & others, 1991, Hambrey & others, 1991). Therefore, the study of the sediments and morphology of the continental shelf in Prydz Bay will enable better modelling of the East Antarctic ice sheet.

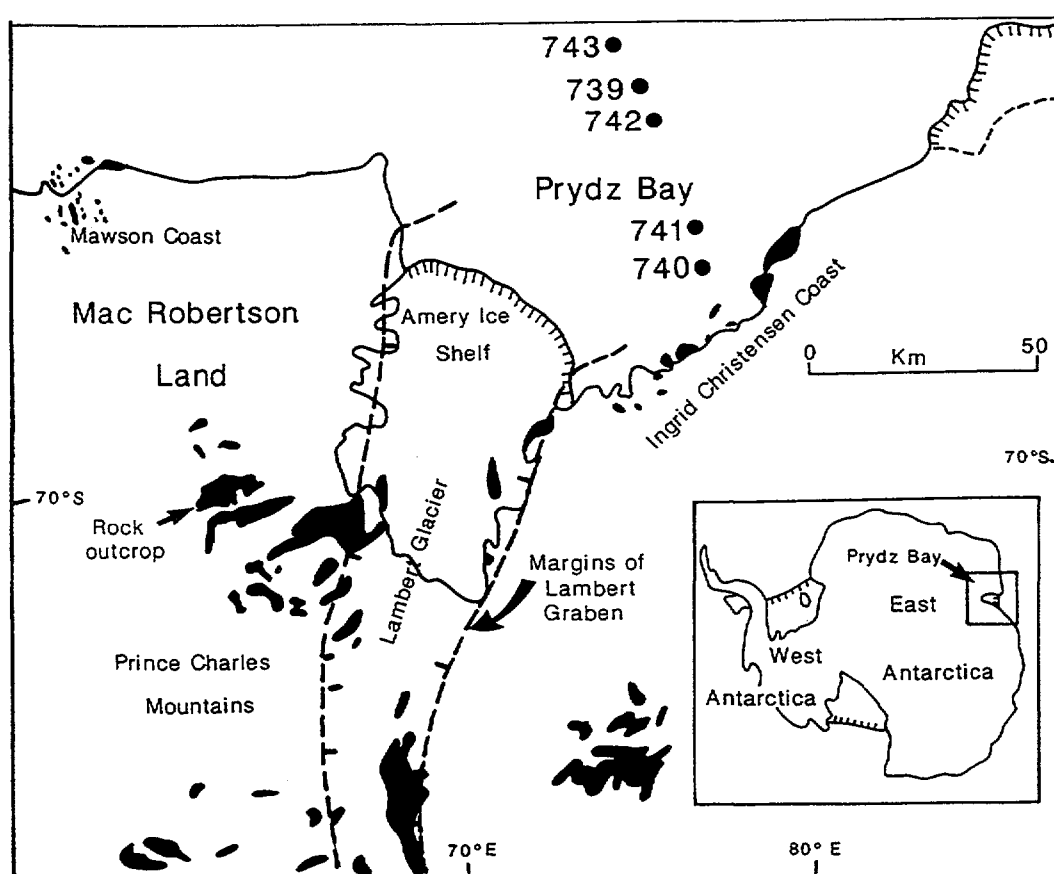


Figure 1. Location of Prydz Bay and the Lambert Graben, East Antarctica, from Turner & Padley (1991).

In contrast to Prydz Bay, the Mac. Robertson shelf to the west of the Amery Ice Shelf is underlain by crystalline basement at shallow depth. This results in rugged topography. The area has probably not suffered extreme glacial erosion because the ice sheet adjacent to the Mac. Robertson shelf has diverging flow lines so that ice may not have advanced far across

the shelf during glacial maxima (Domack, pers. comm. 1990). On the nearshore part of this rugged shelf are deep coast-parallel topographic basins that may contain undisturbed Quaternary sediments that could provide a detailed palaeoclimate record for comparison with ice cores and Antarctic lakes. The proposed marine geoscience cruise to Prydz Bay and the Mac. Robertson shelf may thus provide evidence of the fluctuations of a major ice shelf drainage system and a high resolution record of Quaternary marine sedimentation.

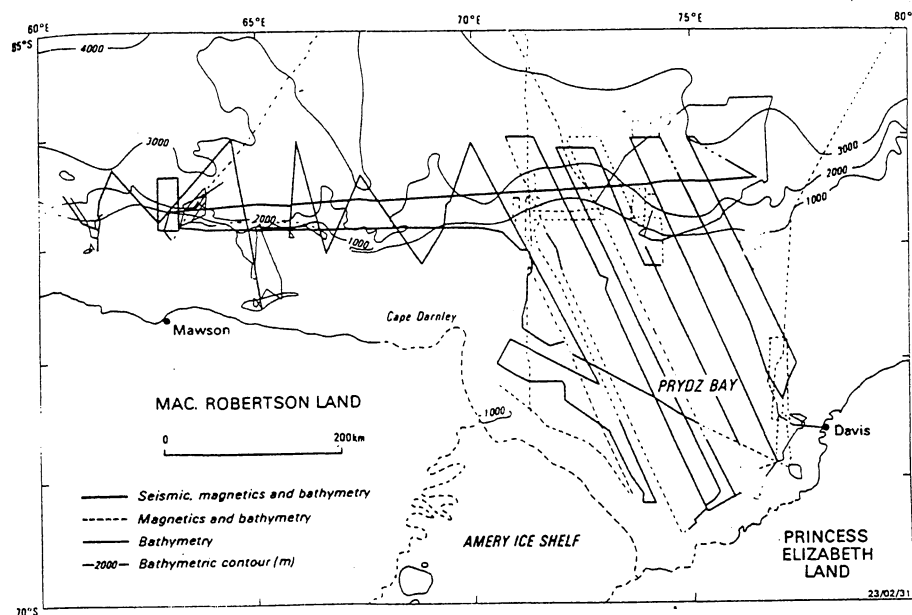


Figure 2. Ship tracks for which 1982 vintage 3.5 kHz echosounder records are available (from Stagg & others, 1983).

Existing Data

Seismic Data - Prydz Bay and the Mac. Robertson shelf have received 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 Bureau of Mineral Resources 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 a systematic grid (Fig.2; Stagg, 1985). Russian and Japanese expeditions have also obtained multichannel seismic data

in the area. 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 & others, 1989). Since 1990, ANARE cruises by the R.V. *Aurora Australis* have collected 12, 35 and 120 kHz echo sounder records.

Sediment Sampling- Only a few sediment samples were collected from the region prior to the 1982 marine geoscience cruise, firstly by H.M.S. *Challenger* in 1873 (Murray & Renard, 1891), then by the Soviet Marine Antarctic Expedition in from 1955 to 1957 (Litvin, 1960). McLeod & others, (1966) describe a few samples from the approaches to Mawson Station. The 1982 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 (Barron & others, 1991). Since then, the 1991 summer cruise by the R.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 in ODP Hole 740A. Domack & others (1991b) identified a clay interval interbedded with diatomaceous ooze. They interpreted the silt as representing deposition beneath an expanded the Amery Ice Shelf. They argue from C-14 dates that this expansion took place during the Holocene warm phase around 7000 yrs BP.

Similar Holocene stratigraphy around East Antarctica led Domack & others, (1991a) to conclude that east Antarctic outlet glaciers expanded during past warm periods.

AIMS AND METHODS

The current study aims to provide a first stage in the investigation of late Quaternary climatic, oceanographic and sedimentation changes in the Prydz Bay - Mac. Robertson land region. It aims to upgrade knowledge of seabed morphology and sediment types to better understand glaciological and oceanographic influences on sedimentation. In future years, voyages employing high resolution seismic, side-scan sonar and more extensive coring will develop a comprehensive data base for palaeoclimatic studies.

The basis of the present study is a re-examination of the 3.5 kHz echo sounder data collected on the 1982 M.V. Nella Dan cruise (Fig. 2). These data have several outstanding advantages when compared to many other data sets from Antarctic waters. Firstly, they were mostly acquired on long straight lines so morphology is reasonably easy to interpret. Secondly, the echo sounder frequency used (3.5 kHz) permits high resolution of sea bed morphology along with some penetration of soft bottom sediments, allowing identification of potential coring sites in a region where overconsolidated sediments frequently bend core barrels. Compared to higher resolution (12 kHz or higher) echo sounders, the 3.5 kHz system is less affected by high sea states.

Paper records of the 3.5 kHz echo sounder were first examined to identify regions of similar echo character. Nine distinctive characters based on fine-scale morphology and degree of penetration were identified. Zones of each type were mapped and domains of distinctive

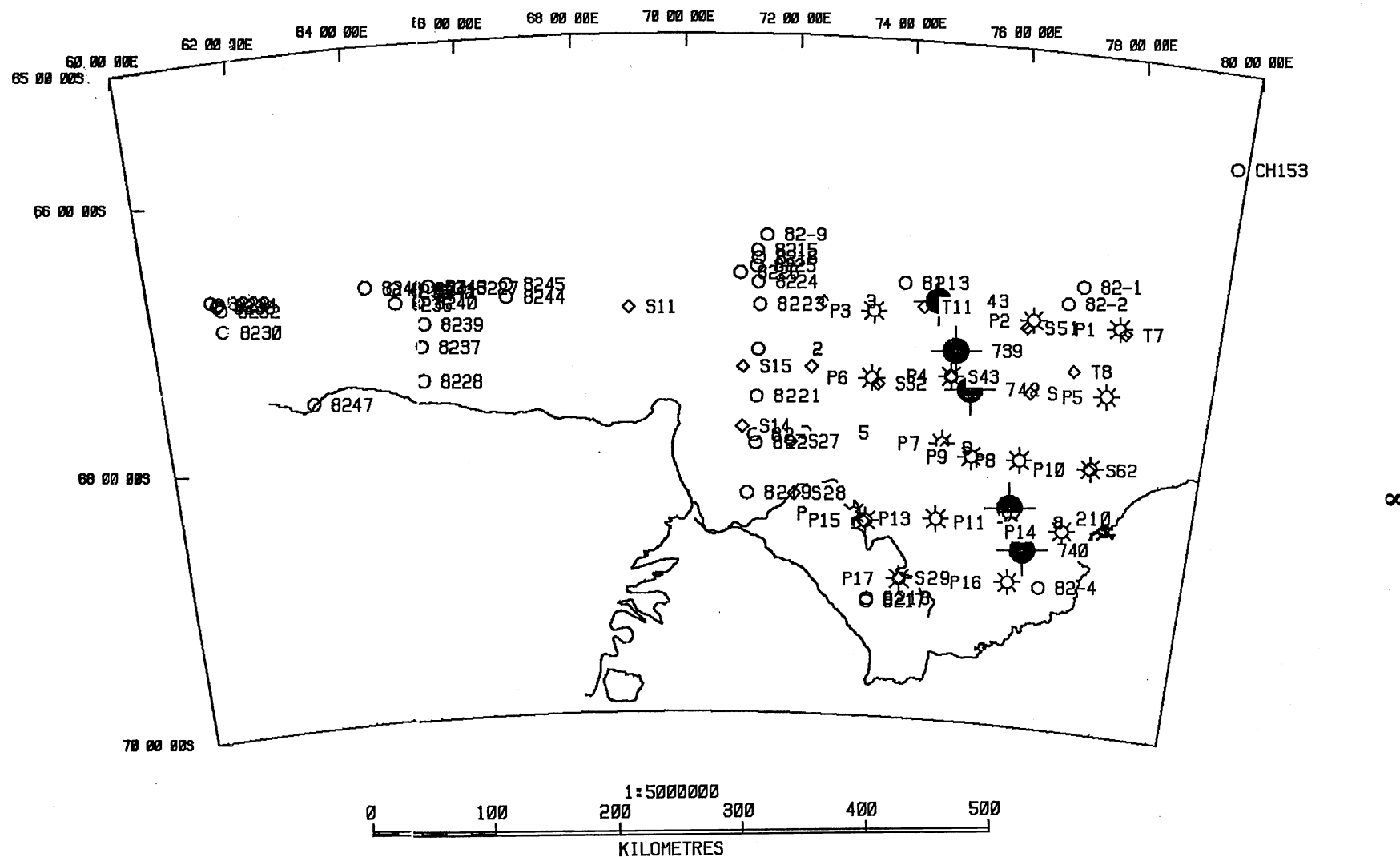


Figure 3. Bottom samples from Prydz Bay and adjacent areas. Sample sets are as follows:
 CH153 - HMS Challenger, 1874.
 82-1 to 8244 - ANARE/BMR 1982 (Quilty, 1985)
 S1 to S62 and T7 to T23 - ANARE 1990 (Franklin, 1991)
 P1 to P17 - ANARE bottom photos (Quilty, pers comm., 1991)
 739 to 743 - ODP holes (Barron, Larsen & others, 1989).

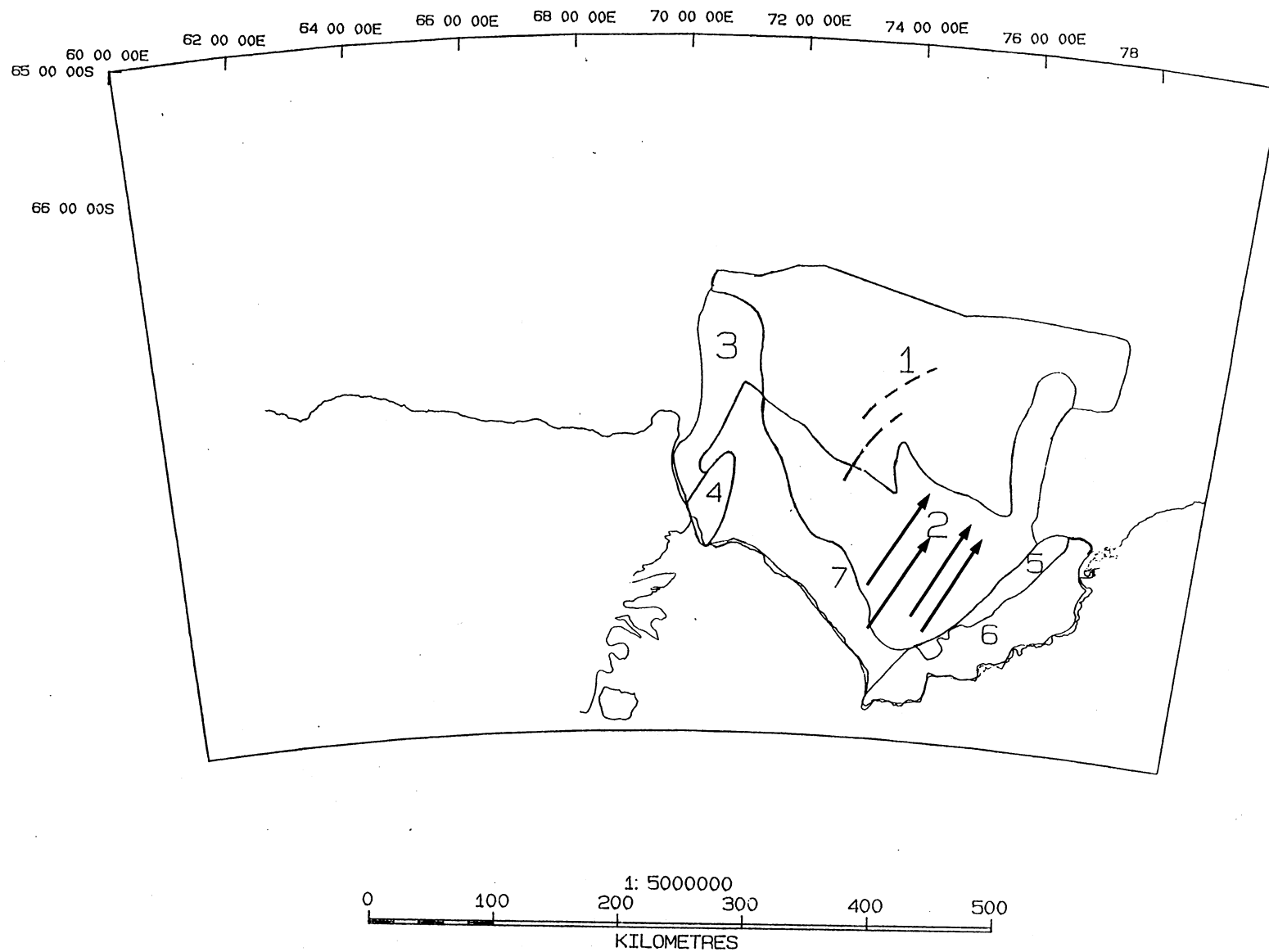


Figure 4. Echo character provinces and important meso-scale bottom features. Arrows indicate orientation of subglacial flutes, dashed line indicates position of grounding line moraines.

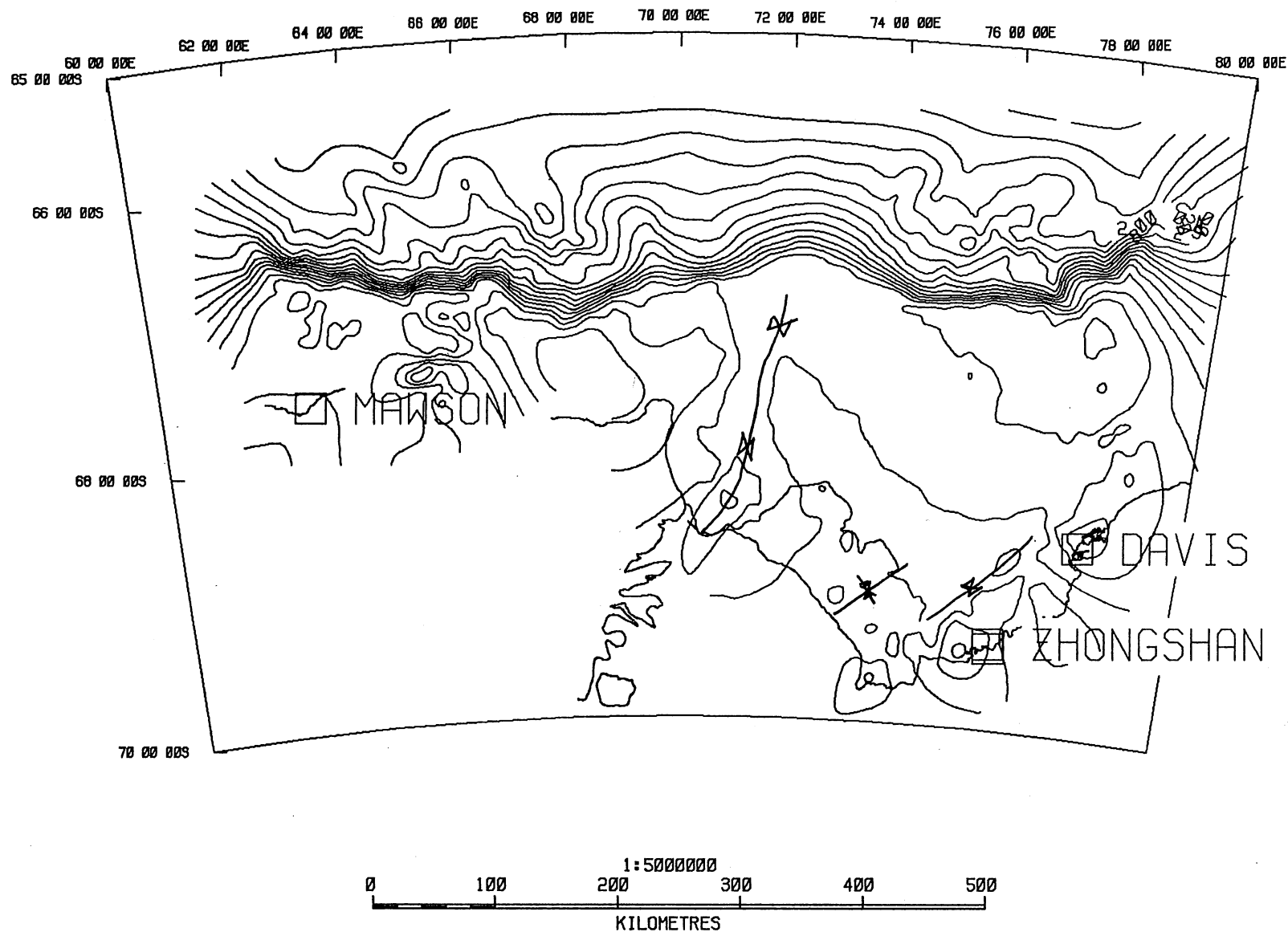


Figure 5. Prydz Bay and adjoining areas bathymetry with major valley axes marked. Data from Antarctic Division and AUSLIG. Contour interval 200 m.

assemblages were identified (Fig. 4). Distinctive mesoscale features that were also mapped from the echo-sounder records. The straight, parallel ships tracks make it possible to view serial sections across Prydz Bay. Both surface type and meso-scale morphology were compared with published data from glaciated continental shelves (Barnes, 1987; Karl, 1989; Solheim & others, 1990) and with a bathymetric map compiled from digitised echo-sounder data from the 1982 M.V. Nella Dan cruise and some more recent R.V. Aurora Australis cruises provided by Antarctic Division and the Australian Survey and Land Information Group (AUSLIG), Canberra (Fig. 5). In areas of sparse soundings, additional control was provided by the bathymetric map of Stagg & others (1983) that used soundings from the General Bathymetric Chart of the Ocean (GEBCO) in regions lacking modern echo-sounder data.

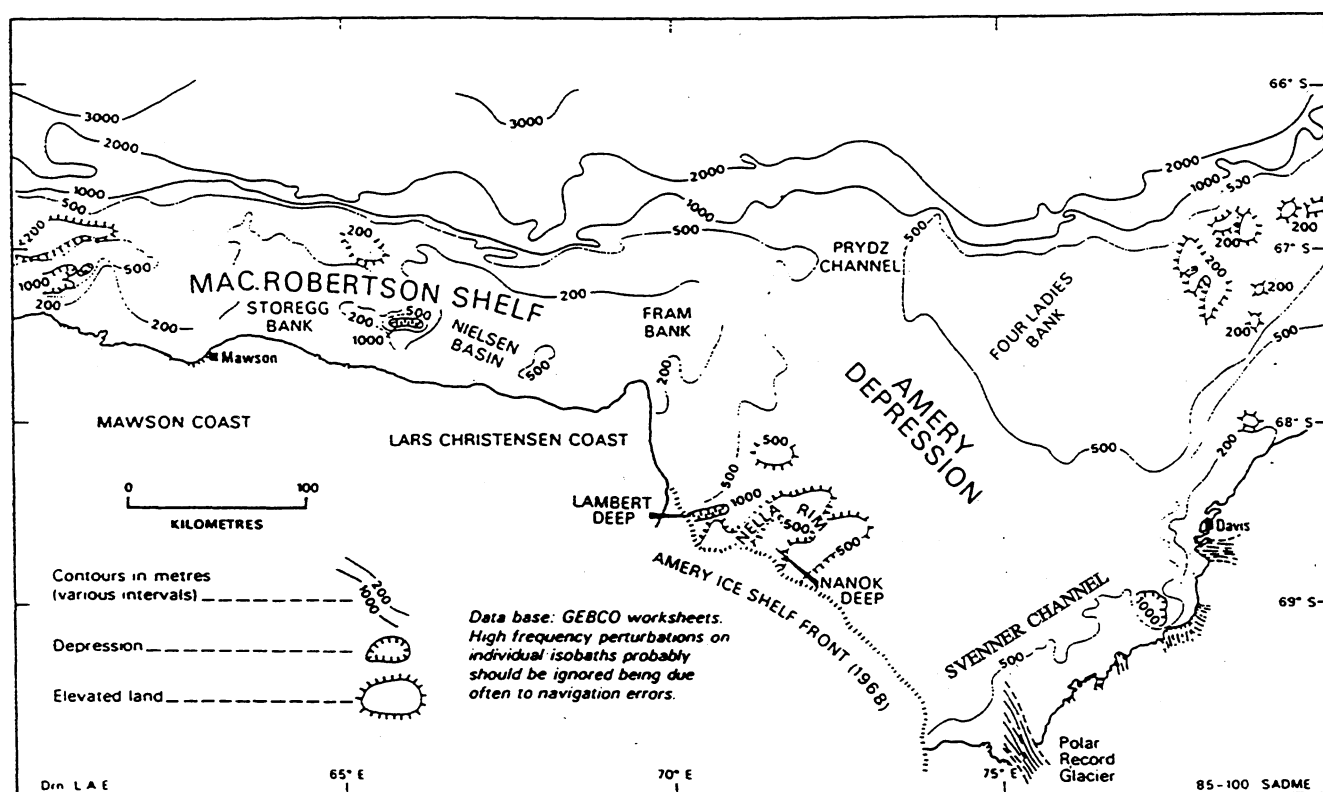


Figure 6. Names of sea floor topographic features from Quilty (1985).

REGIONAL SETTING

Morphology

Echo-sounder records from the Mac. Robertson shelf show a generally rugged sea floor and several major banks with relatively smooth surfaces and water depths of less than 200 m (Storegg and Fram Banks, Fig. 6). Between these two main banks, the Neilson Basin consists of two steep-sided depressions, one more than 600 m deep and the other reaching 1250 m deep (Fig. 6). The Mac. Robertson shelf continental slope is rugged compared to that off Prydz Bay and is relatively steep with seaward slopes of about 5° compared to 2° beyond Prydz Bay.

Prydz Bay is mostly occupied 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. Running parallel to the Ingrid Christensen Coast is an elongate trough up to 1000 m deep called the Svenner Channel (Fig. 6). It overlies the southeastern boundary of the Lambert Graben. Another elongate deep, the Prydz Channel, marks the western edge of the Amery Depression, extending to the continental shelf edge (Fig. 6). Offshore from the Amery Depression, the shelf shallows to be less than 200 m deep along the shelf edge, forming the Four Ladies Bank (Fig. 6). The topography of Prydz Bay is rugged along its southeastern and western flanks, where the seafloor is directly underlain by Precambrian basement rocks bordering the Lambert Graben, and in an area close to the Amery Ice Shelf front.

ECHO-SOUNDER CHARACTER PROVINCES

Eight areas of distinct echo-sounder character can be mapped in Prydz Bay (Fig. 4).

Province 1: Province 1 corresponds roughly to shallow areas such as the Four Ladies Bank

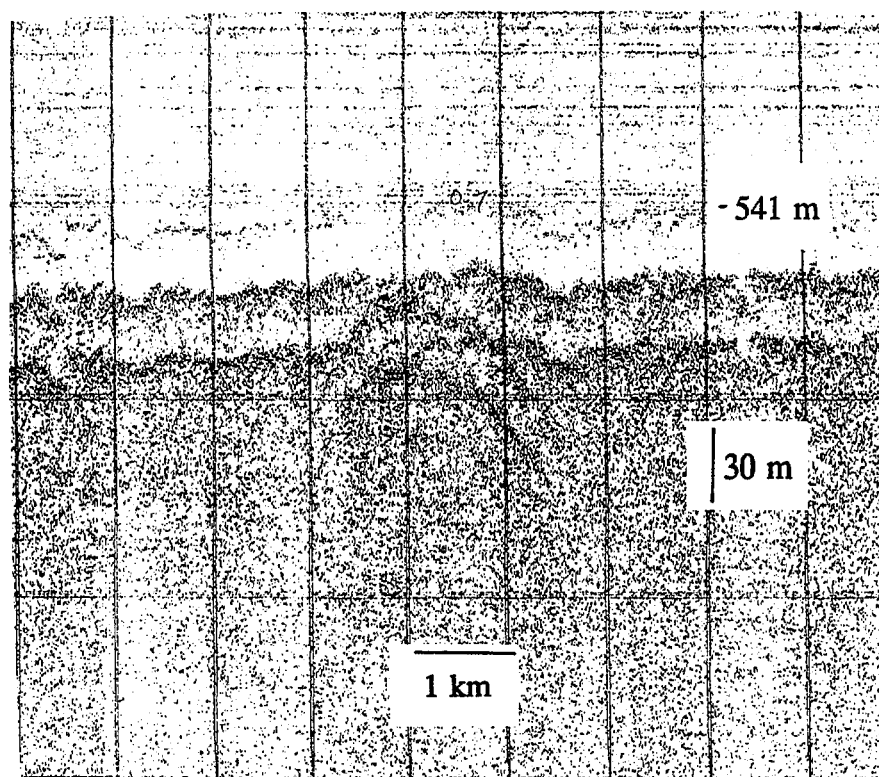


Figure 7. Echo sounder record showing jagged, hashy record from Province 1 caused by intense ice keel gouging of the sea floor.

and the floor of the Prydz Channel where it rises towards the shelf edge. The Province is characterised by mounds 2 to 8 m high and up to 40 m across covering most of the area, producing a jagged, hashy appearance on the profiles (Fig. 7). There is one small area of smooth sea floor in the bottom of a enclosed depression in Prydz Channel. In addition, large ridges up to 50 m high and 10 km across trend north-easterly across the western and southwestern flank of the Four Ladies Bank (Fig. 4). The more inshore ridges are asymmetric with steeper offshore sides (Fig. 8) and continue into Province 2 (Fig. 4).

Province 2: Province 2 encompasses most of the Amery Depression. It has a sea bed that is either smooth or has irregular ridges and swales up to 10 m high and up to 2 km across (Fig. 9). These ridges appear smoother than the rough texture of Province 1 and are very similar

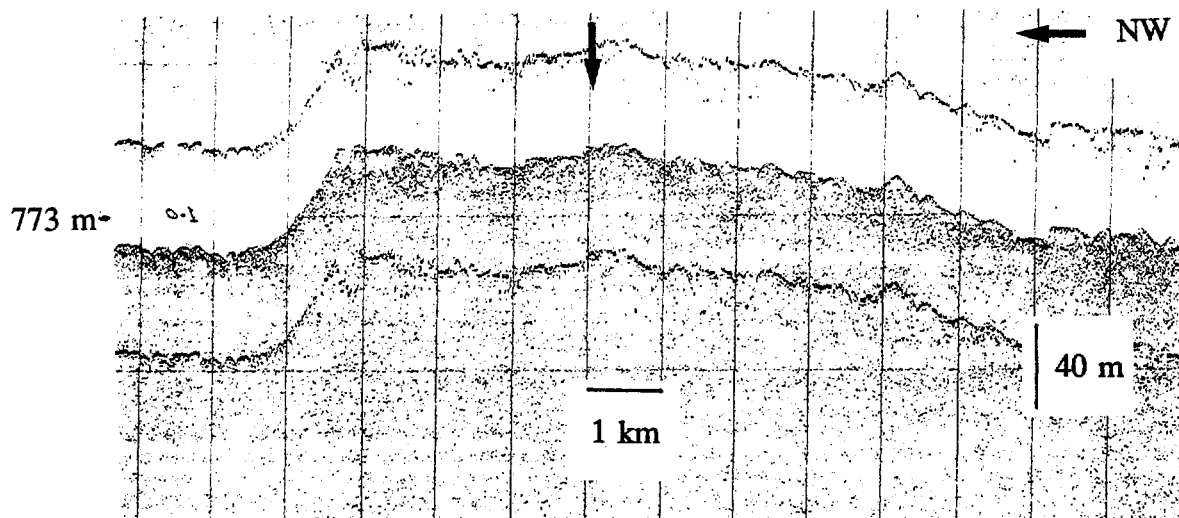


Figure 8. Asymmetric bank formed as a grounding line moraine, Prydz Bay. Arrow indicates proposed core site AA93/004.

to the "channel-levee complexes" described by Karl (1989) from the western Ross Sea. Both smooth sea floor and ridge and swale areas have up to 10 msec of sub-bottom penetration on many profiles. The ridge and swale features of Province 2 have a preferred orientation, trending between 340° and 040°. (Fig. 4).

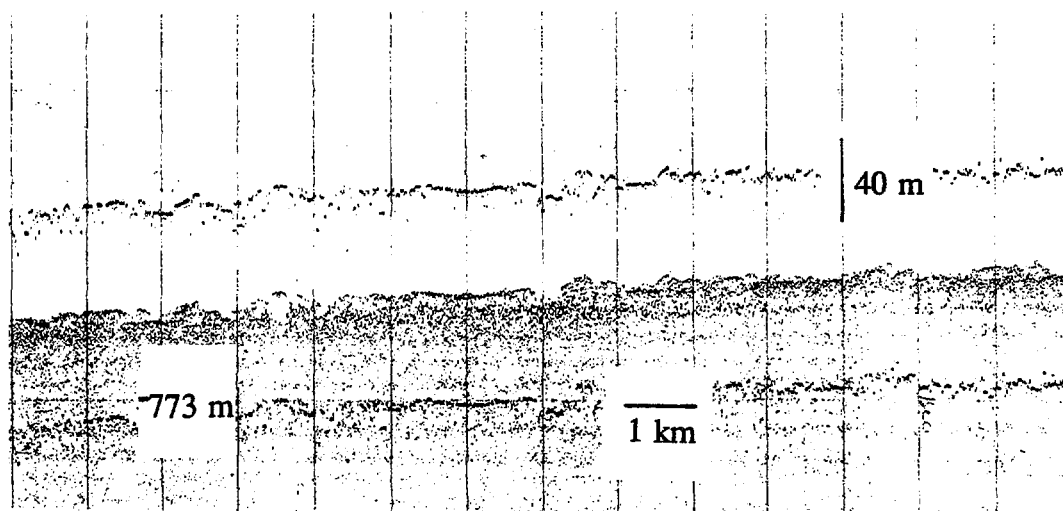


Figure 9. Ridges formed as subglacial flutes or drumlins on the floor of the Amery Depression. This record was run approximately normal to the ridge trend.

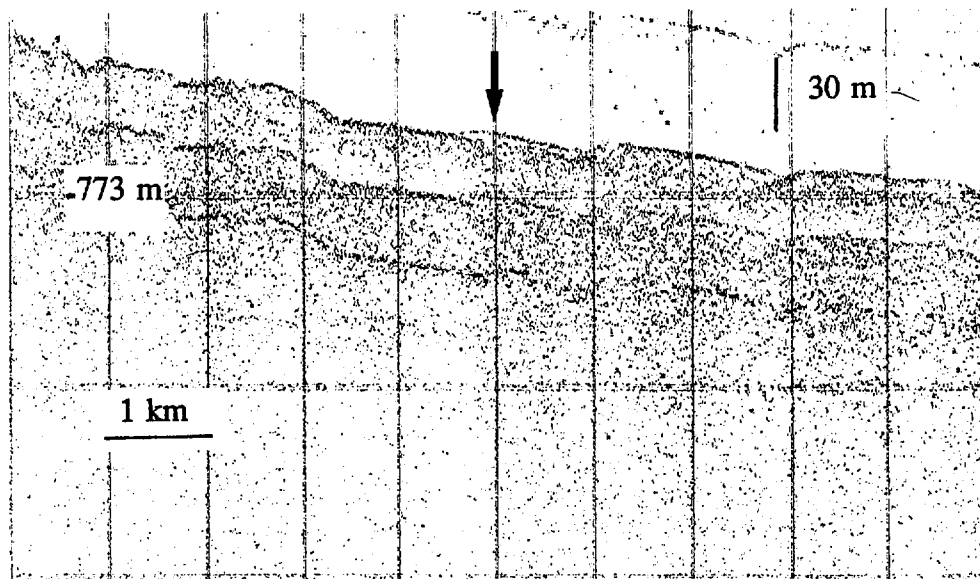


Figure 10. Subglacial ridges recorded on a ships track oblique to the ridge trend. Arrow indicates proposed core site AA93/003.

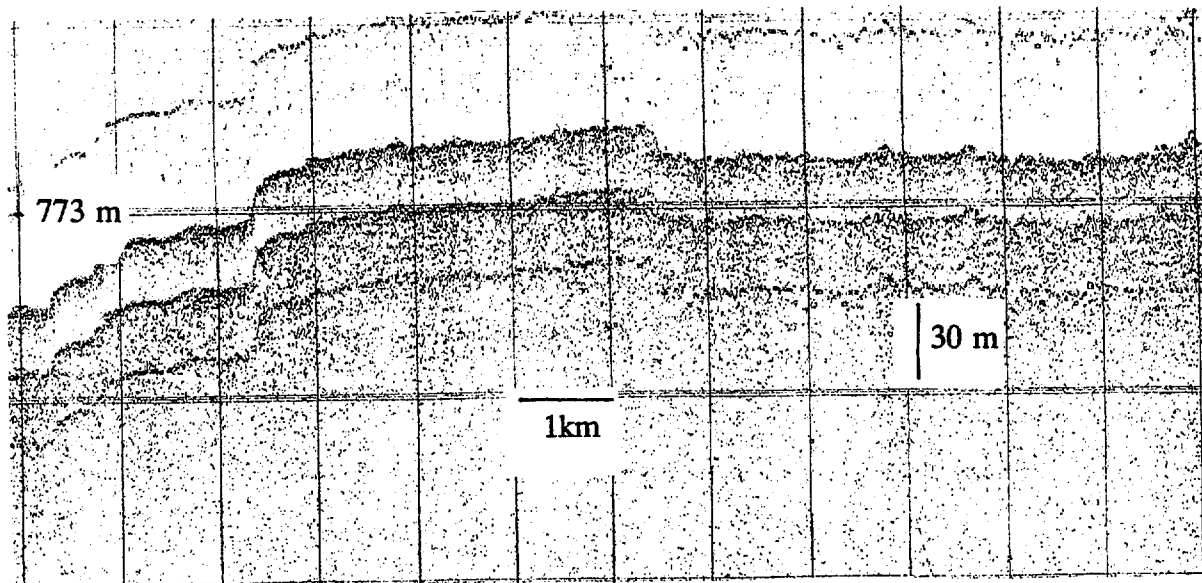


Figure 11. Ice keel gouged top on a large ridge, Province 2. Maximum depth of gouging in 720 m.

The Province 2/Province 7 is somewhat arbitrary as the sea floor shallows into a series of large ridges in that area. In Province 2, the ridges are subdued with smooth sides but where their crests are shallower than 720 m, they have a rough surface like Province 1 (Fig. 11). The change of sea floor character from Province 1 to 2 also takes place at a depth of 720 m around the edge of the Amery Depression. The smooth sea floor of Province 2 extends into much shallower water on the Four Ladies Bank. Adjacent to this region, the sea floor is slightly deeper (350 m) than in the smooth area (340 m) and exhibits the rough surface texture of Province 1. The smooth area is bounded on east, west and north by a low scarp about 5 m high with a low bank at the top, having a steep outer side and a gently sloping inner side (Fig. 12).

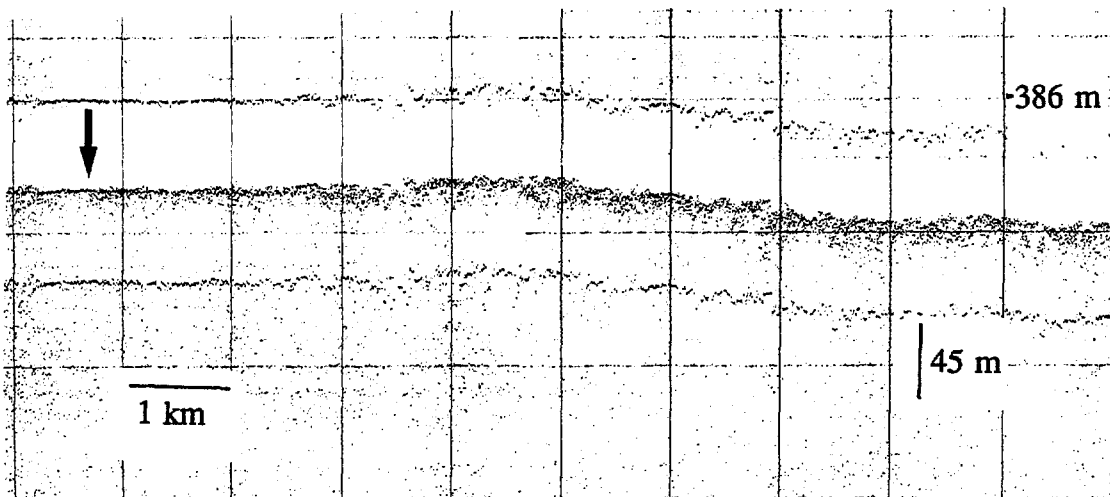


Figure 12. Knick-point & shoal morphology, Four Ladies Bank. Arrow indicates proposed core site AA93/001.

Province 3: The sea floor of Province 3, a shallow bank along the western side of Prydz Bay, topographically resembles, but has greater relief than Province 1. Some swales are clearly flat floored with steep sides (Fig. 13).

Province 4: A ridge of rugged sea floor with similar topography to areas of shelf directly underlain by basement, forms the northwestern side of a deep U-shaped sea floor valley, the Lambert Deep, that is included in Province 7.

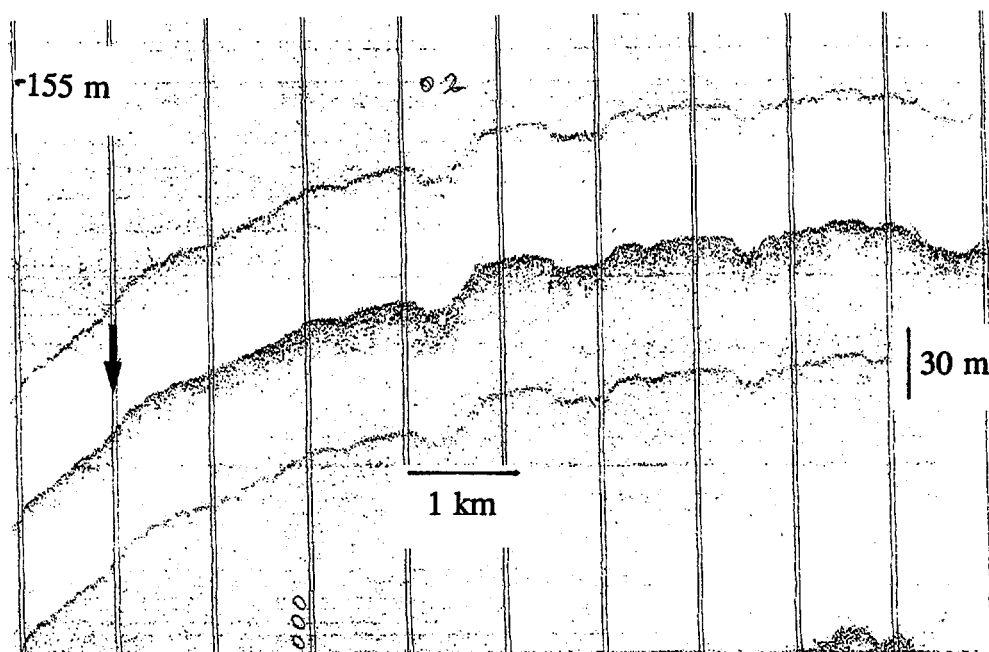


Figure 13. Deep ice keel gouges, Province 3. Arrow indicates proposed core site AA93/013.

Province 5: The floor of the Svenner Channel is smooth on a fine scale, but exhibits steep-sided, rounded ridges and swales (Fig. 14). Some acoustic penetration of the sea floor is common. A lens of sediment up to 30 msec thick onlaps the northwestern side of the channel and ridges in the channel. This lens has distinct internal reflectors (Fig. 14) and may extend for tens of kilometres along the channel flank. ODP Hole 739 drilled through this lens (Barron, Larsen & others, 1989).

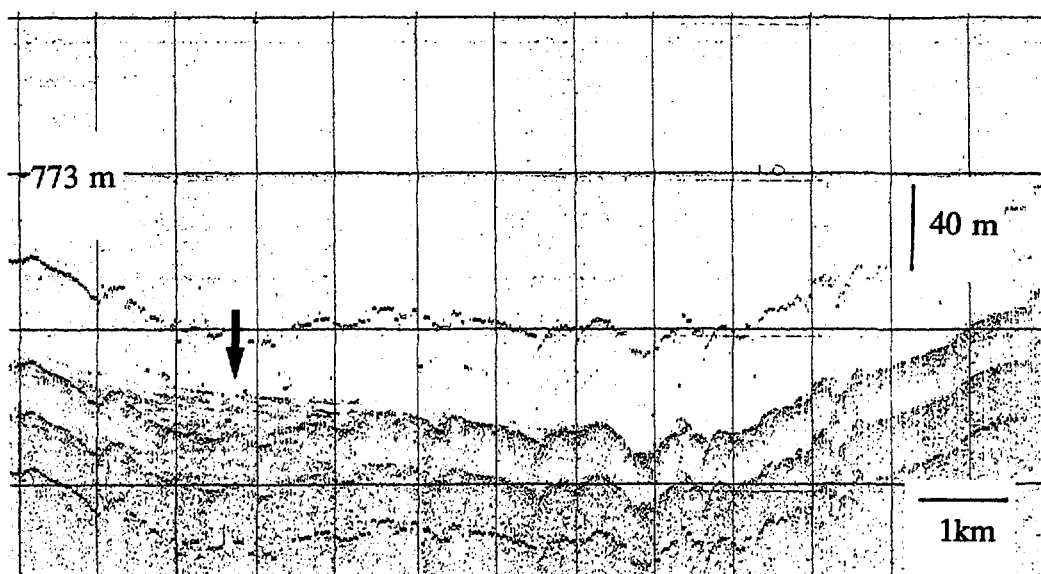


Figure 14. Floor of the Svenner Channel (Province 5). Note sea floor ridges, probably of subglacial origin and the sediment lens draped on the northwestern side of the channel. Arrow indicates proposed core site AA93/002.

Province 6: Province 6 comprises rugged sea floor which in seismic data shows to be directly underlain by crystalline basement (Fig. 15). It is characterised by steep sided hills and valleys with several wide, U-shaped valleys cut by the larger glaciers flowing from Princess Elizabeth Land, such as the Sorsdal Glacier. The boundary between Provinces 6 and 5 (the Svenner Channel) is a steep scarp probably caused by preferential erosion of the softer sediment fill of the Lambert Graben compared to basement underlying Province 6 (Fig. 16). In seismic data, this scarp appears to overlie graben boundary faults.

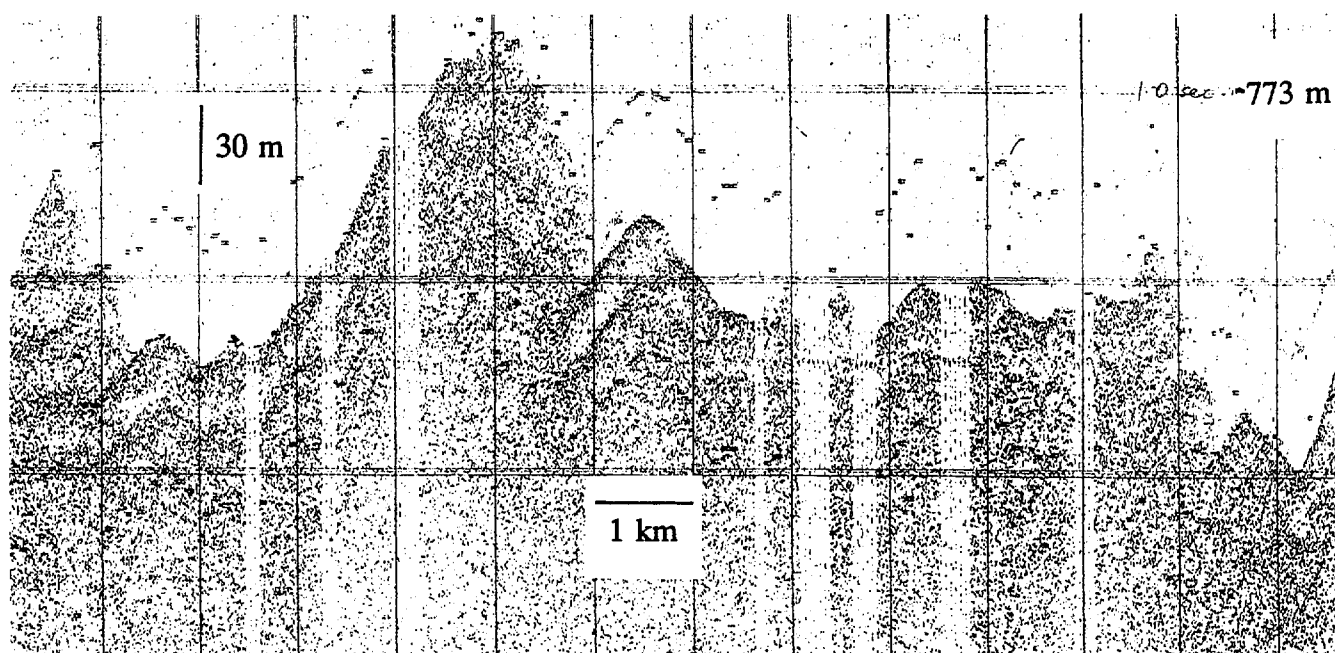


Figure 15. Rugged sea floor underlain by basement rocks, Province 6.

Province 7: Province 7 is characterised by large ridges and troughs sculptured by the Lambert Glacier/Amery Ice shelf ice drainage system and reflecting its major ice streams. These valleys have closed depressions as deep as 1000 m below sealevel. Quilty (1985) named two deeps on the western side of Prydz Bay the Lambert and Nanok Deeps and the ridge that encloses the Nanok Deep, the Nella Rim. The valley floors and ridge sides appear smooth on echo sounder records whereas the ridge crests have rough texture similar to Province 1.

Continental Slope: The continental slope off Prydz Bay is dominated by a large sediment fan offshore from the mouth of the Prydz Channel. Echo-sounder records show the slope as smooth with some sub-bottom penetration although slump scars are common near the shelf edge (Fig. 17). Some subdued mounds near the slope foot are probably slump toes. Away from Prydz Bay, the continental slope is similar although steeper with some areas of rugged basement at the toes of slope. Submarine canyons are present, typically cutting 500 m into the slope and are about 10 km wide. Some have flat floors suggesting sediment infilling.

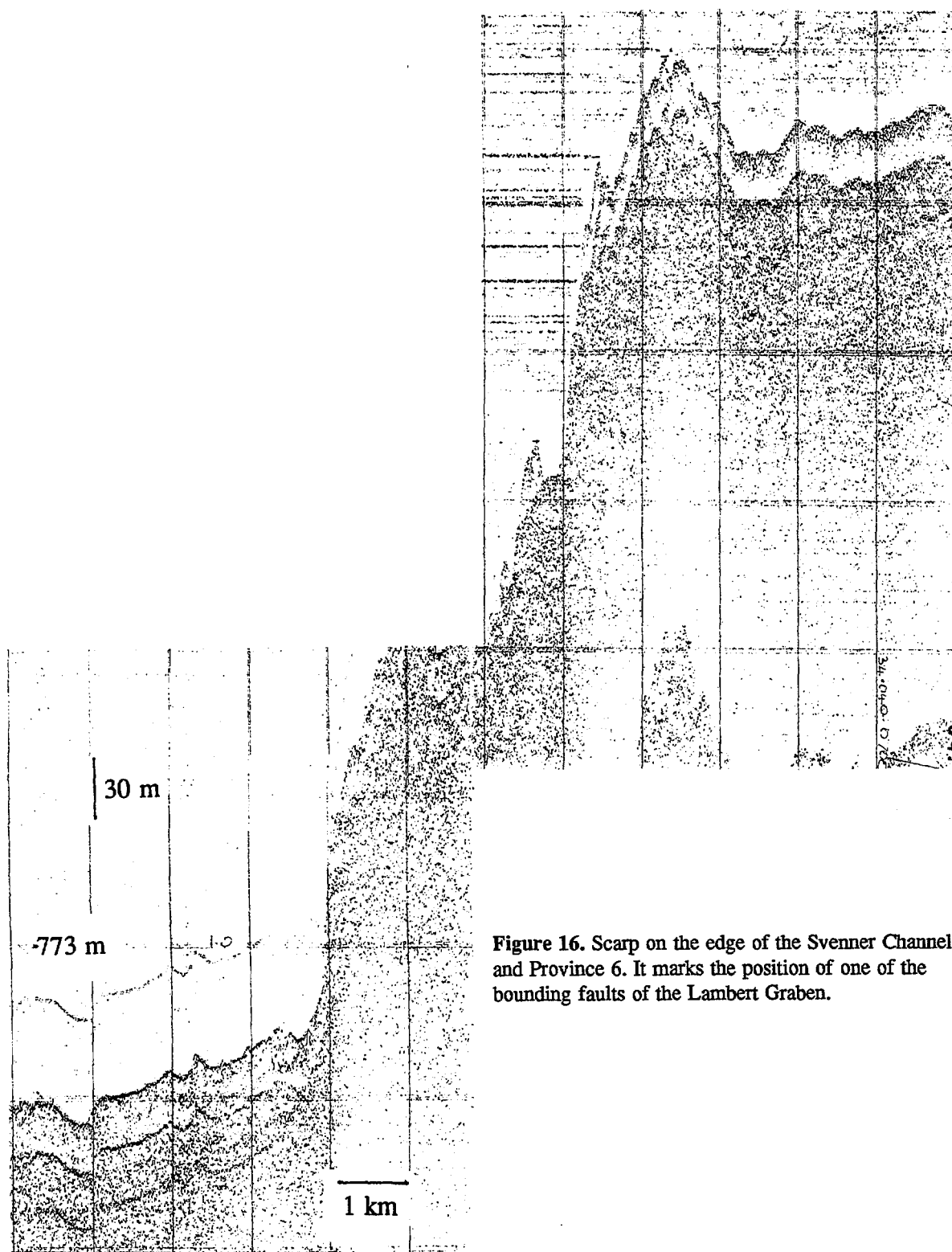


Figure 16. Scarp on the edge of the Svenner Channel and Province 6. It marks the position of one of the bounding faults of the Lambert Graben.

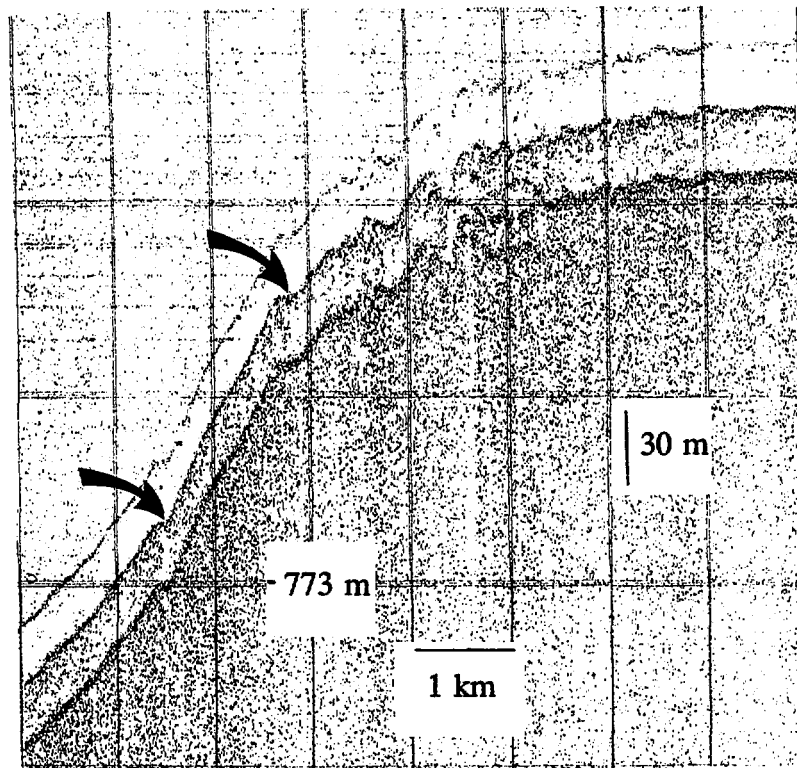


Figure 17. Continental slope on the trough mouth fan off shore of the Prydz Channel. Arrows indicate slump scars.

Mac. Robertson Shelf: The rugged Mac. Robertson Shelf is underlain by basement rocks. Several shallow banks (eg. Storeg Bank, Fram Bank) have relatively smooth upper surfaces cut by steep-sided depressions about 10 m deep and tens of metres across. A shallow core sample from the flank of the Fram Bank contained 32 to 50 percent biogenic carbonate (Franklin, 1991).

One of the most remarkable features of the Mac. Robertson Shelf is the Neilsen Basin, a steep sided, elongate depression trending northeast-southwest and reaching depths greater than 1500 m (Fig. 6, 18). Echo-sounder records suggest that it contains thick sediments. The great depth

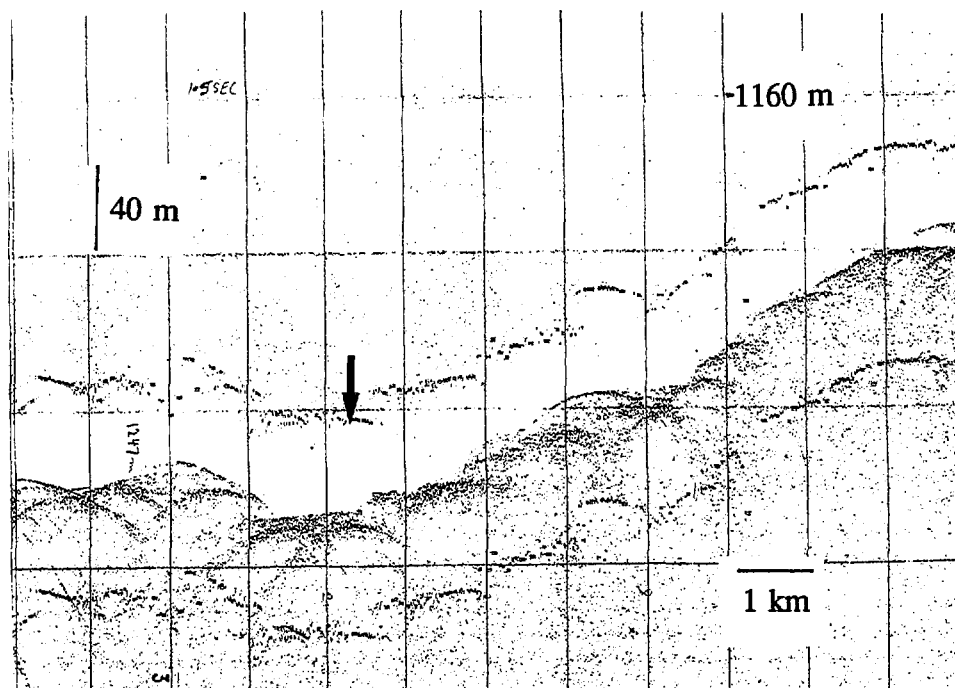


Figure 18. Echo sounder record from the Neilsen Basin, Mac Robertson Shelf. Arrow indicates proposed core site AA93/011.

and location offshore from an area of divergent glacier flow suggest that grounded ice may not have reached its the basin floor depths and therefore it may contain marine sediments undisturbed by glacial erosion. Lenses of sediment in the about 10 m thick are present on the shelf offshore from Mawson (Fig. 19).

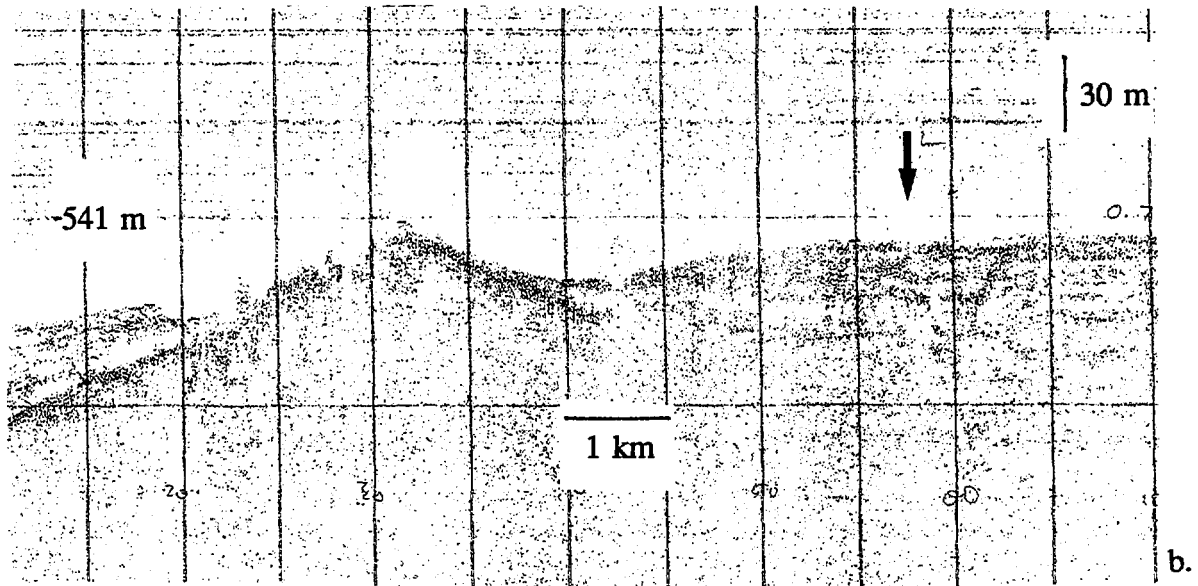
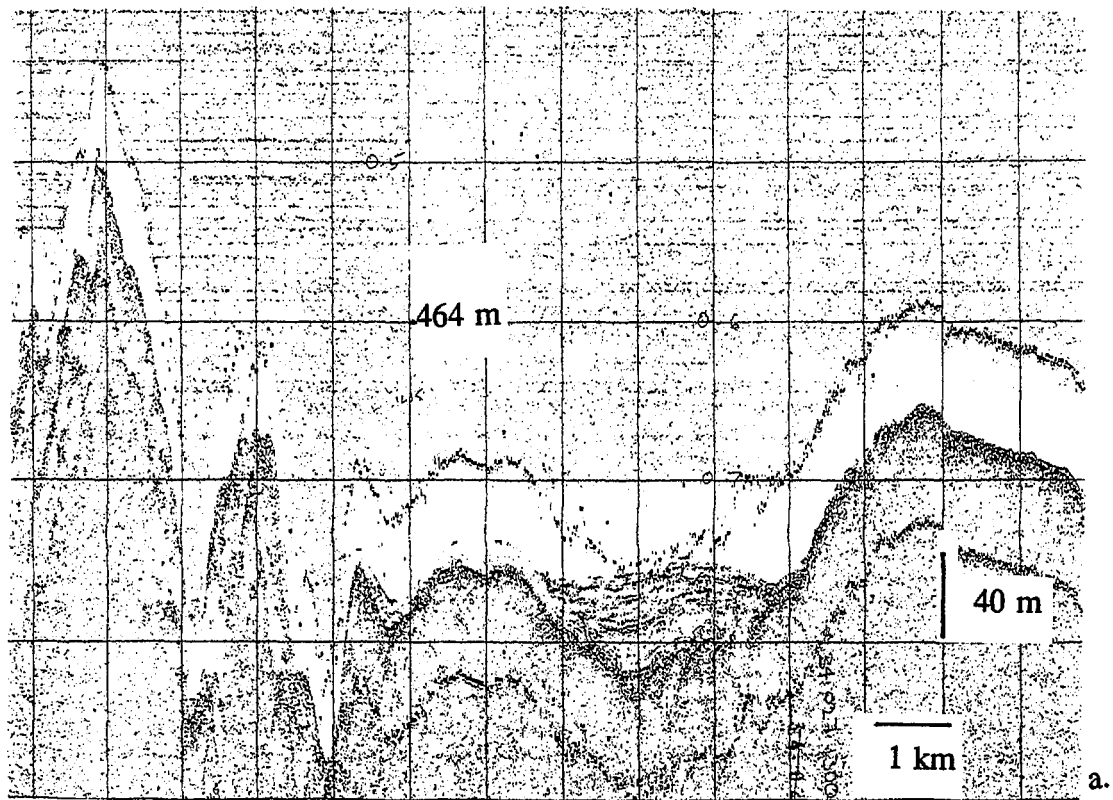


Figure 19. Sediment lenses on the Mac Robertson Shelf offshore from Mawson.
 a. Lens with well developed internal reflectors.
 b. Sediment intended for sampling by core AA93/012.

INTERPRETATION

Prydz Bay

Prydz Bay displays a number of features that are characteristic of glaciated continental shelves, the major ones produced by the advance and retreat of the Lambert Glacier and Amery Ice Shelf since Late Eocene to Oligocene times (Hambrey & others, 1991; Solheim & others; 1990, Boulton 1990; Cooper & others, 1991). Prydz Channel is typical of troughs that cross high latitude shelves and are characterised by large sediment fans on the slope at their seaward ends. They are probably formed by fast flowing ice streams crossing the shelf and delivering subglacial debris to the shelf edge (Boulton, 1990). The debris then builds a fan by sediment gravity flows. The Svenner Channel, however, does not cross the shelf suggesting that the eastern and western sides of the Lambert Glacier behaves differently. The large ridge in Province 7 separates a western valley that clearly passes into the Prydz Channel from an eastern one that opens out into the Amery Depression (Fig. 5).

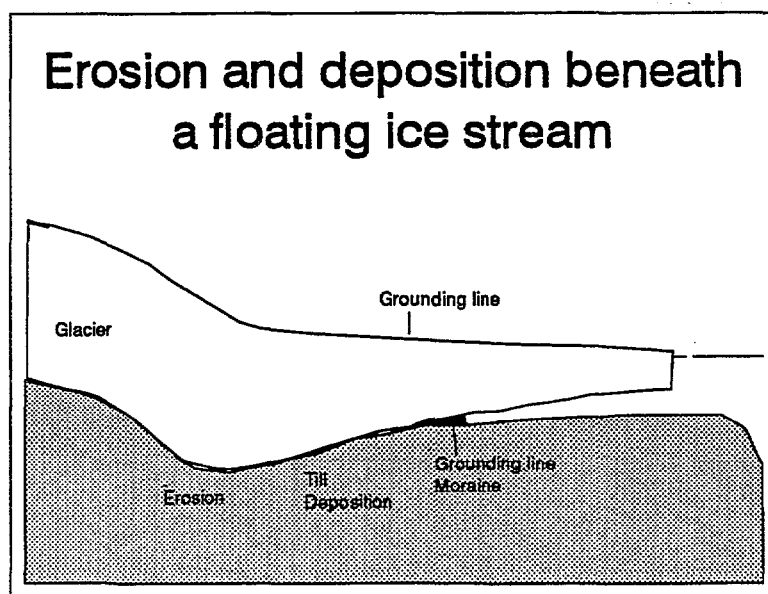


Figure 20. Pattern of erosion and deposition beneath an ice stream on the Antarctic shelf. The area beneath the thickest ice is a zone of erosion. As the ice approaches the grounding line, buoyancy reduces effective pressure promoting deposition. At the grounding line, basal melting deposits most debris entrained in the base of the ice as a grounding line moraine.

The inner shelf deeps and outer banks of Prydz Bay probably form because of isostatic depression of the crust by the ice sheet and by subglacial erosion during repeated glacial advances. It is likely that deeps mark the position of a zone of maximum subglacial erosion during stadia (Fig. 20; Boulton, 1990; Crary, 1966) whereas banks were constructed by subglacial deposition. Subglacial erosion and deposition are basically a function of basal shear stress (Boulton & others, 1984). As glacial ice approaches a grounding line on the outer shelf, increasing buoyant forces decrease effective vertical pressure at the bed, reducing basal shear stress and hence increasing the tendency for subglacial deposition beneath the outer part of the glacier (Fig. 20; Boulton, 1990). Deposition is also favoured on the banks because the ice is relatively slow moving so that basal shear stresses are low (Boulton & others, 1984). This deposition produced the sub-horizontal reflectors detected beneath bank tops by multichannel seismic surveys from Antarctic shelves (Cooper & others, 1991). Channels crossing the continental shelf are maintained because they are zones of convergent, rapid ice flow where basal shear stress is high and subglacial sediment is eroded and transported to the grounding line on the continental shelf edge (Boulton, 1990).

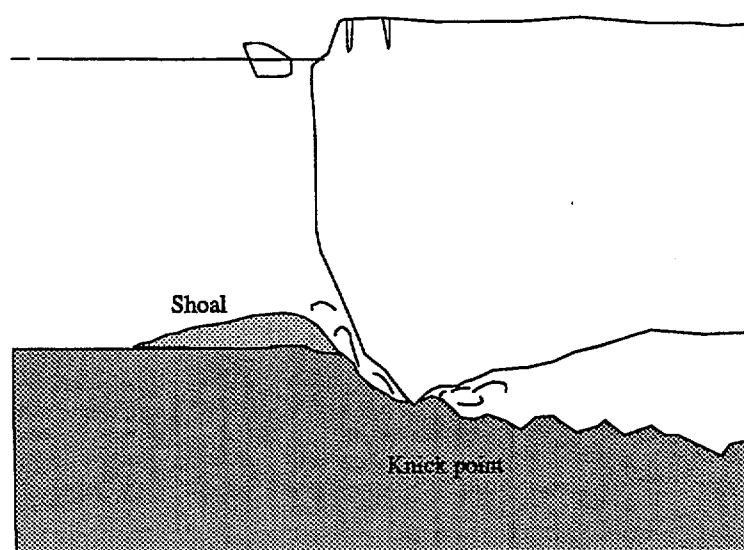


Figure 21. Knick-point and shoal formation by grounding of icebergs after Barnes & others (1987). Bed friction prevents the largest bergs from drifting over the shallowest part of the bank. Where they ground, bergs wallow and suspend sediment that is reworked into a shoal. The bergs either drift along the slope or break up into smaller pieces.

The echo-sounder provinces can be interpreted in terms of glacial processes and modification of the sea floor after ice retreat during the Pleistocene. The jagged, small-scale features seen in Provinces 1, 3 and shallow areas of 4 and 7 are mostly confined to shallow parts of the continental shelf and are randomly oriented, indicating that they are iceberg gouges (Barnes, 1987; Barnes & others, 1987). Shallow parts of the continental shelf that are not cut by these features, are surrounded by "knick point and shoal" morphology originally recognised by Barnes & others (1987) as marking the shallow limit of intense ice gouging on the coast of the Beaufort Sea. In the case of the Four Ladies Bank, these features develop around areas that are so shallow that icebergs ground before crossing them (Fig. 21). Wallowing of the icebergs then suspends sediment that is reworked into the shoal inboard of the knick point. Grounded bergs then break up by calving and spalling, producing much smaller icebergs that drift across the area without touching the seafloor. These areas of little or no iceberg gouging are sites where cores may penetrate undisturbed bank sediments deposited since the ice retreated from the shelf edge, and possibly subglacial till deposited by the glacier the last time it extended onto the bank.

The depth of iceberg gouges in Prydz Bay is extreme, even by Antarctic standards, reaching a maximum of 720 m. Barnes & Lein (1988) report iceberg marks in depths of up to 500 m on the shelf off Wilkes Land and in the Weddell Sea. They interpret these marks as the result of rolling of tabular icebergs with drafts of 330 m. Rolling may produce a draft increase of 50% (Lewis & Bennett, 1984). The Amery Ice Shelf has a draft of 400 m (Budd & others, 1982) so that rolling might produce drafts of up to 600 m, leaving 120 m of clearance above the deepest gouges in Prydz Bay. The most likely explanation is that these gouges formed during a sea level lowstand. If this were the case, then the Amery Ice Shelf must have

retreated from the edge of the continental shelf before or during the early part of a sea level rise, indicating that the East Antarctic Ice Sheet might have started shrinking prior to the northern hemisphere ice sheets. Investigation of these possibilities will involve dating of the age of the deepest gouges and of the time of ice retreat from Prydz Bay. Otherwise, most gouged areas are not suitable for coring because they are underlain by ice-keel turbates (Barnes & Lein, 1988; Vorren & others, 1983) that are probably diamictite formed by overturning of the top several metres of sediment.

The floor of the Amery Depression below the maximum depth of iceberg gouging is characterised by that trend north to northeast (Province 1 and 2), that is parallel to the flow of the Amery Ice Shelf (Fig. 4). They are probably large scale flutes or drumlins produced by subglacial moulding of the till at the glacier sole (Solheim & others, 1990, Barnes, 1987) and their disappearance into smooth sea floor downstream is attributed to the reduction of effective pressure at the glacier bed as a consequence of a downstream increase in the buoyancy of the ice shelf (Boulton, 1975). This pressure reduction resulted in less moulding of the soft subglacial sediments.

The extensive asymmetric ridges crossing Provinces 1 and 2 resemble morainal banks from a variety of settings (Powell, 1990; Barnes, 1987; Solheim & others, 1990). Their location and the likelihood that the Amery Ice Shelf carries most of its sediment load as subglacial debris suggests that they are grounding line moraines. The moraines are not oriented normal to ice flow but are arcuate, starting parallel to flow line as continuations of a major ridge (Province 7) that separates the two major valleys beneath the Amery Ice Shelf (Fig. 5). Their steep sides face west to northwest. The Amery Ice Shelf probably deposited these banks initially by

subglacial lodgement as effective pressure reduced on approaching the grounding line and then by relatively passive meltout from the floating glacier sole (Drewry & Cooper, 1981). Minor re-advances of the grounding line bulldozed sediment into a steep offshore face. Thus, bank asymmetry indicates that ice was grounded on the eastern side of Prydz Bay while floating on the western side, demonstrating significant differences in behaviour of the eastern and western sides of the Amery Ice Shelf during deglaciation. The presence of two clear ridges and the possible presence of another that it is severely degraded by iceberg gouges on the outer shelf, indicates several relative stillstands during ice retreat.

The orientation of the grounding line moraines parallel to ice flow for much of their length and their steep west to north-west facing sides indicate that they were formed at several grounding line positions of the eastern part of the Amery Ice Shelf during a time when the western side was floating or had retreated further inland. This could be taken to indicate different mass balance conditions for the two sides of the Lambert Glacier during deglaciation, but is more likely to reflect a difference in the response of the two sides of the glacier to sea level rise (Boulton, 1990). The western part of the glacier flowing in the Prydz Channel would have probably been a fast flowing ice stream moving on a deformable bed and so been thinner than the part flowing onto the Four Ladies Bank (Boulton, 1990) and have had its base further below sea level (about 100 m lower, Fig. 5). During the last deglaciation and its accompanying sea level rise, the western side of the Lambert Glacier would thus have floated earlier than the eastern side (Fig. 23a). Once it started to float, basal shear stresses would have reduced to zero, causing rapid thinning of the ice and retreat of the grounding line (Fig. 22, Thomas & Bentley, 1978). The eastern side of the glacier would, for a time, have maintained contact with the substrate so that a grounding line would have developed along

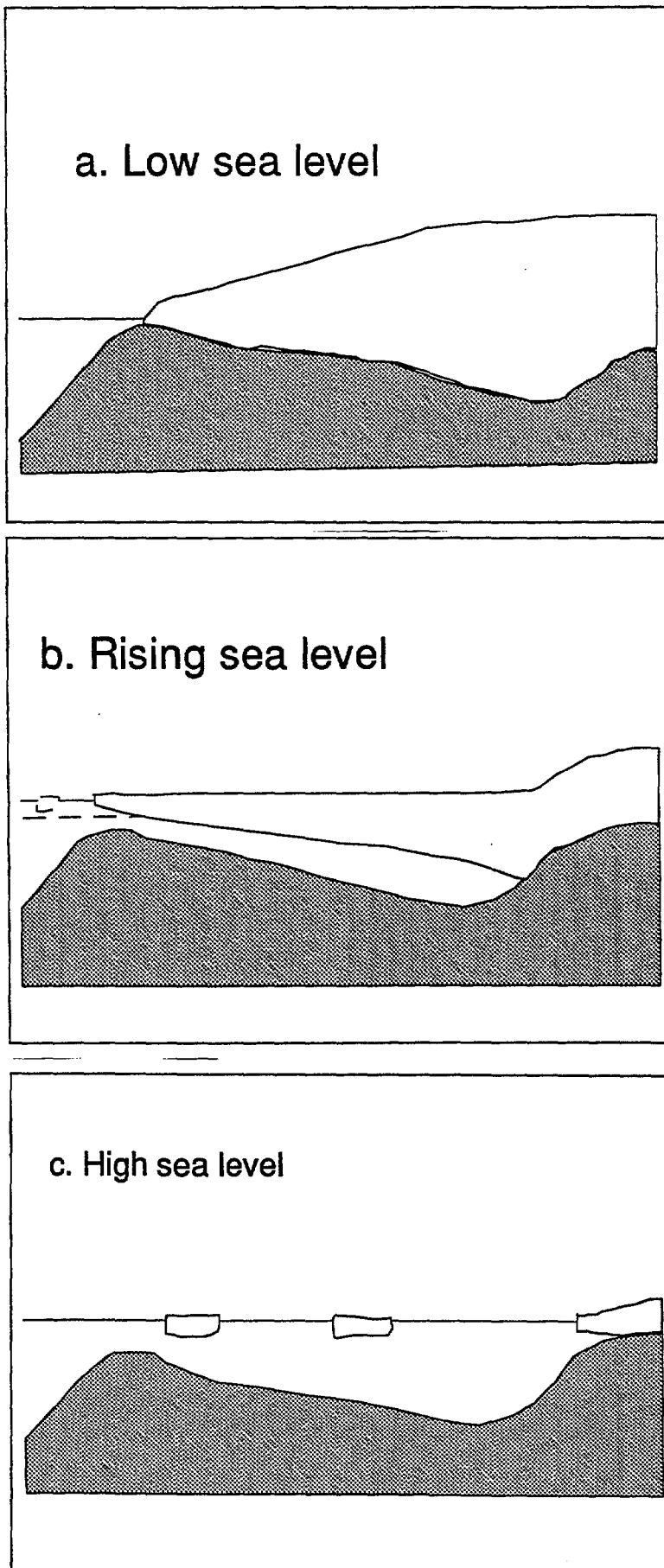


Figure 22. Ice retreat caused by sea level rise.

a. During glacial low sea level phases, the ice is grounded at the continental shelf edge.

b. Sea level rise floats the grounded ice at the shelf edge, reducing basal shear stress to zero. This produced rapid spreading and thinning of the ice tongue and draw down of the interior ice.

c. Ice retreats to a new stable position.

the boundary between the two ice streams (Fig. 23b). The rapid decay of the western side of the Lambert Glacier would also have drawn ice from the eastern side. This, coupled with continued sea level rise eventually caused the retreat of the eastern side.

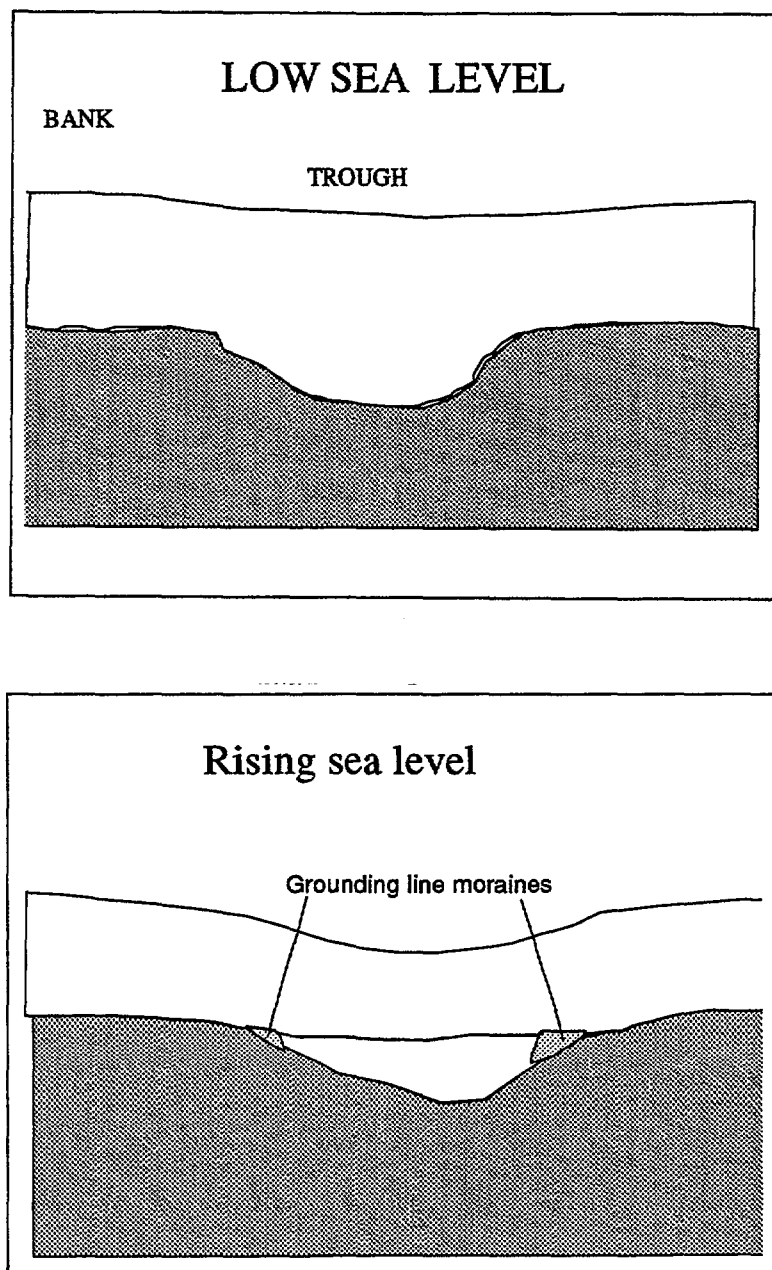


Figure 23. Effect of sea level rise on a glaciated continental shelf with troughs and banks.

- a. During glacial low sea level phase, ice is grounded in the trough and on the bank.
- b. When sea level starts to rise, ice in the trough will float earlier than on the bank and so will experience rapid retreat of the grounding line. A grounding line between ice grounded on the bank and floating ice in the trough will develop.

Mac. Robertson Shelf

The echo-sounder records suggest that the Mac. Robertson Shelf was not extensively glaciated and that the depths of iceberg gouging is similar to Prydz Bay. Some areas have significant sediment accumulations. Franklin (1991) collected one sample of biogenic carbonate from this region.

SAMPLING OBJECTIVES

The echo-sounder data described above and previous sampling in the region suggest three broad objectives for a coring and grab sampling program. They are:

1. Obtain additional surface sediment samples to elucidate sedimentary processes in Prydz Bay and on the Mac. Robertson Shelf. More work is required to identify sources of terrigenous and biogenic sediments and transport and depositional processes.
2. Obtain as many cores of Holocene sediments as possible to confirm the facies change identified by Domack & others (1991a,b) and interpret its sedimentological cause in order to understand the changes in the Lambert Glacier/Amery Ice Shelf that occurred during the Holocene hypsothermal episode.
3. Sample sediments deposited during the deglaciation of Prydz Bay to investigate the timing and pattern of ice retreat.

With these objectives in mind, the following sites have been selected for coring:

SAMPLE SITES

In the light of the preceding discussion the 15 sites will be sampled using first a Van Veen grab to assess sediment suitability and then by a 6 m gravity corer. Locations are shown on Figure 24 and their co-ordinates listed in Table 1.

TABLE 1. Coring sites for Voyage 7, marine geoscience program, 1993.

Number	Latitude	Longitude	Depth
93/001	-67.354086	76.585627	375
93/002	-68.652091	76.711094	855
93/003	-68.101847	73.192770	727
93/004	-68.082567	73.168234	630
93/005	-68.061371	72.277167	825
93/006	-66.562714	70.752169	1980
93/007	-66.608986	69.405612	1537
93/008	-66.822468	69.315002	727
93/009	-66.915947	69.230619	577
93/010	-67.059222	69.024035	163
93/011	-67.475783	64.975674	1247
93/012	-66.900011	63.171711	526
93/013	-66.603476	62.739919	1000
93/014	-66.824248	64.746231	1100
93/015	-66.364090	69.707169	2000
93/016	-62	83	~2000 (BANZARE Bank)
Grab Sites			
K2	-69	75	750
K7	-68.5	72	700
K8	-68.5	70.5	700
K10	-68	76.5	450
K22	-67.5	67.5	200
K25	-67	76.5	400
K27	-67	73.5	500
K28	-67	72	550
K29	-67	70.5	325
F01	-68.516218	77.971479	
F02	-68.581401	77.656361	
F03	-68.694916	77.513312	
F04	-68.673121	77.266243	
F05	-68.820041	77.164677	
F06	-68.914943	76.892880	
F07	-68.780320	76.808462	
F08	-68.710226	76.742313	

Site AA93/001 - This site will sample an area of the Four Ladies Bank in an area unaffected by ice keel gouging (Province 2; Fig 12). It is expected to yield post glacial marine sediments overlying subglacial till. The age of the transition will indicate the time at which the eastern stream of the Lambert Glacier retreated from the outer continental shelf.

Site AA93/002 - This site will sample a stratified sediment lens draped along the northwestern flank of the Svenner Channel (Province 5; Fig. 14) that was penetrated by ODP Hole 740A. It is expected to yield the same Holocene marine sediments intersected in the ODP hole and will be subjected to biofacies, sedimentological and palaeomagnetic studies for comparison with the ODP results (Domack & others, 1991b).

Site AA93/003 - This site samples the fluted sea bed of the Amery Depression below the depth of ice keel gouging (Province 2; Fig. 8). It is expected to yield marine sediment overlying subglacial till with the age of the transition marking the retreat of the east Lambert Glacier from the youngest grounding line moraine in Prydz Bay.

Site AA93/004 - Grabs and cores from this site will identify the sediments making up the youngest grounding line moraine in Prydz Bay (Province 1; Fig. 8). The surface was subject to ice keel gouging, so the stratigraphy could consist of marine sediment post dating the gouges overlying ice keel turbates that will reflect the composition of the moraine.

Site AA93/005 - This site should provide marine sediments overlying subglacial till deposited by the western stream of the Lambert Glacier in Prydz Channel (Fig. 25). Dating of the transition should indicate when the western stream retreated from the continental shelf edge.

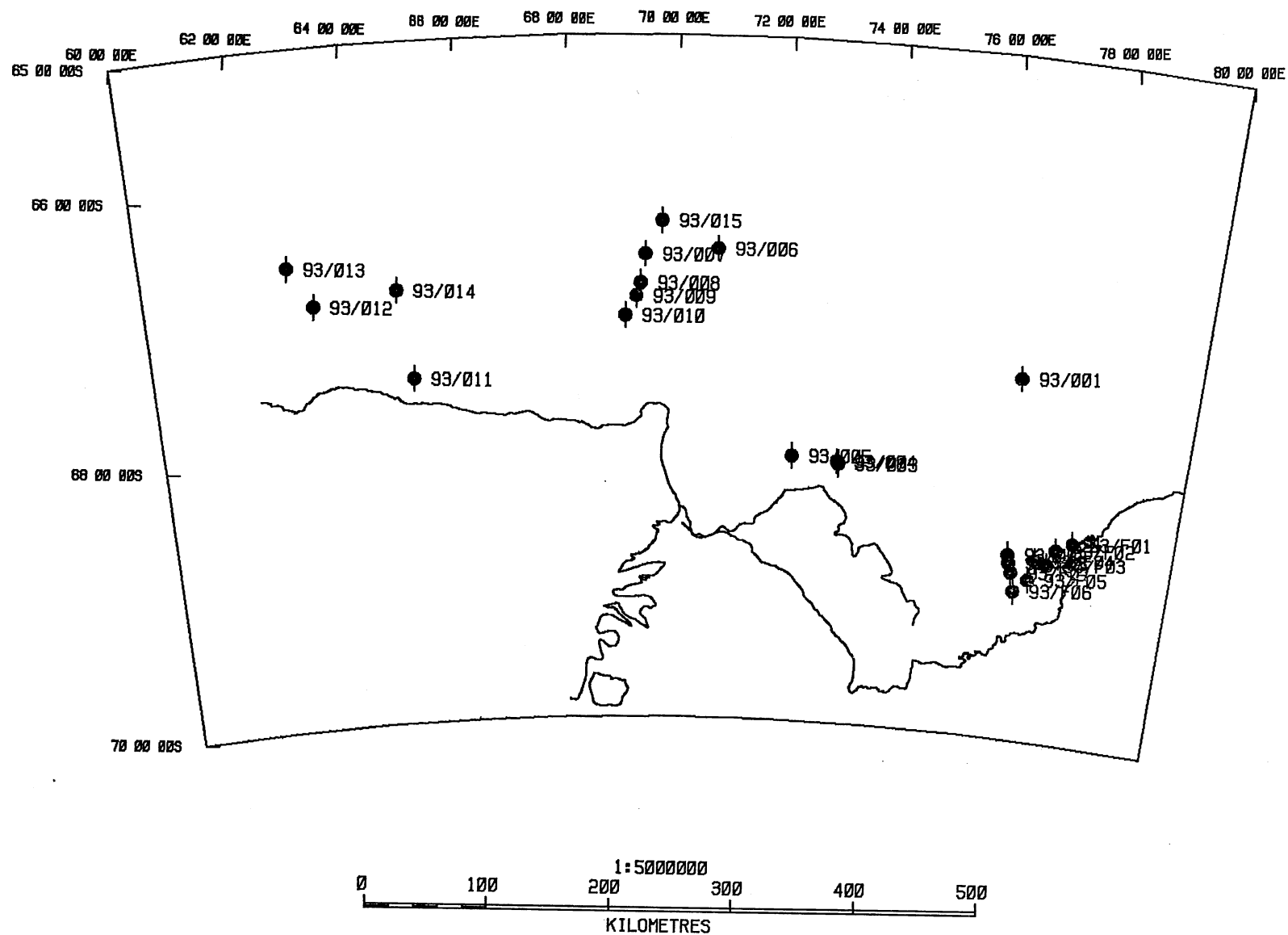


Figure 24. Location of proposed coring sites, Voyage 7, 1992/1993.

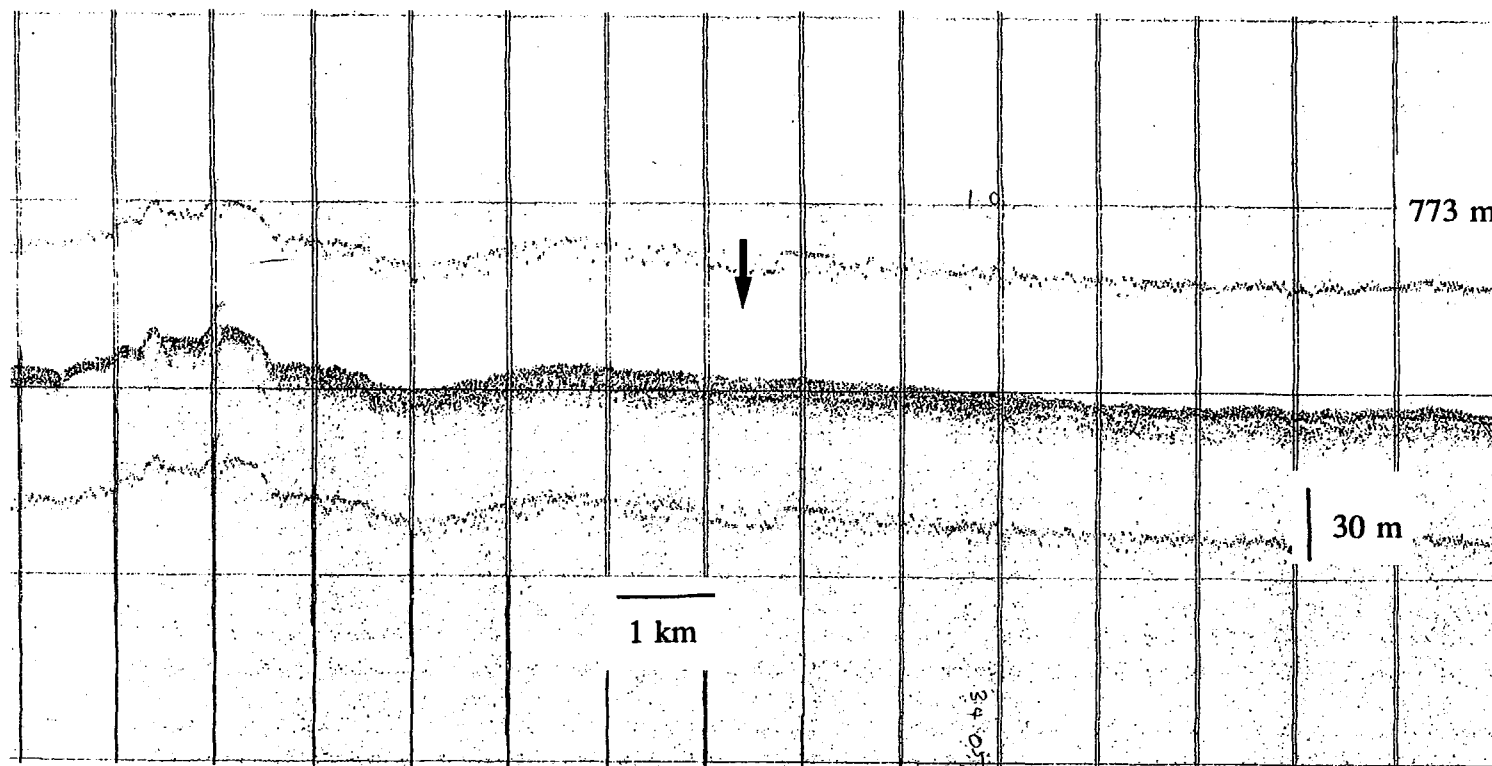


Figure 25. Proposed core site AA93/005 in Prydz Channel.

Site AA93/006 - Situated on the continental slope at the mouth of Prydz Channel (Fig. 17), this site will sample the sediments that have accumulated since the Amery Ice Shelf retreated from the shelf edge and possibly the upper most part of the material bulldozed over the shelf edge by the ice shelf when it was at its greatest extent.

Sites AA93/007, AA93/008, AA93/009, AA93/010 - These sites will sample the area of shelf just west of the Prydz Channel in which Franklin (1991) found bottom sediments rich in biogenic carbonate. They form a transect from the continental slope to the shelf, and should provide information on sediment variations with depth. The core sections will provide records of the history of carbonate sedimentation in the area, and the abundant carbonate may be suitable for isotope studies.

Site AA93/011 - This site will sample the floor of the deepest part of the Neilsen Basin within the Mac. Robertson Shelf (Fig. 18). It may provide a thick, high resolution section for the Holocene and may include anoxic sediments because of the steep-sided, enclosed depositional basin.

Site AA93/012 - A thick lens of sediment showing layering on the echo-sounder records will be cored at this site on the Mac. Robertson Shelf offshore from Mawson (Fig. 19). It may give an indication as to whether or not grounded ice reached this far across the Mac. Robertson Shelf and provide a sedimentary record back to the last glaciation.

Site AA93/013, AA93/014, AA93/015 - These sites will sample the continental slope offshore of the Mac. Robertson Shelf to provide a transect for comparison with the slope sample sites

to the east.

Site AA93/016 - This site is on BANZARE Bank, the southern end of the Kerguelen Plateau, and will provide a core section remote from terrigenous input for use in a study of organic geochemical palaeotemperature indicators being conducted at the Antarctic Research Centre by Drs. E. Sikes and J. Volkman.

Grab Sampling

In addition to the gravity core sites, grab samples will be taken at 15 sites during the krill population survey that will take place before the dedicated geoscience leg of the cruise (Fig. 24). These samples will provide additional indications of bottom sediment variations in Prydz Bay. Those along the Ingrid Christensen Coast (F01-F08) will provide material for the study comparing Holocene sediments of the Vestfold Hills and modern marine sediments being undertaken by D. Franklin as a PhD project at the Antarctic CRC in Hobart.

Equipment

The primary sampling tools to be used are:

1. Van Veen grabs for grab sample sites and for preliminary samples of coring sites to avoid attempts to core coarse, gravelly sediments or hardgrounds. Grabs will be deployed on the Aurora Australis hydro-winch.
2. A 6m long, 7.5 cm diameter gravity corer to be deployed from the stern gantry on the Aurora Australis. Six core barrels will be taken, five for use at Antarctic margin sites and one for use on one core site the BANZARE Bank on the return voyage to support other CRC programs (see below).

CRUISE TIMETABLE

Voyage 7 departs Hobart 6th January, 1993.

21st January - Commencement of marine biological program. Twelve grab samples will be taken during this part of the voyage.

15th February - Geoscience part of the cruise, commencing with coring near Mawson, proceeding east.

24th February - Arrive Davis.

24th February - Depart Davis, core one site on BANZARE Bank on return journey for use in CRC program.

9th March - Arrive Hobart.

Total geoscience sampling time and steaming between sites will be about 6.5 days leaving 3.5 days for contingencies out of the allotted 10 days.

GEOSCIENTIFIC PERSONNEL

Dr. P.E. O'Brien - Senior Research Scientist, AGSO.

B. Dickinson - Technical Officer, Engineering, AGSO.

D. Franklin - PhD student, Antarctic Research Centre Hobart.

Dr. A. Rathburn - Post Doctoral Research Fellow, Department of Geology, ANU.

ADDITIONAL PROGRAMS

Sea bed sampling on Voyage Seven will also support a study of benthonic marine life in Prydz Bay by Drs C.C. Lu and A.J. Constable who will use grab samples obtained for the marine geoscience program. An extra gravity core will be obtained from the western side of BANZARE Bank during the return voyage for use by Drs E.L. Sikes and J.K. Volkman. They

will use it to study the use of C_{37} alkenone chemistry for deducing palaeotemperatures in high southern latitudes. Dr. A. Rathburn will sample material obtained on this cruise for benthonic foraminifera. Geoscientific personnel (O'Brien and Franklin) will also participate in the iceberg logging program. This is part of an ongoing Antarctic Division program, that will provide important input into Prydz Bay sedimentological work because of the significant role of iceberg rafting of sediment and sea floor gouging.

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