# LEG 178

## ANTARCTIC PENINSULA

## Antarctic Glacial History and Sea-level Change

**Modified at ODP/TAMU from Proposal 452-Rev2 Submitted by**

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### ABSTRACT

Leg 178 will drill eight sites off the Pacific margin of the Antarctic Peninsula to provide a high-resolution record of Antarctic continental climate over the past 6-10 m.y. and a direct check on the presumed glacio-eustatic origin of global sea-level change over the same period. Moreover, it is an essential preliminary to the more difficult task of extracting the complete Cenozoic record of Antarctic glacial history that will be obtained by drilling on the East Antarctic margin.

The glacial prograded wedges of the Antarctic Peninsula margin are particularly well-developed, and their glacial record is well-preserved, because of the margin's tectonic youth, high snowfall rates, small-reservoir proximal glacial regime, and underlying 2-D geometry. Associated terrigenous hemipelagic drifts on the adjacent continental rise contain a continuous, high-resolution record of continental climate that will act as a reference section for the topset and foreset records of the shelf. International collaboration through the Antarctic Offshore Seismic Stratigraphy initiative has made extensive data sets available for the planning of a drilling campaign. Site locations strike a balance between the greater density and diversity of data in the northeast and the greater time

separation between tectonic and glacial control of sedimentation in the southwest. The sites aim to sample sedimentation over the last 10 m.y. in all three depositional environments (shelf topsets and foresets, and rise drifts). This conservative, overlapping sampling strategy allows comparison of depositional environments before attempting to sample the longer and more complex history of East Antarctic glaciation.

Inshore paleoproductivity in Palmer Deep (companion Proposal 502) seems representative of regional climate, so that this section can be used to compare decadal and millennial-scale variability with that of low-latitude regions and recorded ice cores.

## INTRODUCTION

The Antarctic Ice Sheet is both a major earth system component (involved in global deep- and bottom-water formation and sea-level change) and a source of "noise" in the oxygen isotopic record that limits the value of this record to other studies throughout most of the Cenozoic. The proposal on which this leg is based is one of four or five linked proposals intended to extract Antarctic Cenozoic glacial history from the sediments of its continental margin. Leg 178 will drill eight sites (Fig. 1) on the continental margin of the Antarctic Peninsula. Sites include a transect of the outer continental shelf, complementary holes in a hemipelagic drift on the continental rise, both extending back 6-10 m.y., and a shallow hole on the inner continental shelf that will provide an ultra-high resolution Holocene record.

At present, the history of the Antarctic Ice Sheet is unknown. It has been inferred from low-latitude proxy data such as oxygen isotopic measurements on deep-ocean benthic foraminifers and the record of eustatic sea-level change adduced from sediments on low-latitude margins (Miller et al., 1987; Haq et al., 1987). However, these inferences are ambiguous, and in disagreement (Sahagian and Watts, 1991; Barker, 1992), which not only leaves the history unresolved, but also limits the credibility and usefulness of both sets of proxy data. For example, there is dispute over whether the principal increases in Antarctic ice volume, which affect the benthic isotopic record, occurred at ~35 Ma, 16-13 Ma, or only after ~3 Ma. Within these various hypotheses, assumptions that may be incorrect have been made about the constancy of equatorial surface temperatures or the high-latitude surface origins and temperatures of intermediate to deep waters at low latitudes. Similarly, changes in grounded ice volume provide the only generally accepted repeatable, rapid-acting cause for global eustatic sea-level change, yet the timing and amplitudes of sea-level change adduced from low-latitude margin sediments are disputed, and changes also occur at times when there is no independent evidence for the existence of substantial volumes of grounded ice on Antarctica or elsewhere. Further, the isotopic and sea-level estimates of grounded ice volume disagree substantially with each other at both long and short periods through most of the Cenozoic. Onshore Antarctic evidence of glacial history is sparse and is also presently controversial. Argument continues as to how stable the Antarctic ice sheet has been (Webb and Harwood, 1991; Denton et al., 1993).

Deep and intermediate waters of the Southern Ocean have generally been corrosive to the carbonate microfossil tests that are almost exclusively used in isotopic analysis. Therefore, the problems in using distal proxy data to make indirect estimates of ice volume will persist. Some progress may be made by detailed analysis at very high resolution of carbonate sections from a large number of lower-latitude sites, but the solutions will remain ambiguous. The Antarctic margin sediments hold a direct record of Antarctic ice-sheet fluctuation that can help resolve the ambiguities of ice-volume change and clear the way for more useful interpretation of isotopic and sea-level data in the future.

The ultimate aim of the four or five linked Antarctic Offshore Seismic Stratigraphy (ANTOSTRAT) drilling proposals is to provide an estimate of variations in size of the Antarctic Ice Sheet through the Cenozoic. This will necessarily include periods when the ice sheet was much smaller and warmer than today, reaching the margin only occasionally and in a few places, with significant fluvial sediment transport and deposition elsewhere. It is therefore necessary for drilling to sample both East and West Antarctic glacial history, and to distinguish a small interior ice sheet, barely reaching the margin, from a much larger ice sheet with a large coastal ice budget. This means making use of numerical models to suggest what might have been the patterns of past glaciation and drilling in different regions, as the models or other relevant information might suggest. For example, Figure 2 (from Huybrechts, 1993) shows a glaciological model of ice sheets that cover only parts of the continent during warmer conditions. It is clear that some regions will be more sensitive to particular stages of ice-sheet volume change than others, and that no single region will provide a complete history. The models provide the means of combining data from different regions of the Antarctic margin into a complete history of ice sheet development.

## BACKGROUND

### Regional Features of Antarctic Glaciation

Different parts of Antarctica have had different glacial histories. The present Antarctic ice sheet comprises an East Antarctic component grounded largely above present sea level and a West Antarctic component grounded largely below sea level. Marine-based (West Antarctic) ice sheets are considered less stable. There is evidence from around Antarctica that, although East and West Antarctic climates were coupled in the past, changing approximately in phase, the climate of West Antarctica (including the Antarctic Peninsula) has varied around a consistently warmer baseline. Although East Antarctic glaciation extends to 35 Ma or earlier, West Antarctic glaciation probably began more recently, during generally colder times. Further, there is strong evidence that Northern Hemisphere glaciation has been the main contributor to global sea-level change over the past 0.8 Ma and probably 2.5 Ma and has therefore partially driven the more subdued changes in Antarctic glaciation. Another significant local control may have been the Transantarctic Mountains, which probably attained much of their present elevation and influence on the East Antarctic ice sheet during late Cenozoic time.

### Glacial Sediment Transport

Great strides have been made in recent years in collaborative interpretation of seismic data from the Antarctic margin (through the ANTOSTRAT initiative: see Cooper et al., 1994; 1995). Together with the simplicity of the modern Antarctic glacial regime (compared with that of the Arctic), these have led to the rapid emergence and application of a unifying model of glacial sediment transport and deposition ( Alley et al., 1989; Larter and Barker, 1989; Bartek et al., 1991; Cooper et al., 1991; Kuvaas and Kristoffersen, 1991). Briefly, almost all ice transport to the ice sheet margins takes place within broad, rapidly-moving ice streams. Rapid flow is enabled by low-friction basal conditions, the main source of which is the existence of an overpressured and undercompacted, unsorted, shearing basal till. The necessary shear ensures that ice transport is accompanied by till transport, and virtually all of the transported till is melted out/dropped/deposited very close to the grounding line, where the ice sheet becomes ice shelf before calving into icebergs and drifting north. The ice stream therefore essentially erodes and transports inshore of the grounding line and deposits directly offshore in a high-latitude analogue of the low-latitude subaerial erosion/shoreline/marine sedimentation system. Further, the grounding line advances and retreats under the influence of upstream ice provision and basal sediment supply—and sea-level change—that are all related to climate. The very large prograded sediment wedges beneath the Antarctic margin were developed during a series of glacial maxima, when the ice sheet was grounded all the way to the continental shelf edge.

The glacial sedimentation regime has other characteristics. Progradation is usually focussed into broad "trough-mouth fans" opposite the main ice streams, the shelf is overdeepened (generally 300-600 m depth, but in places is much deeper) and inward-sloping occurs. Continental slopes are often steep, and in places, turbidity current transport of the unstable component of slope deposition (with down-current deposition of suspended fines) has produced large hemipelagic sediment drifts on the continental rise (Kuvaas and Leitchenkov, 1992; Rebesco et al., 1996). Sediment supply to the slope and rise is highly cyclic, with large quantities of unsorted diamicton deposited during glacial maxima and very little during interglacial periods.

Three depositional environments are recognized:  shelf topsets and slope foresets of the prograded wedge, and proximal hemipelagic drifts on the continental rise. Of these, the shelf record is potentially the least continuous. There, sediment is preserved mainly as a result of slow subsidence from cooling and from flexural response to the topset and foreset load, and the sediment is prone to re-erosion during the next glacial advance. The topsets tend to mark only the major changes in glacial history, so that the more continuous foreset record is an essential complement. The proximal rise drifts may not always be present and are as yet sparsely sampled, but potentially contain an excellent record, closely related to that of the upper slope foresets from which they are derived. Existing seismic data and drill sites from around Antarctica have demonstrated the coarse (but not as yet the fine-scale) climate record in continental rise sediments and the likely climatic sensitivity of margin wedge geometry (Barker, 1995), and have revealed the partial nature of the shelf topset record (Hayes, Frakes, et al., 1975; Barron, Larsen, et al., 1989).

The continental shelf is an area of high biogenic productivity during interglacial periods. Although long-term sediment preservation on the shelf is limited owing to the erosional effects of grounded ice sheets during subsequent glacials, biogenic interbeds will be preserved within sequence groups composed mainly of thick glacial diamicton topsets and foresets. In addition, glacially eroded deeps can preserve expanded Holocene sections that may be continuous and essentially biogenic, provided the ice sheet grounding line is sufficiently remote that ice-rafted debris is minor or absent and the section is sufficiently protected from bottom current action. Such sections can provide a record of decadal and millennial variability that can be compared with records from low latitudes and the ice sheet itself. This environment is available on the inner shelf of the Antarctic Peninsula (Domack and McClennen, 1996) and will be sampled during Leg 178.

## Antarctic Peninsula Region

### *Influences on Glacial Sedimentation*

The ultimate aim of the four or five linked ANTOSTRAT drilling proposals is to provide an estimate of the variation in size of the Antarctic Ice Sheet through the Cenozoic. Each ANTOSTRAT proposal is focussed on the particular contributions its region might make toward understanding Antarctic glacial history. A single region does not offer the best opportunities for drilling in all respects. The particular value of drilling on the Antarctic Peninsula is made clear below, in terms of the main influences on glacial sedimentation.

1. All Antarctic margins are extensional or effectively so, in a thermal and flexural sense, but most are old. Age governs thermal subsidence and rigidity, which controls response to erosion and deposition and to cyclic ice loading. The Antarctic Peninsula behaves as a young passive margin, having subducted a ridge crest (50 Ma in the southwest to only 6-3 Ma in the northeast; Barker, 1982; Larter and Barker, 1991a). The margin undergoes steady thermal subsidence, which means better preservation of topset beds of the prograded wedge than at an older, colder margin and a more local isostatic response to sediment load.

2. Snow accumulation varies with temperature and is greatest around the continental edge and particularly along the Antarctic Peninsula, which is warmer than East Antarctica (Drewry and Morris, 1992). Snow accumulation governs the required rates of ice transport, hence basal sediment transport. Greater accumulation means an expanded sediment record. Warmer ice means (probably) faster ice flow, which also contributes to a rapid response to climate and an expanded sediment record.

3. The extent of the ice drainage basin affects the speed of response to climate change and adds the complexity of a distal to a proximal signal (which allows the possibility of seeing the effects of a small, purely inland ice sheet at the coast during less-glaciated periods). The Antarctic Peninsula is a narrow strip of interior upland, dissected by fjords and bordered by a broad continental shelf. It thus, has a low-reservoir, high-throughput glacial regime with only a proximal source, so it is both simple and highly responsive to climate change.

4. Subice geology (resistance to erosion) is a significant variable, to the extent that a till base facilitates ice streaming. The Peninsula interior is 2000 m high, composed largely of Andean-type plutonic and volcanic rocks. Before ridge subduction, the Pacific margin was a well-developed forearc terrain on which the glacial regime has superposed an extensive prograded wedge (Larter and Barker, 1989, 1991b; Anderson et al., 1990; Larter and Cunningham, 1993; Bart and Anderson, 1995). The topography and geology of the Peninsula vary very little along strike, which simplifies models of erosional and depositional response to climate change. Short cores on the outer shelf show diamicton beneath a thin cover of Holocene hemipelagic mud (Pope and Anderson, 1992; Pudsey et al., 1994).

Onshore evidence of Eocene glaciation on the South Shetland Islands (northern Antarctic Peninsula) has been published (see Birkenmajer, 1992), but this conflicts with other evidence of regional climate. Generally, it is considered that the Antarctic Peninsula can provide a high-resolution record of glaciation back to perhaps 10 Ma. To go back farther could involve entanglement with the tectonics of ridge crest collision (see below), making this a problem rather than an asset. However, because of the Antarctic Peninsula's more northerly position, its glacial history is shorter than East Antarctica's. The record before 10 Ma may be largely nonglacial or reveal a stage of valley glaciation lacking regular ice sheet extension to the continental shelf edge.

*Tectonics, Glaciation, and Shelf Sedimentation*

The tectonic setting of the Antarctic Peninsula is unusual, but straightforward. Subduction of the Pacific ocean floor that occurred for 150 m.y. or more ended with collision of a (Phoenix-Antarctic) ridge crest at the trench, earliest (~50 Ma) in the southwest and latest (6-3 Ma) in the northeast. In the far northeast, the surviving South Shetland Trench and extensional Bransfield Strait form a modern complexity that does not concern us here. Generally, the effects of collision have included: (a) some terrigenous sedimentation in and beyond the ridge crest in the last 2-3 m.y. before collision; and (b) uplift of the margin soon after collision followed by slow subsidence, leading to a hiatus in terrigenous sediment supply to the rise in that particular collision segment for a few million years after collision. In the southwest, collisions were well before the onset of glaciation, but not in the northeast. In the northeast, this provides a useful constraint on the maximum age of glacial sediments (they overlie ocean floor of known age), but also threatens interference between tectonic and glacial events. For the older glacial history it is prudent to avoid the northeast area of the margin.

## SCIENTIFIC OBJECTIVES

The principal drilling objectives of Leg 178 are to

- Extract and compare high-resolution records of the past 10 Ma of continental glaciation contained in topset beds (paleoshelf) of the glacial prograded wedge at the Antarctic Peninsula Pacific margin, in foreset beds (paleoslope) of the same sequence groups, and in a hemipelagic sediment drift on the continental rise,
- Compile an optimal high-resolution history of grounded ice-volume fluctuation and compare it with low-latitude records of sea-level change and isotopic estimates of ice-volume change over the past 10 Ma,
- Assess the main controls on sediment transport and deposition during glacial intervals and use the insights gained to optimize investigation of the longer, more complicated East Antarctic record of glaciation and glacio-eustatic sea-level change, and
- Extract an ultra-high-resolution Holocene record from a protected basin on the inner continental shelf for comparison with similar records from the ice sheets and lower-latitude sites to investigate decadal- and millennial-scale climatic variation.

## PROPOSED SITES AND DEPOSITIONAL FEATURES

The prime sites for Leg 178 are

- A linked proximal/distal pair of reference sites on a rise drift (APRIS-01A, 02A on Fig. 1; R1, R2 on Fig. 2),
- A 4-site transect of the margin prograded wedge of Lobe 1 (APSHE-01A to 04A on Fig. 1; S1-S4 on Fig. 2),
- An interlobe site to examine the "preglacial" S3 (APSHE-05A on Fig. 1; S5 on Fig. 2), and
- An ultra-high-resolution Holocene inner shelf site in Palmer Deep (APSHE-13A on Fig. 1; S13 on Fig. 2).

Figure 2 shows the distribution of the main depositional features along the Antarctic Peninsula margin. On the shelf, a mid-shelf high running continuously along the margin and discontinuous mid-shelf basins inside it are relics of subduction and ridge crest collision. The volcanics and plutonics of the central spine of the Peninsula have been dissected by glacial erosion. At present, the ice cover on the Peninsula is thin (a few hundred meters at most), and the grounding line lies at the heads of the numerous overdeepened fjords. Around the glacial maximum, the ice was grounded over most or all of the continental shelf, and shallow troughs draining the interior transported basal till to four depositional lobes, L1-4 (trough-mouth fans), that have extended the shelf edge.

**Sites APSHE-01A to 04A**

Figure 3 shows a section through Lobe 1, along our prime drilling transect (S1 to S4 on Fig. 2) that consists of proposed Sites APSHE-01A to 04A. Sequence groups S1 and S2 (Fig. 3) are considered to have been produced by ice stream transport during ice sheet grounding to the shelf edge over the past 5 m.y. or so. Glacial deposition is largely confined to the lobes and is discontinuous between them, so strict correlation between sequence groups cannot be made. However, sequence group geometries virtually identical to S1 and S2 are seen within Lobes 2 to 4. S1 is moderately progradational, with minor versions of the feature that dominate and distinguish S2—the erosional truncation of foresets at its upper boundary. The main aim of the drilling transect is to date the major components of this characteristic geometry: the beginning of S2, the beginning and end of the episode of truncation with which it ended, and the assumed continuous foreset deposition in S1. It should also be possible to characterize quite fully the lateral coherence and degree of discontinuity of topset deposition within both S1 and S2.

**Site APSHE-05A**

Beneath sequence group S2 is sequence group S3 (Fig. 3) that, except in the northeast, is clearly post-collision but is different from S1 and S2 as it is much more continuous along the margin, is parallel-bedded down-dip (lacking a clear paleoshelf break), and either pinches out or is truncated at its down-dip end. In many of its characteristics, it resembles a sequence found elsewhere beneath the glacial prograded wedge (the Type IIA of Cooper et al., 1991). We have called S3 "pre-glacial," but that is a shorthand term as it most probably reflects an earlier or transitional stage of glacial deposition before ice sheets regularly extended to the shelf break. This sequence will be sampled at proposed Site APSHE-05A, between Lobes 3 and 4, where it is more accessible and clearly separated from collisional tectonics. Sequence group S4 is pre- and syn-collisional, and in general its erosionally truncated upper boundary reflects collision-related uplift. If the S3/S4 boundary were to be sampled in the northeast, it would show pronounced collision-related unconformity; but here there is the possibility that S3 sediment represents a sufficiently long period where its basal sediments are more clearly pre-glacial and conformable on S4. The full depth of penetration at APSHE-05A is uncertain.

**Sites APRIS-01A and 02A**

The present slope of the depositional lobes L1 to 4 (Fig. 4) is steep (15°-20°) and is assumed to be at the limit of stability. The GLORIA survey of the northeastern area of the rise (Tomlinson et al., 1992; Rebesco et al., 1996) and a deep-tow boomer examination of the upper slope (Vanneste and Larter 1995) show a small-scale dissection of the upper slope and a dendritic pattern of channels at the base of slope, which feed major channels that head northwestward toward the lower continental rise (Fig. 2). Between the major channels lie large depositional mounds rising more than 1 km above the channel floors. These mounds were interpreted to have formed as the result of ambient bottom-current entrainment of suspended fines from the many small-scale turbidity currents that "drain" the continental slope via the channels (Rebesco et al., 1994, 1996; McGinnis and Hayes, 1994, 1995). These mounds are fine-grained hemipelagic sediment drifts. Those within the GLORIA survey area (Drifts D1-D4) are clearly separated from the margin by tributary channels, and the larger drifts to the southwest are probably the same. It is doubtful if direct deposition of turbidites has contributed to the drift deposits, except at their distal extremity. Seismic reflection profiles show a remarkable similarity in reflection character of the separate drifts over distances of

400 km or more.

The drifts are likely to provide a fine-grained equivalent of the slope foreset record of glacial history, provided that the residence time of the unstable component of upper slope deposition is short compared with the glacial cycle, and individual slope turbidites are small. Recent gravity coring on Drift 7 (Camerlenghi et al., in press) confirms these conditions: a biogenic mud at the core top (rich in diatoms and radiolaria with benthic and planktonic foraminifers) overlies barren, laminated glacial silty clays above another biogenic mud (interglacial Stage 5). Average sedimentation rate is 3.5 to 5 cm/k.y. All the evidence indicates that the drifts provide a viable high-resolution record of glacial history. Leg 178 will drill one drift at two sites (APRIS-01A and 02A on Drift 7). One site is located at the proximal end of the drift and the other is a distal offset site designed to penetrate deeper in the section where it is thinner in the event that silica diagenesis at the prime site eliminates biostratigraphic control (there is a silica diagenetic bottom simulating reflector [BSR] at about 600 m within Drift 7).

In summary, these seven sites will sample the 6-10 m.y. of Antarctic Peninsula glacial history in all three primary depositional environments (shelf topsets, slope foresets, rise drift). The rise sites (Sites APRIS-01A and 02A) will provide a high-resolution record that will serve as a reference for the shelf transect (Sites APSHE-01A to 04A), allowing correlation of the major changes in prograding wedge geometry and assisting in the interpretation of all three records in terms of climate change. The result will be a high-resolution record of glaciation through a period when sea-level change has been (for Antarctica) imposed from outside (i.e., Northern Hemisphere glaciation over the past 0.8 and/or 2.5 Ma) to a preceding regime in which the main contribution to sea-level change was from Antarctic glaciation itself, and when the isotopic signal of insolation change was of lower amplitude and shorter period (Tiedemann et al., 1994; Shackleton et al., 1995). A major global sea-level drop occurred at 10 Ma, and there is controversy over the climate of the warm Pliocene in the Antarctic and over the depth of the preceding late Miocene cool period. Through most of the past 10 m.y., the contribution of ice-volume change to the isotopic signal is unknown. This will be the first Antarctic high-resolution record of any kind. In addition, the core recovered from Leg 178 will greatly improve our understanding of the potential and limitations of the main glacial depositional environments.

**Site APSHE-13A**

Proposed Site APSHE-13A (Proposal 502 by G. Domack) is located in the Palmer Deep on the inner continental shelf directly south of Anvers Island (Leventer et al., in press). It lies in one of three linked basins that contain an ultra-high-resolution Holocene record of Antarctic Peninsula climate. Short piston cores from this basin show a pronounced 200-300 yr periodicity in paleoproductivity that is also seen in some Antarctic Peninsula fjords. This region is particularly interesting because of its current apparent sensitivity to climate change. The expanded, presumed pelagic section may be compared with recently-acquired records from low and intermediate latitudes (Santa Barbara Basin, Saanich Inlet, Cariaco Basin) and ice-core records from Greenland and Antarctica, to examine decadal and millennial variability on a global scale. This record may provide opportunities to examine secular magnetic variation and, for the inshore environment, the time variability of the $^{14}C$ "reservoir effect," which is large but uncertain for waters south of the Polar Front.

## DRILLING STRATEGY

All sites have an alternate site in case pack ice covers the primary sites (although this is most unlikely). In addition, lower-priority sites (each with an alternate) were retained in the mid-shelf basin where pre-collision sediments occur (APSHE-11A) and in the South Shetland trench where a high-resolution paleoclimate record is preserved within a trench turbidite succession (APSST-01A). Also, the Planning Committee (PCOM) recommended that an originally-specified Plio-Pleistocene paleoclimate site in Bransfield Strait (APBRS-01A) be removed from the drilling plan because of a shortage of time. In fact, only the prime sites listed above will be drilled as planned if the leg proceeds without massive disruption by ice.

Drilling on the rise will involve double or triple APC and XCB at the proximal site (to about 700 m), followed by RCB to the full 1400 m depth, or more probably, offset to the distal APC/XCB site where the same full section is accessible within 600 m. The decision to drill will depend on the effects of silica diagenesis on the biostratigraphy and on time constraints. These sites are in fine-grained alternating biosiliceous and barren muds and mudstones. The 50-m ultra-high-resolution site assumed to be essentially a diatom ooze will be sampled by quadruple APC. The other shelf sites pose problems, in that the unsorted diamictons are unsuitable for APC/XCB sampling. Therefore, all five sites (that are between 500 and 800 m deep) will probably (in the absence of advice to the contrary) be rotary-drilled from the seabed down. Recovery will be reduced because of their lithology (with the possible exception of APSHE-05A), but we shall try for as complete a section as possible.

## LOGGING PLAN

Prior ODP/DSDP experience in Antarctic margins (Legs 28, 113, and 119) has shown that core recovery, particularly in diamictons, can be poor. Although only limited logging was attempted during Legs 113 and 119, the good quality results (sonic-resistivity, lithoporosity) underscore the potential contributions of wireline logging to this program. These include:

- Characterization of the stratigraphic response of the margin to sea-level and ice-volume changes, using Formation MicroScanner (FMS) and geophysical logs. The integration of logs with core data has the potential to offset the anticipated low core recovery, particularly on the shelf sections.

- Characterization of the fine scale bedding on the slope and drift deposits using FMS images. This may be of particular significance to assess cyclicity in the sedimentary section and help evaluate the climatic forcing functions and to refine timing by tuning the downhole log records.

- Site-to-site correlation, both on the shelf and from shelf to rise. These correlations can be facilitated if a magnetic reversal sequence is obtained with the GHMT. Previous dating in the Antarctic has relied on diatom biostratigraphy and magnetostratigraphy from core samples. Given that recovery is likely to be low at some sites (particularly in the shelf-slope), the GHMT could be an important tool to help date the sedimentary record.

- Seismic calibration with check-shot surveys.

Logging will be important to the success of the leg, and all but the Palmer Deep site (which is too shallow) will be logged. We aim to deploy the two standard suites IPLT-DLT and Formation MicroScanner (FMS)/sonic, plus the GHMT, and possibly the seismic calibration tool (WST) at some sites. The logs will be useful as paleoclimate proxies and crucial in the shelf holes as a way of locating incompletely-recovered core (by comparison with shipboard multisensor track [MST] measurements) and identifying missing section. We shall be particularly interested in the GHMT, which in combination with shipboard magnetic measurements, will be a means of establishing ties between biostratigraphy and magnetostratigraphy and between shelf and rise sections. On the drift sites, magnetic susceptibility records, together with other geophysical logs, will help decipher the climatic signals recorded through changes in the proportion of pelagic vs. margin derived sediments, as well as to provide excellent records for detailed core-log integration (e.g., Leg 162 results).

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# TABLE 1

## PROPOSED SITE INFORMATION AND DRILLING STRATEGY

| | | |
|---|---|---|
| **SITE**: APRIS-01A | **PRIORITY**: 1 | **POSITION**: 67°34.00´S, 76°57.78´W |
| **WATER DEPTH**: 3200 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 700 m |
| **SEISMIC COVERAGE:** Explora lines IT92-109 and AI95-130 | | |

**Objectives**: Sample long continuous section in fine-grained hemipelagic drift to Base M4, the onset of drift formation. Prime section is in Drift 7 (because of its thick section), but with alternates in Drift 6 and Drift 4. Each section comprises two sites: a main and a standby distal (~50 km) offset. Offset required if stratigraphic control seriously degraded below silica diagenetic BSR at ~600 m at main site.

**Drilling Program**: Double APC to 200 m and XCB to 700 m, then either RCB from 700 m to base M4 at same site OR single APC and XCB to base M4 (at ~550 m) at offset site (APRIS-02A), where upper section is thinner. Alternates APRIS-03A, -05A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Alternating (interglacial) biosiliceous clay and (glacial) laminated barren gray clay, becoming claystone downhole.

| | | |
|---|---|---|
| **SITE**: APRIS-02A | **PRIORITY**: 1 | **POSITION**: 66°59.91´S, 78°29.16´W |
| **WATER DEPTH**: 3850 m | **SEDIMENT THICKNESS**: 1500 m | **TOTAL PENETRATION**: 550 m |
| **SEISMIC COVERAGE**: Explora line AI95-135A | | |

**Objectives**: Sample long continuous section in fine-grained hemipelagic drift to Base M4, the onset of drift formation. Is standby distal (~50 km) offset to main Site APRIS-01A. Offset required if stratigraphic control seriously degraded below silica diagenetic BSR at ~600 m at main site.

**Drilling Program**: Single APC and XCB to base M4 (at ~550 m) where upper section is thinner. Alternate

Sites APRIS-04A, -06A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Alternating (interglacial) biosiliceous clay and (glacial) laminated barren gray clay, becoming claystone downhole.

| | | |
|---|---|---|
| **SITE**: APSHE-01A | **PRIORITY**: 1 | **POSITION**: 63°48.16´S, 65°51.46´W |
| **WATER DEPTH**: 450 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 505 m |
| **SEISMIC COVERAGE:** Explora line AI95-152 and Discovery line AMG845-08 | | |

**Objectives**: Part of a 4-hole transect along the axis of progradational Lobe 1 to identify and date the main changes in wedge geometry (including the "pre-glacial"/glacial transition), examine foreset and topset lithologies, and compare with rise drift. This site contains young S1 foresets from the present shelf break. Lobe 1 was selected on the basis of site survey: better definition of sequence boundaries than the alternate on Lobe 3 and a more extensive dataset.

**Drilling Program**: Single RCB hole. Alternate site is Site APSHE-07A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Diamicton (mainly proximal glacial marine) with thin biosiliceous interbeds

| | | |
|---|---|---|
| **SITE**: APSHE-02A | **PRIORITY**: 1 | **POSITION**: 63°52.03´S, 65°44.73´W |
| **WATER DEPTH**: 440 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 560 m |
| **SEISMIC COVERAGE**: Explora line AI95-152 and Discovery line AMG845-08 | | |

**Objectives**: Part of a 4-hole transect (each a single rotary cored hole) along the axis of progradational Lobe 1 to identify and date the main changes in wedge geometry (including the "pre-glacial"/glacial transition), examine foreset and topset lithologies, and compare with rise drift. This site contains S1 topsets down to the onset of S1 deposition (when topset deposition recommenced), where the S1/S2 boundary is conformable, then upper S2 foresets.

**Drilling Program**: Single RCB hole. Alternate site is Site APSHE-08A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Diamicton (alternations of lodgement till in topsets and proximal glacial marine) with thin biosiliceous interbeds

| | | |
|---|---|---|
| **SITE**: APSHE-03A | **PRIORITY**: 1 | **POSITION**: 63°52.93´S, 65°42.69´W |
| **WATER DEPTH**: 440 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 505 m |
| **SEISMIC COVERAGE:** Explora line AI95-152 and Discovery line AMG845-08 | | |

**Objectives**: Part of a 4-hole transect along the axis of progradational Lobe 1 to identify and date the main changes in wedge geometry (including the "pre-glacial"/glacial transition), examine foreset and topset lithologies, and compare with rise drift. This site contains the time when erosion of S2 topsets started (NOT the same as Apshe-02A).

**Drilling Program**: Single RCB hole. Alternate site is Site APSHE-09A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT

**Nature of Rock Anticipated**: Diamicton (alternations of lodgement till in topsets and proximal glacial marine) with thin biosiliceous interbeds

| | | |
|---|---|---|
| **SITE**: APSHE-04A | **PRIORITY**: 1 | **POSITION**: 63°56.52´S, 65°34.62´W |
| **WATER DEPTH**: 490 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 785 m |
| **SEISMIC COVERAGE:** Explora line AI95-152 and Discovery line AMG845-08 | | |

**Objectives:** Part of a 4-hole transect along the axis of progradational Lobe 1 to identify and date the main changes in wedge geometry (including the "pre-glacial"/glacial transition), examine foreset and topset lithologies, and compare with rise drift. At this site, the oldest part of S2 and youngest ("pre-glacial") S3, where the boundary is conformable.

**Drilling Program**: Single RCB hole. Alternate site is Site APSHE-05A.

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Diamicton (alternations of lodgement till in topsets and proximal glacial marine) with thin biosiliceous interbeds to base S2, then uncertain lithology (glacial marine diamicton or biosiliceous hemipelagic)

| | | |
|---|---|---|
| **SITE**: APSHE-05A | **PRIORITY**: 1 | **POSITION**: 66°23.57´S, 70°45.40´W |
| **WATER DEPTH**: 600 m | **SEDIMENT THICKNESS**: >2000 m | **TOTAL PENETRATION**: 785 m |
| **SEISMIC COVERAGE:** Polar Duke PD88-B and PD88-04 | | |

**Objectives:** To examine ("pre-glacial") S3 in detail, test the synchroneity of the conformable S3/S2 boundary along the margin, and sample the near-conformable (probably tectonic) S4/S3 boundary. Will test hypotheses of the "pre-glacial" nature of S3, and of the uplift/subsidence origin of the S4/S3 boundary. Required to be remote from the main wedge transect, and better in an older RC-T collision zone. Access to S3 is eased by site location in interlobe area.

**Drilling Program**: Single RCB hole. Alternate site is Site APSHE-10A

**Logging and Downhole Operations**: Standard suites IPLT-DLT and FMS-sonic, plus GHMT.

**Nature of Rock Anticipated**: Diamicton (lodgement till and proximal glacial marine) with thin biosiliceous interbeds to base S2 (ie top ~150 m), then uncertain (glacial marine diamicton or biosiliceous hemipelagic) in S3 to base of hole

| | | |
|---|---|---|
| **SITE**: APSHE-13A | **PRIORITY**: 1 | **POSITION**: 64°51.72´S, 64°12.51´W |
| **WATER DEPTH**: 1040 m | **SEDIMENT THICKNESS**: ~60 m | **TOTAL PENETRATION**: 50 m |
| **SEISMIC COVERAGE:** PD92 Deep-tow Boomer (Explora lines planned 3/97) | | |

**Objectives:** Ultra-high-resolution Holocene record of paleoproductivity (from Domack et al., Proposal 502) in inner shelf basin. Examine decadal-millennial variability, compare with low-latitude and ice core records.

**Drilling Program**: Quadruple APC to 50 m or base of biogenic sediments if deeper. Alternate site is Site APSHE-14A

**Logging and Downhole Operations**: None

**Nature of Rock Anticipated**: Pelagic/hemipelagic siliceous ooze and mud, with <1% ice-rafted component

# Antarctic Peninsula

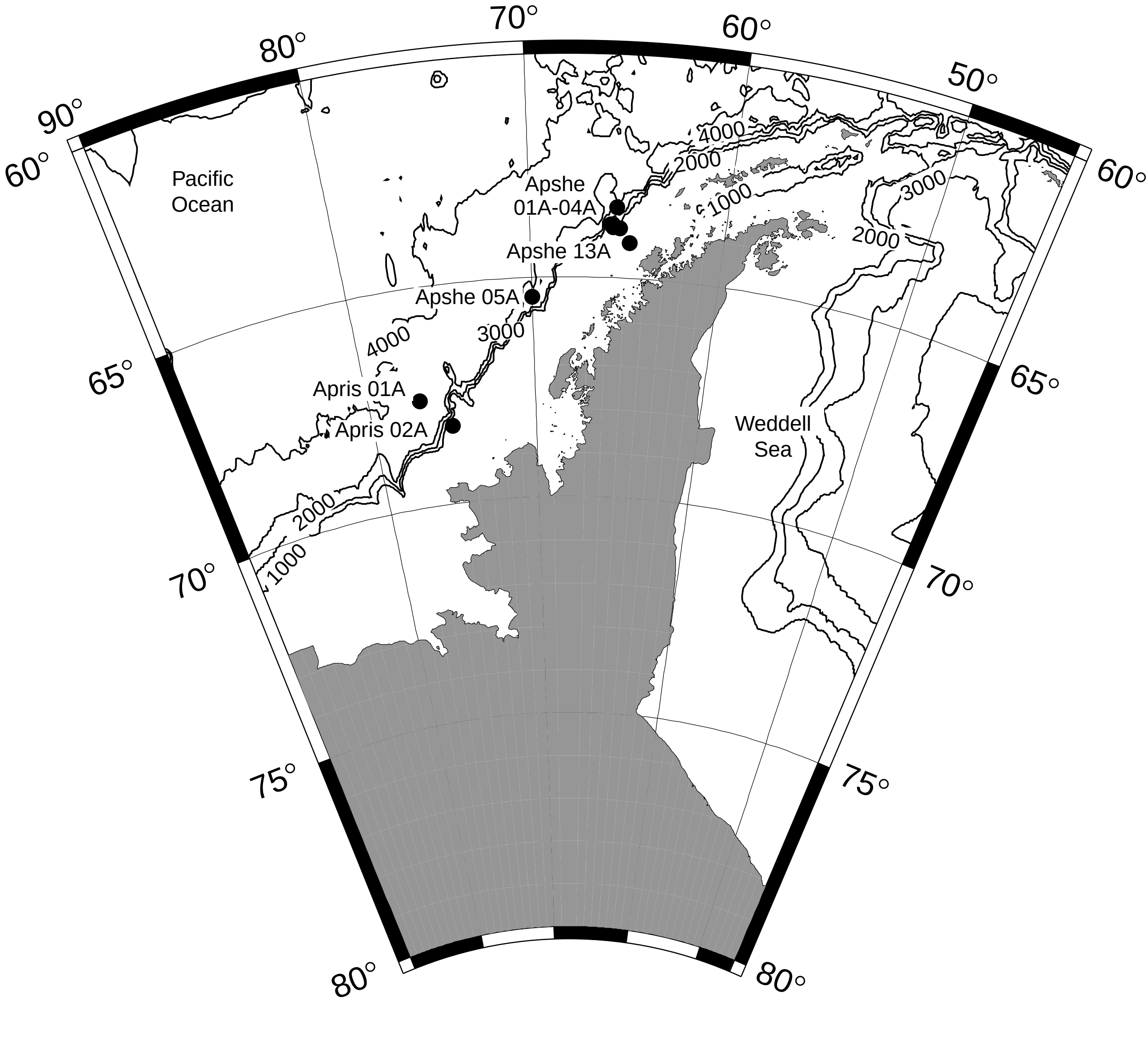


Figure 1. Map of the Antarctic Peninsula showing the location of the proposed drill sites.

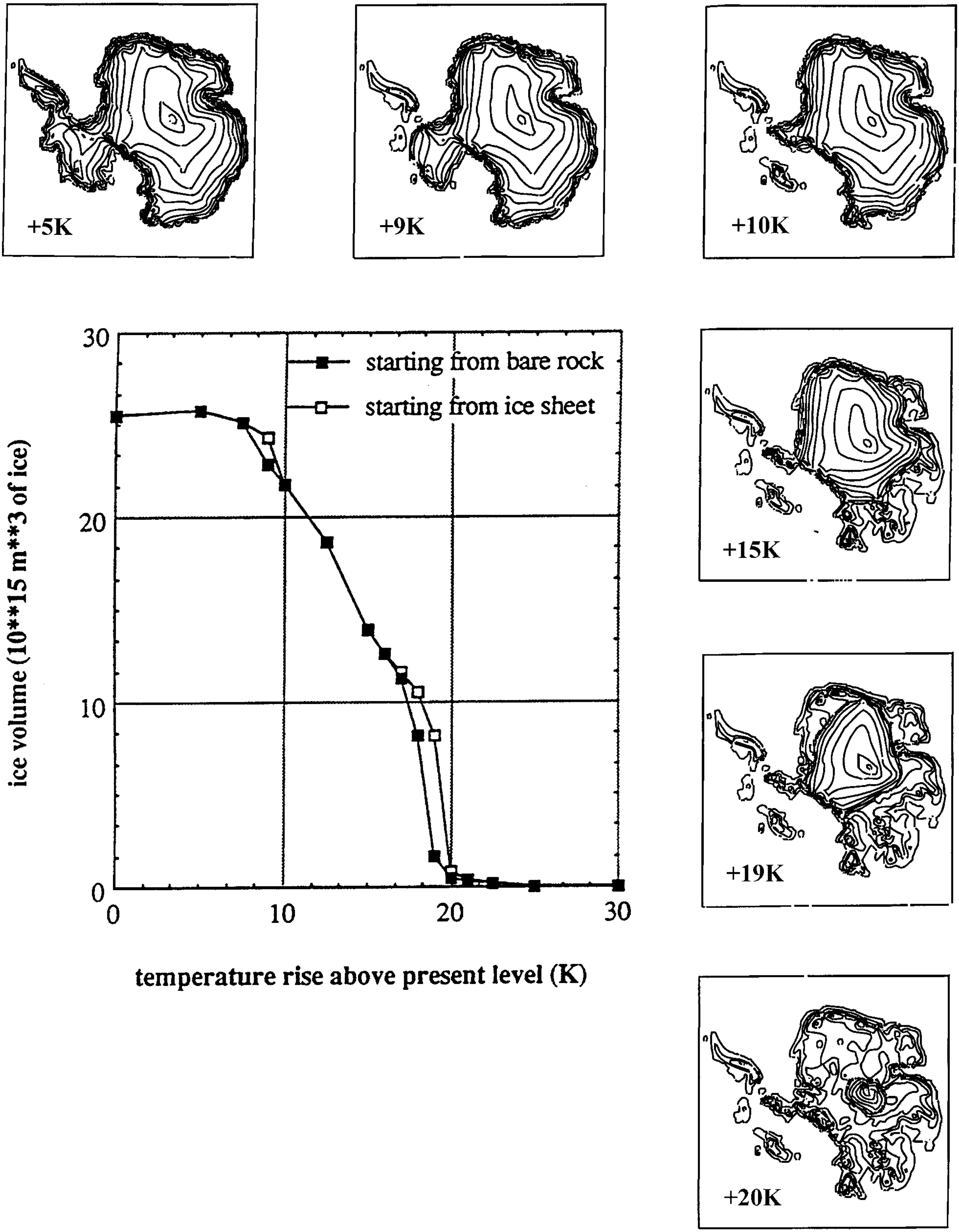


Figure 2. Ice-sheet growth showing ice-sheet size and location at 5, 9, 10, 15, 19, and 20 k.y. before present, with a graph that shows the change of mean temperature at sea level. The maps indicate where margin sedimentation might be sensitive to particular stages of ice sheet growth. Antarctic Peninsula glaciation appears to have developed during the last 5-9 k.y. of cooling (from Huybrechts, 1993).

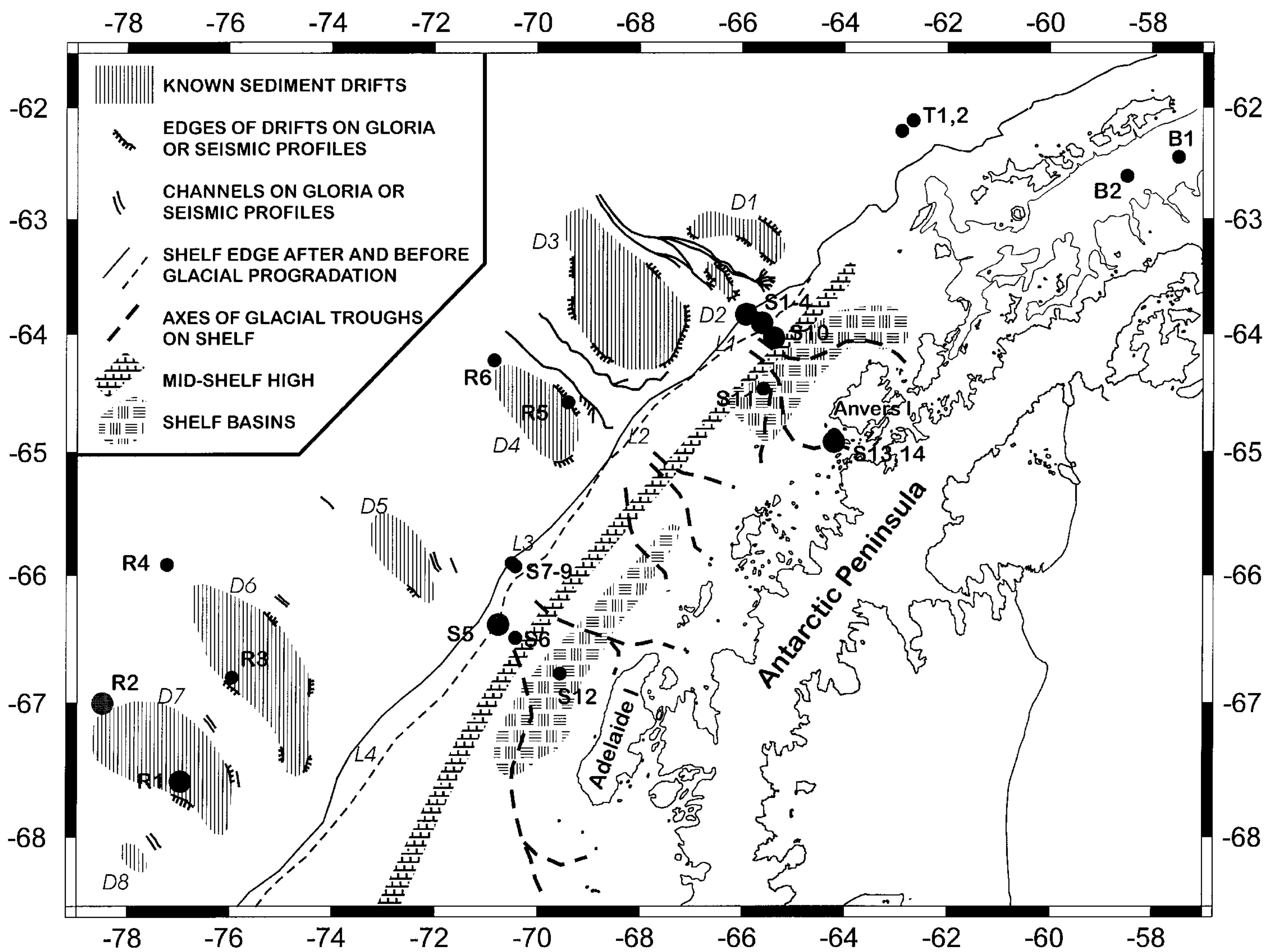


Figure 3. Pacific margin of the Antarctic Peninsula (revised from Barker, 1995) showing sedimentary features of the continental shelf, slope, and rise, including drifts D1-8 and Lobes L1 4, with proposed sites for ODP Leg 178. Large spots mark primary sites (APRIS-01A, 02A as R1, R2; APSHE-01A to 04A as S1-4; APSHE-05A as S5; and APSHE-013A as S13), and smaller spots (unnumbered) mark alternate and lower priority sites.

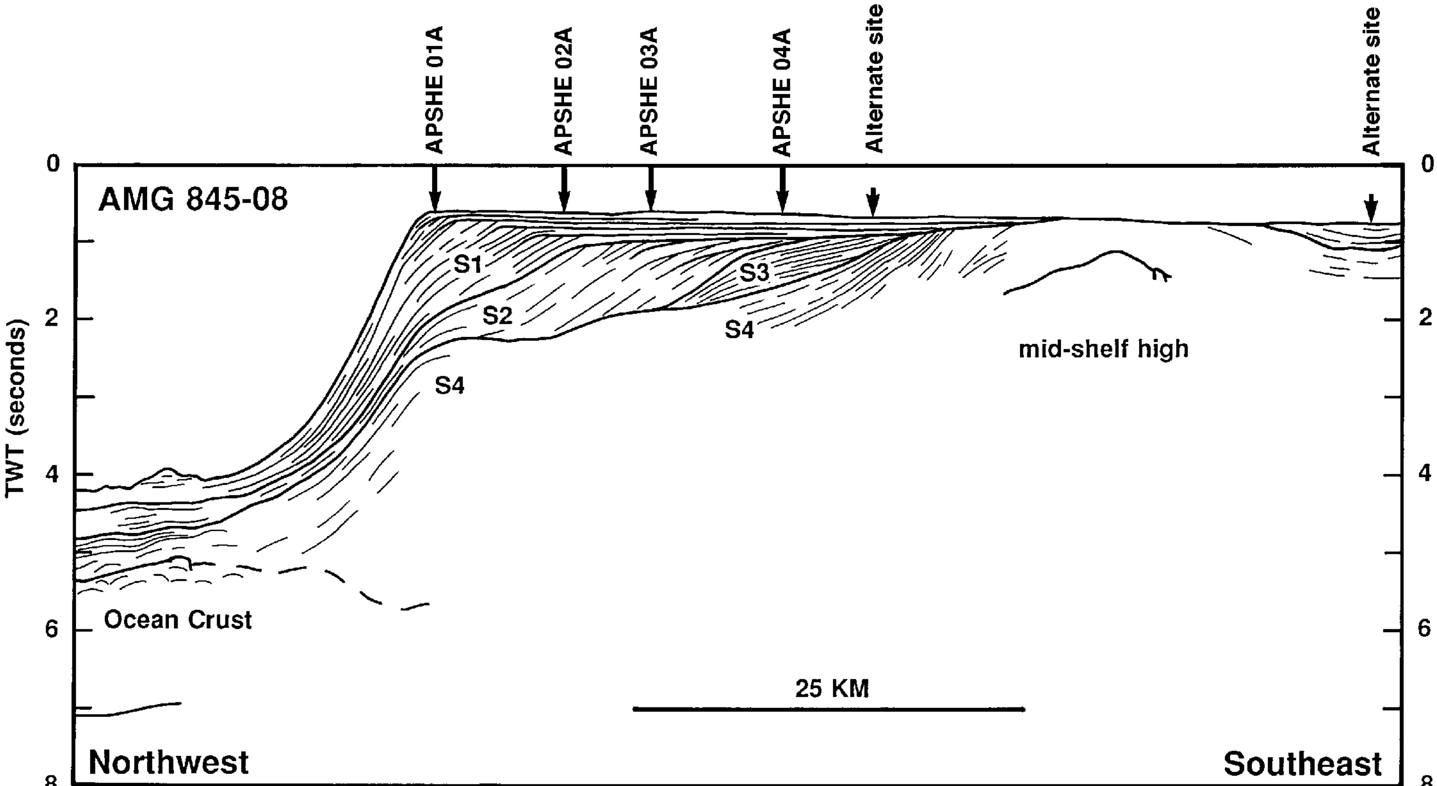


Figure 4. Schematic dip section of Lobe 1 (revised from Barker, 1995), showing (long arrows) prime Sites APSHE-01A to -04A and sequence groups S1-4 (from Larter and Barker, 1989; 1991b) on outer shelf. Shorter arrows show lower-priority sites on the flank of the mid-shelf high and in the mid-shelf basin.

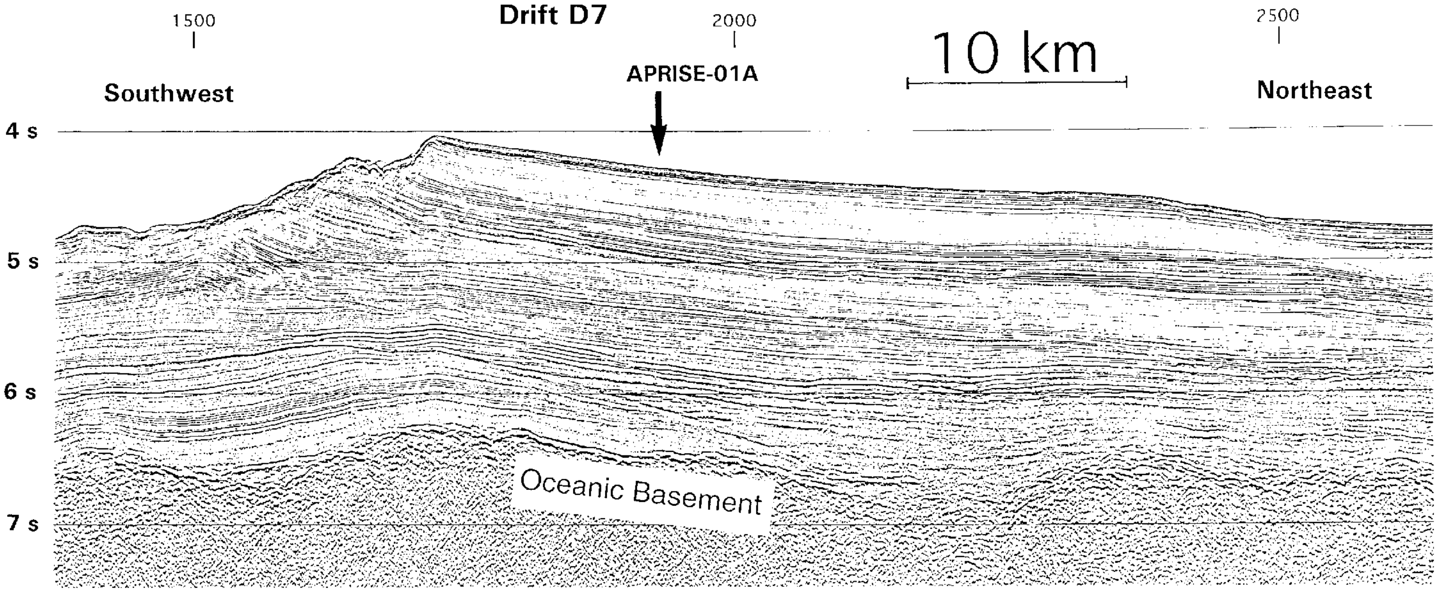


Figure 5. Seismic profile (part of IT92-109: Rebesco et al., 1996) through Drift 7 parallel to continental margin, showing primary Site APRIS-01A. Fine-grained sediments from turbidity currents draining the margin are entrained in, and deposited from, gentle ambient southwest flowing bottom currents. Channels to the northeast supply this drift, and its steep, unstable southwest slope is maintained by turbidity currents flowing down the next channel to the southwest.