OCEAN DRILLING PROGRAM

LEG 178 SCIENTIFIC PROSPECTUS

ANTARCTIC PENINSULA

Antarctic Glacial History and Sea-level Change

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

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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 by drilling 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, 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 Acoustic 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 glacial sedimentation over the past 10 m.y. in three related depositional environments (shelf topsets and foresets and rise drifts). This conservative, overlapping sampling strategy allows comparison of depositional environments before attempting to investigate the longer and more complex history of East Antarctic glaciation.

Drilling in Palmer Deep, a glacially overdeepened basin on the inner shelf, will sample an expanded Holocene section. Paleoproductivity in Palmer Deep seems representative of regional climate, so this section can be used to compare decadal- and millennial-scale regional climate variability with that of low-latitude regions and with that recorded in ice cores.

INTRODUCTION

The Antarctic Ice Sheet is both a major 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 through 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 (Figs. 1-3) on the continental margin of the Antarctic Peninsula. Sites include a transect of the outer continental shelf and 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 about 35 Ma, at 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 Acoustic 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 warmer periods when the ice sheet was much smaller 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 the 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 using the modeling results or other relevant information to select drilling locations in different regions. For example, Figure 4 (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

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 data 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 (Fig. 5).

The glacial sedimentation regime has other characteristics. Progradation is usually focussed into broad "trough-mouth fans" opposite the main ice streams, and the shelf is overdeepened (generally to 300-600 m depth, but in places much deeper) and inward-sloping. 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; Fig. 6). Sediment supply to the slope and rise is highly cyclic, with large quantities of unsorted diamicton deposited during glacial maxima and very little deposited 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 because of 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.

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 m.y. and probably 2.5 m.y., 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.

Antarctic Peninsula Region

Tectonic Influences On Sedimentation

The tectonic setting of the Antarctic Peninsula is unusual, but straightforward. Subduction of the Pacific ocean floor that had 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 (1) some terrigenous sedimentation in and beyond the ridge crest in the last 2-3 m.y. before collision and (2) 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. Collisions occurred well before the onset of glaciation in the southwest, 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.

Antarctic Peninsula 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 therefore 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, 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 may reveal a stage of valley glaciation lacking regular ice-sheet extension to the continental shelf edge.

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 and 02A);
- a four-site transect of the margin prograded wedge of Lobe 1 (APSHE-01A to 04A);
- an interlobe site to examine the "preglacial" S3 (APSHE-05A); and
- an ultra-high-resolution Holocene inner shelf site in Palmer Deep (APSHE-13A).

Figures 2 and 3 respectively show the bathymetry and 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 (Fig. 3). 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 glacial maxima, 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 APRIS-01A and 02A

The present slope of the depositional lobes L1 to 4 (Fig. 7) is steep (15°-20°) and is assumed to be at the limit of stability. A GLORIA survey of the northeastern area of the rise (Tomlinson et al., 1992; Rebesco et al., 1996) and deep-tow boomer examination of the upper slope (Vanneste and Larter 1995) show small-scale dissection of the upper slope and a dendritic pattern of channels at the base of slope, which feed major channels heading northwestward toward the lower continental rise (Figs. 2, 3 and 6). Between the major channels lie large depositional mounds rising more than 1 km above the channel floors. These mounds are thought 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). The mounds are fine-grained hemipelagic sediment drifts. Those within the GLORIA survey area (Drifts D1-D4; Fig. 3) 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 (Sites APRIS-01A and 02A on Drift 7). Site APRIS-01A is at the southeast end of the drift, proximal to the margin, and Site APRIS-02A 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 sites (Sites APSHE-01A to 05A), 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 m.y.), 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.

Sites APSHE-01A to 04A

Figure 7 shows a section through Lobe 1, along our prime drilling transect that consists of proposed Sites APSHE-01A to 04A. Seismic sequence groups S1 and S2 (Larter and Barker, 1989, 1991b) 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 features that dominate and distinguish S2—the erosional truncation of foresets at their 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. 7) that, except in the northeast, is clearly post-collisional, 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 (Fig. 3), where it is more accessible and clearly separated from collisional tectonics. Sequence group S4 is pre- and syncollisional, 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 period sufficiently long that its basal sediments are more clearly pre-glacial and conformable on S4. The full depth of penetration at Site APSHE-05A is uncertain.

Site APSHE-13A

Proposed Site APSHE-13A (Proposal 502 by E. 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 magnetic secular 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 in case pack ice covers the primary sites (although this is most unlikely). In addition, lower priority sites (each with an alternate) have been selected 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 primary sites listed above will be drilled as planned if the leg proceeds without massive disruption by ice.

Drilling on the rise will involve double advanced hydraulic piston corer (APC) and extended core barrel (XCB) coring at the proximal site (to about 700 m), followed possibly by rotary core barrel (RCB) coring to 1450 mbsf, or most probably by offset to the distal APC/XCB site where the same full section is accessible within 600 m. The depth limit of drilling at Site APRIS-01A 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 (APSHE-13A), assumed to be essentially a diatom ooze, will be sampled by triple 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 Site APSHE-05A), but we shall try for as complete a section as possible.

LOGGING

We plan to log shelf sites APSHE-01A to 05A and rise sites APRIS-01A and 02A with the following tool strings: the Triple Combination (litho-density, porosity, resistivity, and natural gamma tools); Formation MicroScanner (FMS)-Sonic (resistivity imaging, sonic velocity, and natural gamma tools); and Geological High-sensitivity Magnetometer (GHMT; magnetic field, susceptibility, and natural gamma tools). Also, we plan a vertical incidence vertical seismic profile (VSP) survey, using the well seismic tool (WST; downhole geophone), at one of the rise sites and at one or more of the shelf sites.

Thus, an extensive logging program is planned. Briefly, geophysical and geochemical logs will provide lithological information to complement core data and to help offset possible low recovery on the shelf; the FMS images can be used to investigate fine-scale bedding and fabric, including orientation; the GHMT will provide a magnetic stratigraphy; and the WST and synthetic seismograms will be used to correlate hole depths with travel times on the seismic section. The good quality logging results obtained on previous Antarctic Ocean Drilling Program (ODP) legs (113 and 119) in similar sediments, bode well for successful logging on this leg.

UNDERWAY GEOPHYSICS

Standard ODP practice is to collect 3.5- and 12-kHz echo-sounder data on approach to each site. In addition, long magnetic and 3.5-kHz profiles will be acquired on the transits from Punta Arenas to the Antarctic Peninsula and from there to Cape Town.

SAMPLING PLAN

For Leg 178, almost all sampling will probably be accomplished during the cruise; no postcruise sample party is currently planned. Most sites consist of a single hole, where fairly standard sampling is envisaged. At other sites, which will be double (Site APRIS-01A) and triple (Site APSHE-13A) cored, a composite section will be constructed for each site and then a sampling strategy will be developed. Nonstandard sampling at some of the sites might include high-resolution whole-round sampling for physical properties and geochemical studies, U-channel sampling for paleomagnetism, and microbiological sampling.

All sampling to be conducted on Leg 178 must be approved by the sampling allocation committee (SAC), consisting of the Co-chiefs, Staff Scientist, and Curatorial Representative. Sampling plans are subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the leg.

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FIGURE CAPTIONS

Figure 1. Map of the Antarctic Peninsula showing the location of the proposed drill sites and ship track from Punta Arenas (Chile) to Cape Town (S. Africa).

Figure 2. Bathymetric map of the Antarctic Peninsula margin, showing primary sites APRIS-01A to 02A, APSHE-01A to 05A, and APSHE-13A as circles, and alternate and lower priority sites as squares (R3 and R4 are Sites APRIS-03A and 04A, respectively; S6 to S12 are Sites APSHE-06A to 12A, respectively; and T1 and T2 are Sites APSST-01A and 02A, respectively).

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; APSHE-01A to 05A and APSHE-013A); smaller spots mark alternate and lower priority sites (labelled as in Figure 2).

Figure 4. Graph and maps of ice-sheet growth, showing ice-sheet size and location at mean sea-level temperatures 5, 9, 10, 15, 19, and 20 Kelvin (K) above present. 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 of cooling (from Huybrechts, 1993).

Figure 5. Seismic sequence model of a single glacial cycle (Larter and Barker, 1989, 1991b). Unsorted diamicton is deposited on the upper slope during glacial (GS) maxima, and on the shelf during retreat. Pelagic and hemipelagic deposition takes place on shelf and slope during interglacials (IGS). With re-advance, some or all shelf topsets may be eroded.

Figure 6. Cartoon of processes leading to construction and maintenance of a hemipelagic drift deposit along the Antarctic Peninsula margin (from Rebesco et al, in press), showing a section through a shelf progradational lobe and adjacent continental rise during a glacial maximum when an ice sheet grounded to the shelf edge is transporting unsorted basal till to the upper slope. Small-scale slumps on

the uppermost slope become debris flows. Farther downslope, these become turbidity currents which flow via tributaries on the uppermost rise into the main channel running between the drifts towards the abyssal plain. Suspended fines are entrained in ambient bottom currents and deposited down-current. Subsequent turbidity-current flow in the channels, and slope instability on the steeper drift slopes sweep those recent deposits away, leaving a permanent sediment increment only on the gentle slope of the drifts.

Figure 7. Schematic dip section of Lobe 1 (revised from Barker, 1995), showing (long arrows) primary Sites APSHE-01A to 04A and sequence groups S1-4 (from Larter and Barker, 1989, 1991b) on the outer shelf. Shorter arrow shows lower priority Site APSHE-10A on the flank of the mid-shelf high.

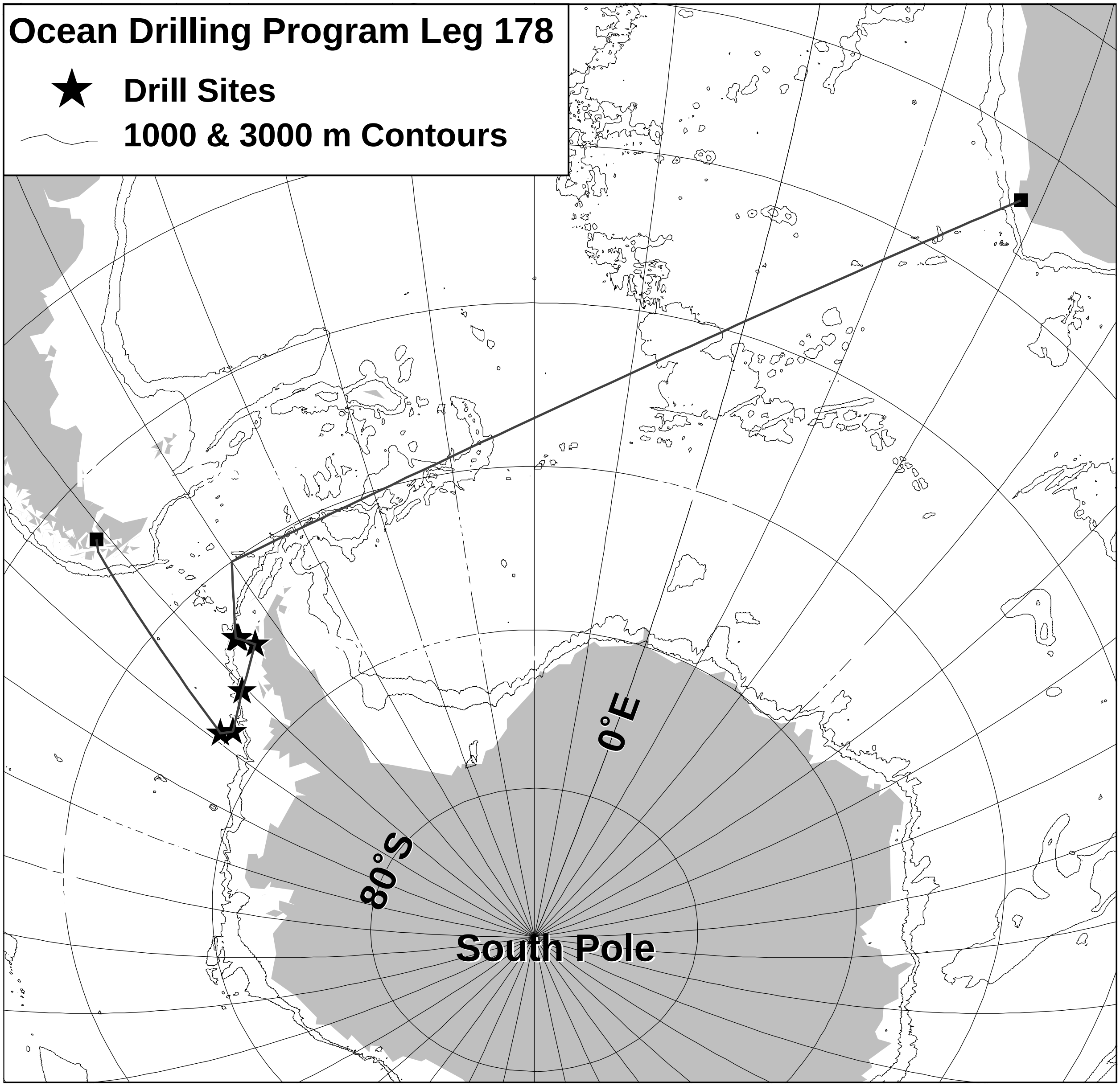
Figure 8. Locations of all available multichannel seismic (MCS) and single-channel seismic (SCS) profiles on the Antarctic Peninsula margin (from UK, Italian, U.S.A., Brazilian, and German cruises and from Spanish, Chinese, Polish, and Japanese data in S. Shetlands/Bransfield Strait area). Boxes (Figs. 9, 10, and 11) are areas where almost all primary and alternate sites are located.

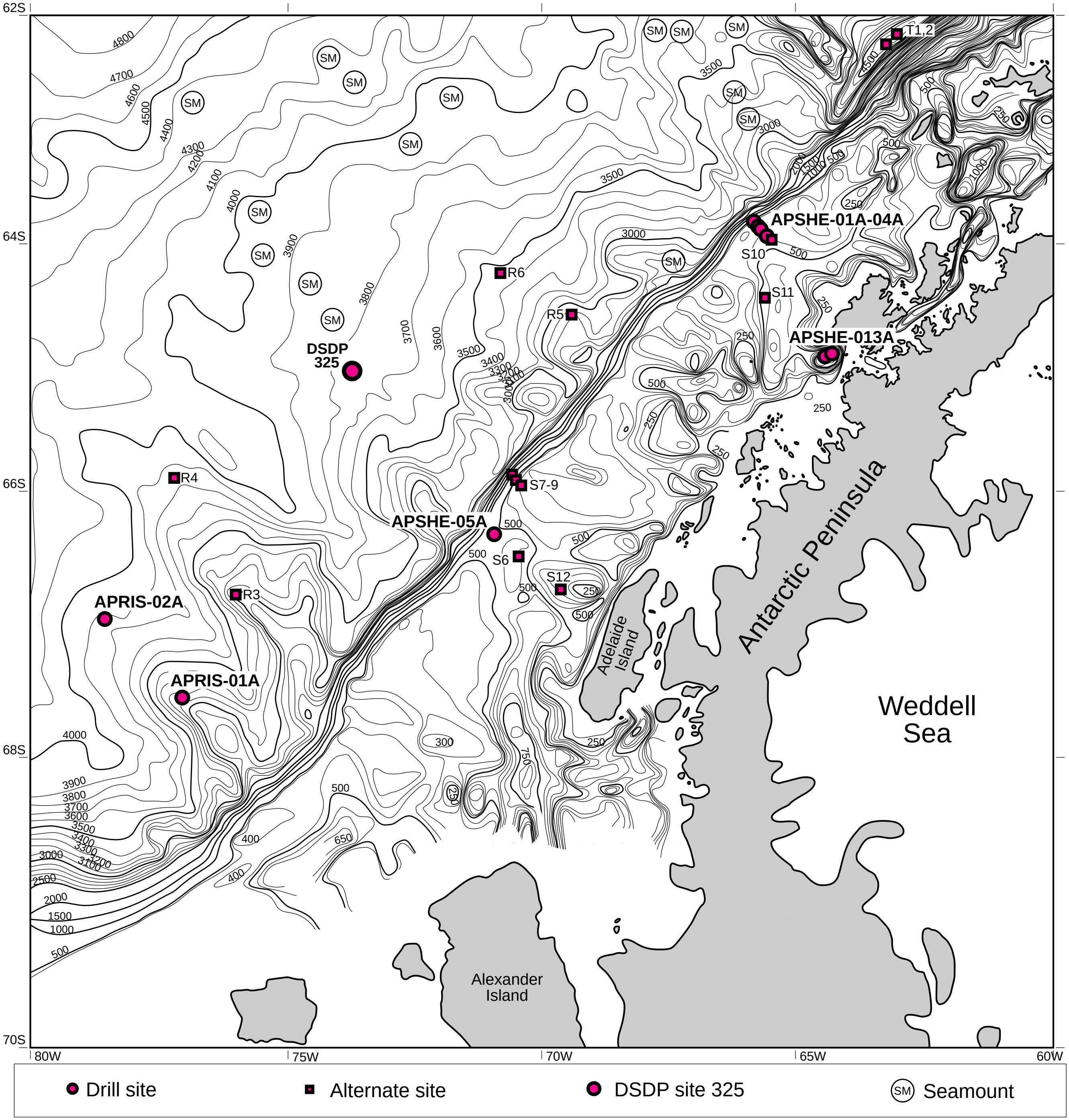
Figure 9. Track chart in Drifts D7 and D6 area (Fig. 3) showing primary (large circles) and alternate (small circles) sites. Each drift has a proximal and distal site, with Drift D7 as the prime target.

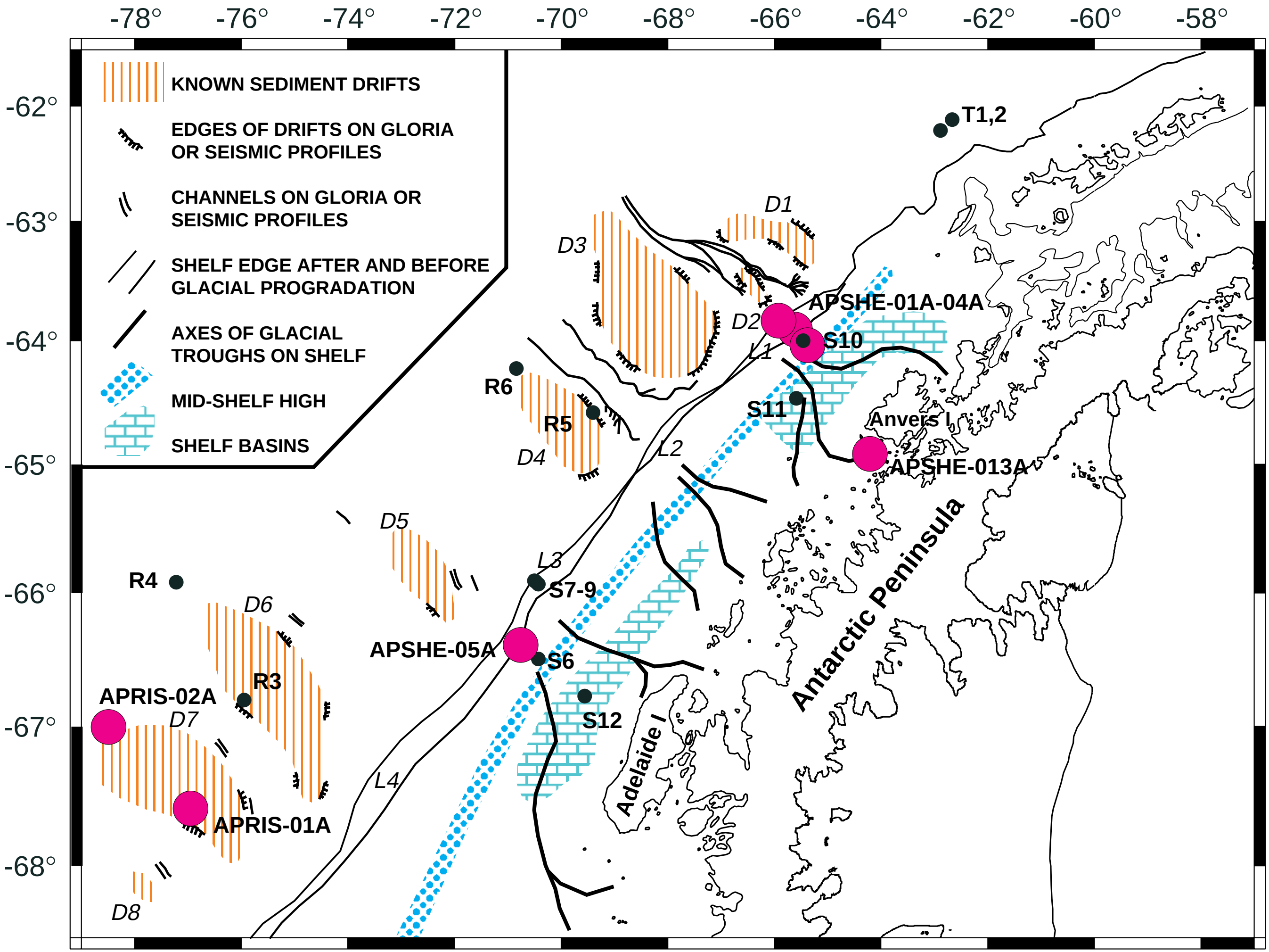
Figure 10. Track chart in Lobe 1 area (Fig. 3) showing primary (large circles), alternate (small circles) sites, and lower priority sites (squares).

Figure 11. Track chart in Lobe 3 area (Fig. 3) showing primary (large circles), alternate (small circles) sites, and lower priority sites (squares).

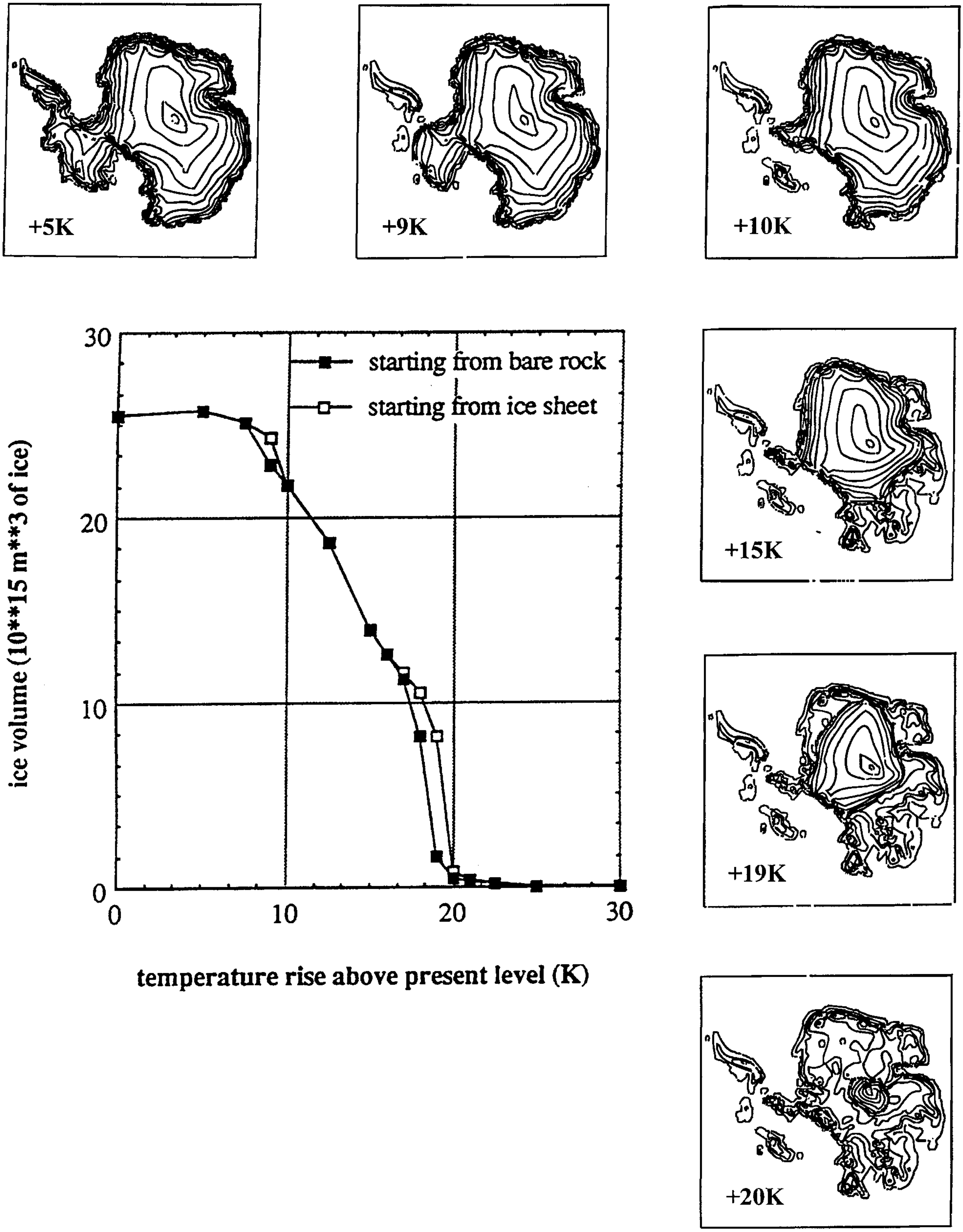
Figure 12. Track chart showing MCS profiles in the South Shetland Trench area (Figs. 2 and 3), where alternate Sites APSST-01A (large triangle) and APSST-02A (small triangle) are located.

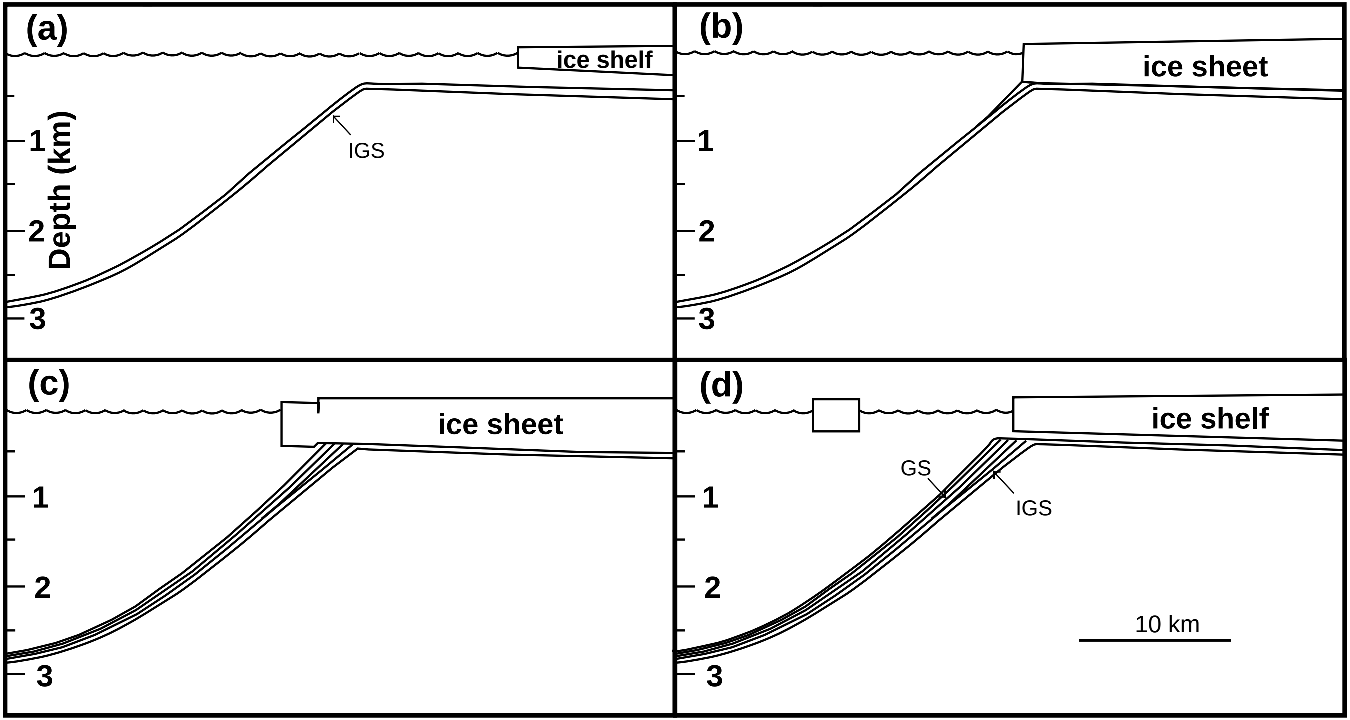

Ocean Drilling Program Leg 178
Drill Sites
1000 & 3000 m Contours
0°E
80°S
South Pole


62S
64S
66S
68S
70S
80W
75W
70W
65W
60W
T1,2
APSHE-01A-04A
S10
S11
R6
R5
APSHE-013A
DSDP
325
S7-9
R4
APSHE-05A
S6
S12
R3
APRIS-02A
APRIS-01A
Antarctic Peninsula
Adelaide
Island
Weddell
Sea
Alexander
Island
SM
Drill site
Alternate site
DSDP site 325
Seamount

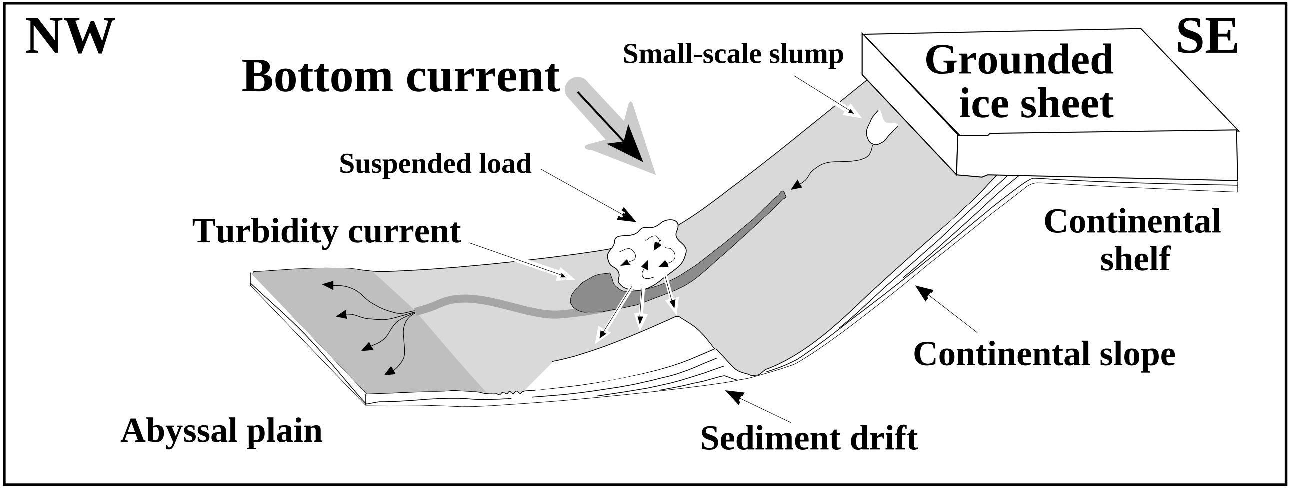


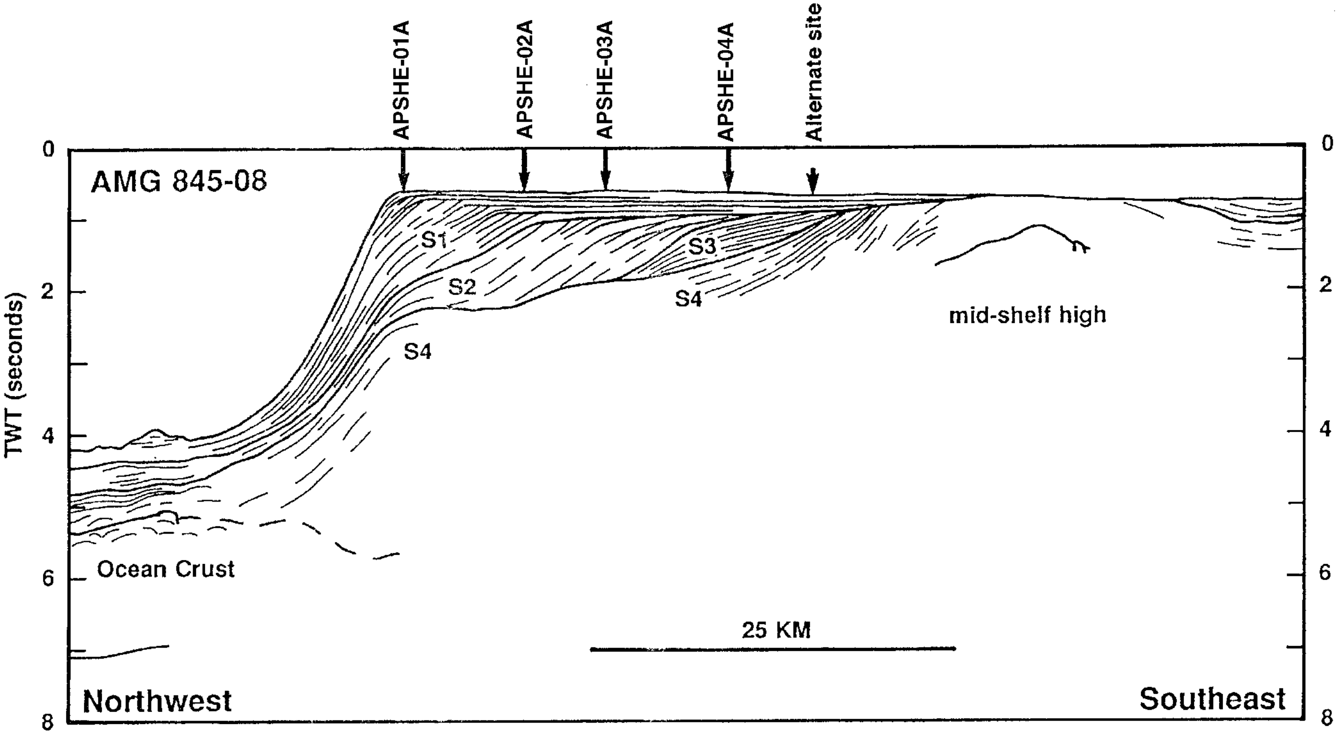
-78°
-76°
-74°
-72°
-70°
-68°
-66°
-64°
-62°
-60°
-58°
-62°
-63°
-64°
-65°
-66°
-67°
-68°
KNOWN SEDIMENT DRIFTS
EDGES OF DRIFTS ON GLORIA OR SEISMIC PROFILES
CHANNELS ON GLORIA OR SEISMIC PROFILES
SHELF EDGE AFTER AND BEFORE GLACIAL PROGRADATION
AXES OF GLACIAL TROUGHS ON SHELF
MID-SHELF HIGH
SHELF BASINS
T1,2
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
L4
APSHE-01A-04A
S10
R6
R5
S11
Anvers I
APSHE-013A
R4
S7-9
APSHE-05A
S6
R3
APRIS-02A
S12
APRIS-01A
Adelaide I
Antarctic Peninsula


+5K
+9K
+10K
starting from bare rock
starting from ice sheet
ice volume (10**15 m**3 of ice)
30
20
10
0
0
10
20
30
temperature rise above present level (K)
+15K
+19K
+20K

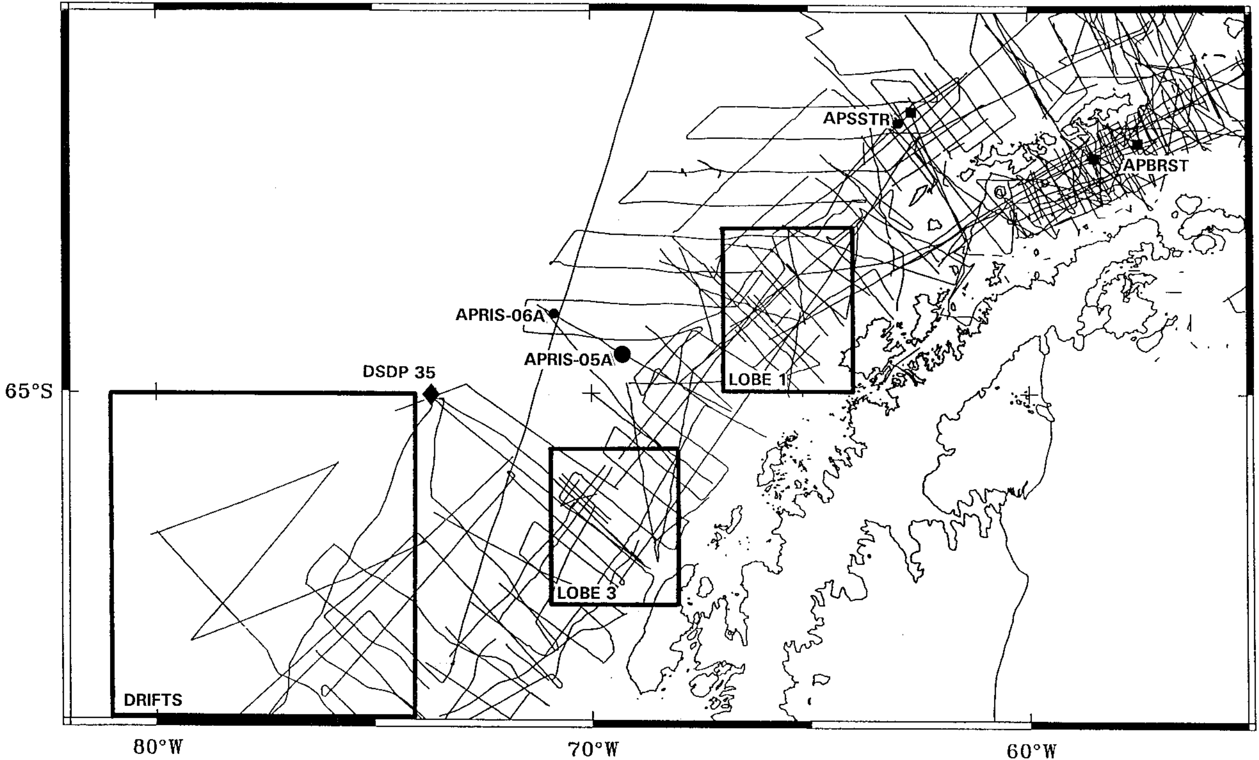


(a)
ice shelf
IGS
Depth (km)
1
2
3
(b)
ice sheet
1
2
3
(c)
ice sheet
1
2
3
(d)
ice shelf
GS
IGS
1
2
3
10 km

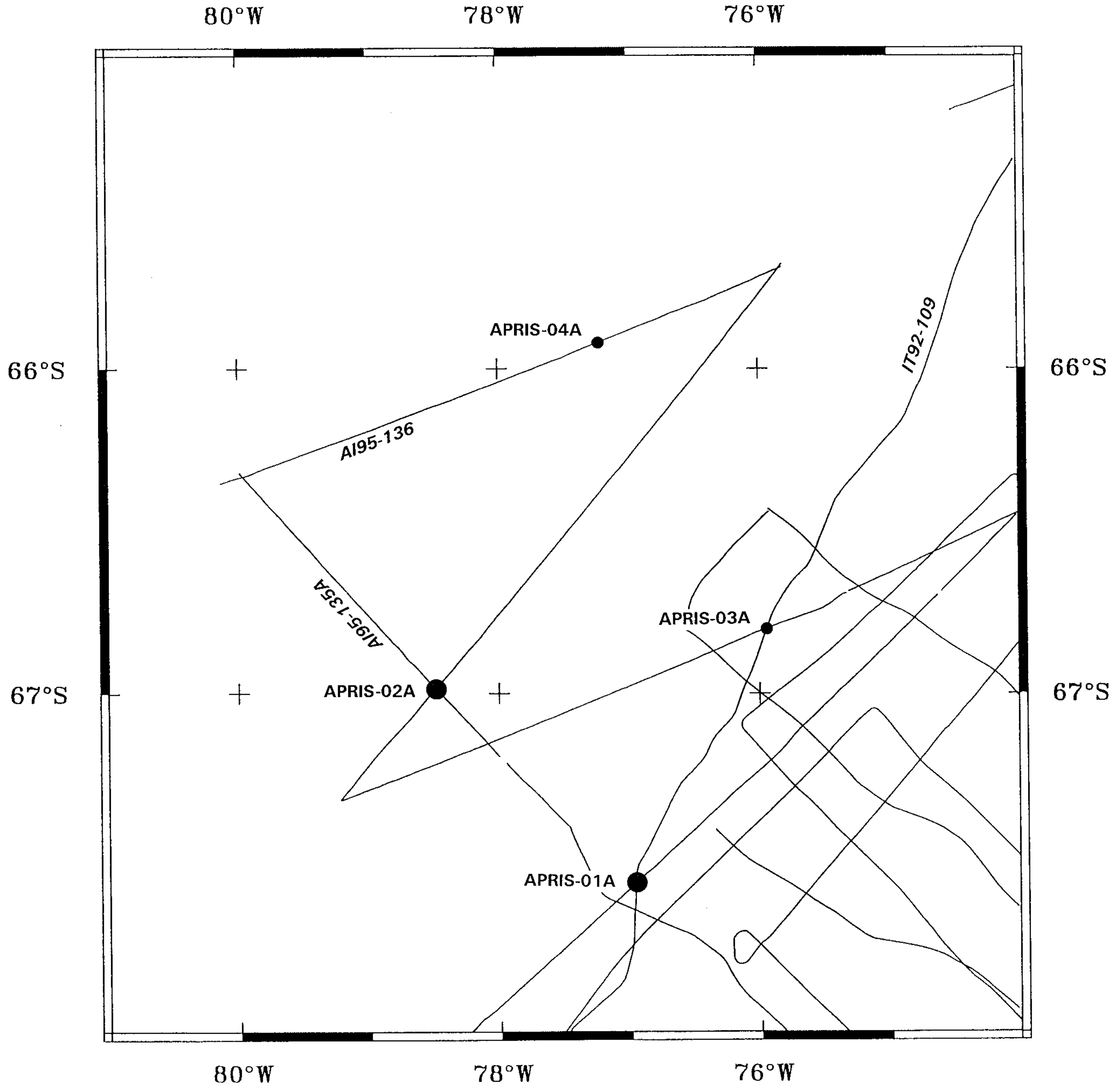

NW
SE
Bottom current
Small-scale slump
Grounded ice sheet
Suspended load
Turbidity current
Continental shelf
Continental slope
Abyssal plain
Sediment drift

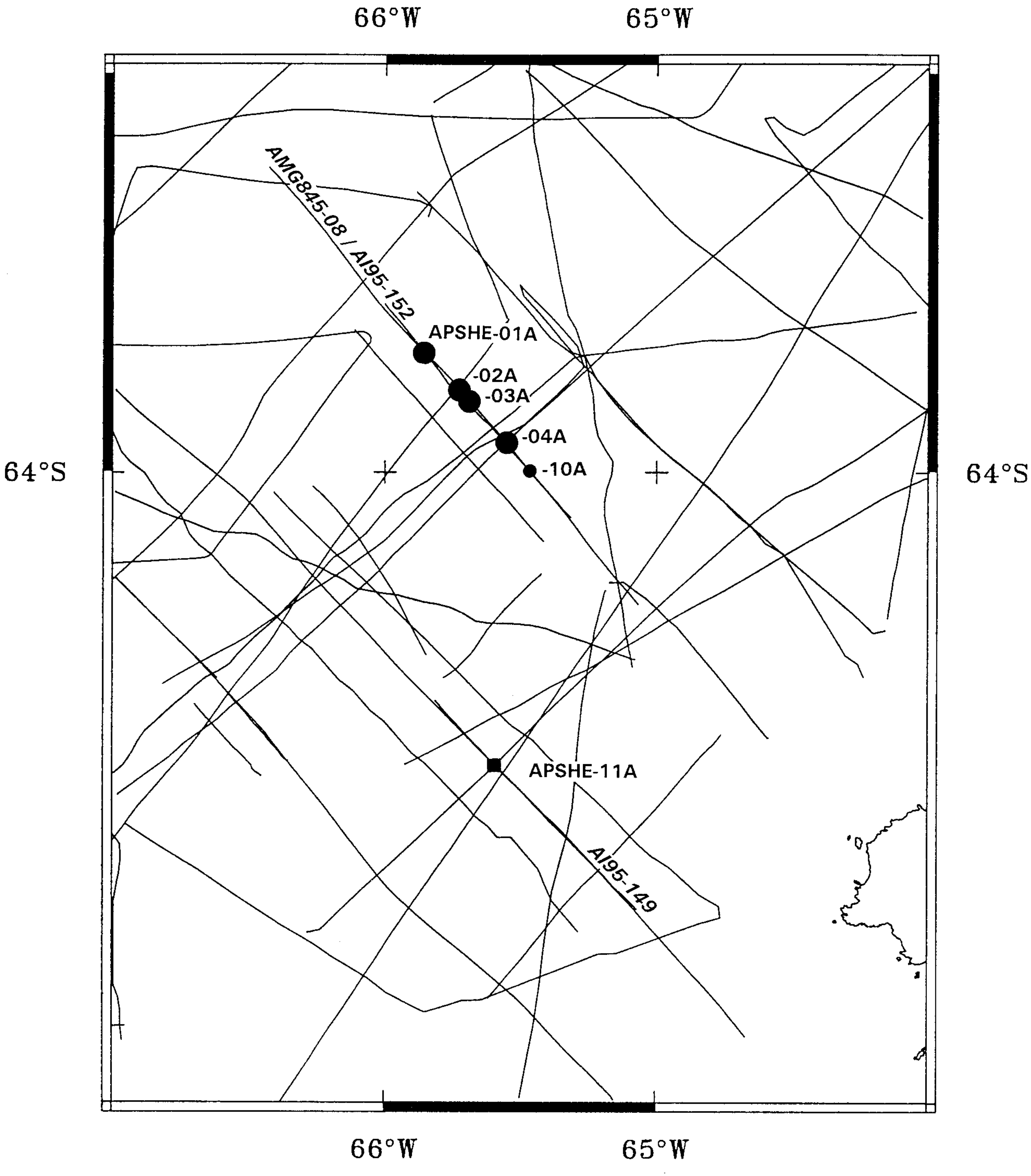


APSHE-01A
APSHE-02A
APSHE-03A
APSHE-04A
Alternate site
AMG 845-08
0
2
4
6
8
TWT (seconds)
S1
S2
S3
S4
S4
mid-shelf high
Ocean Crust
25 KM
Northwest
Southeast

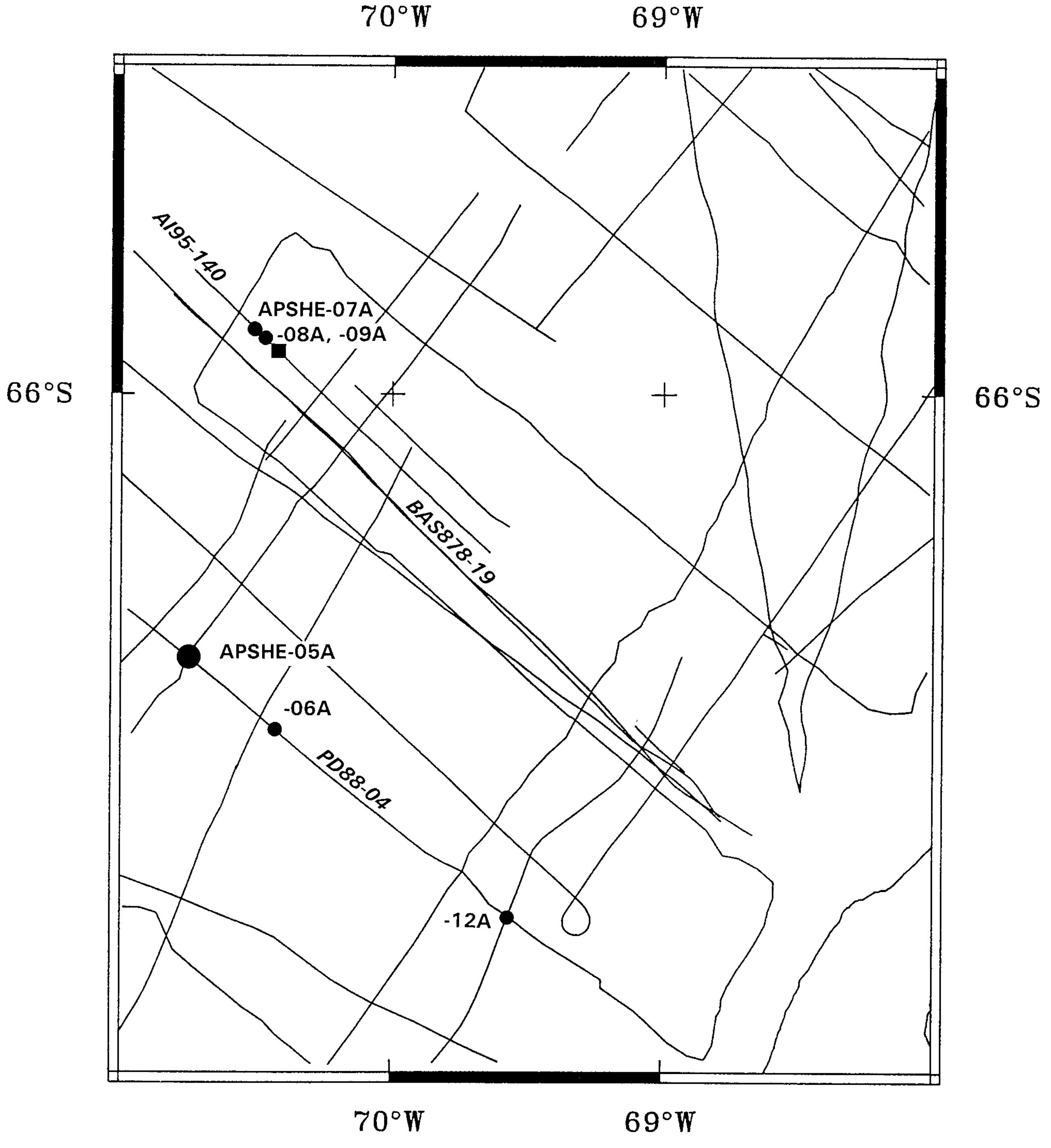


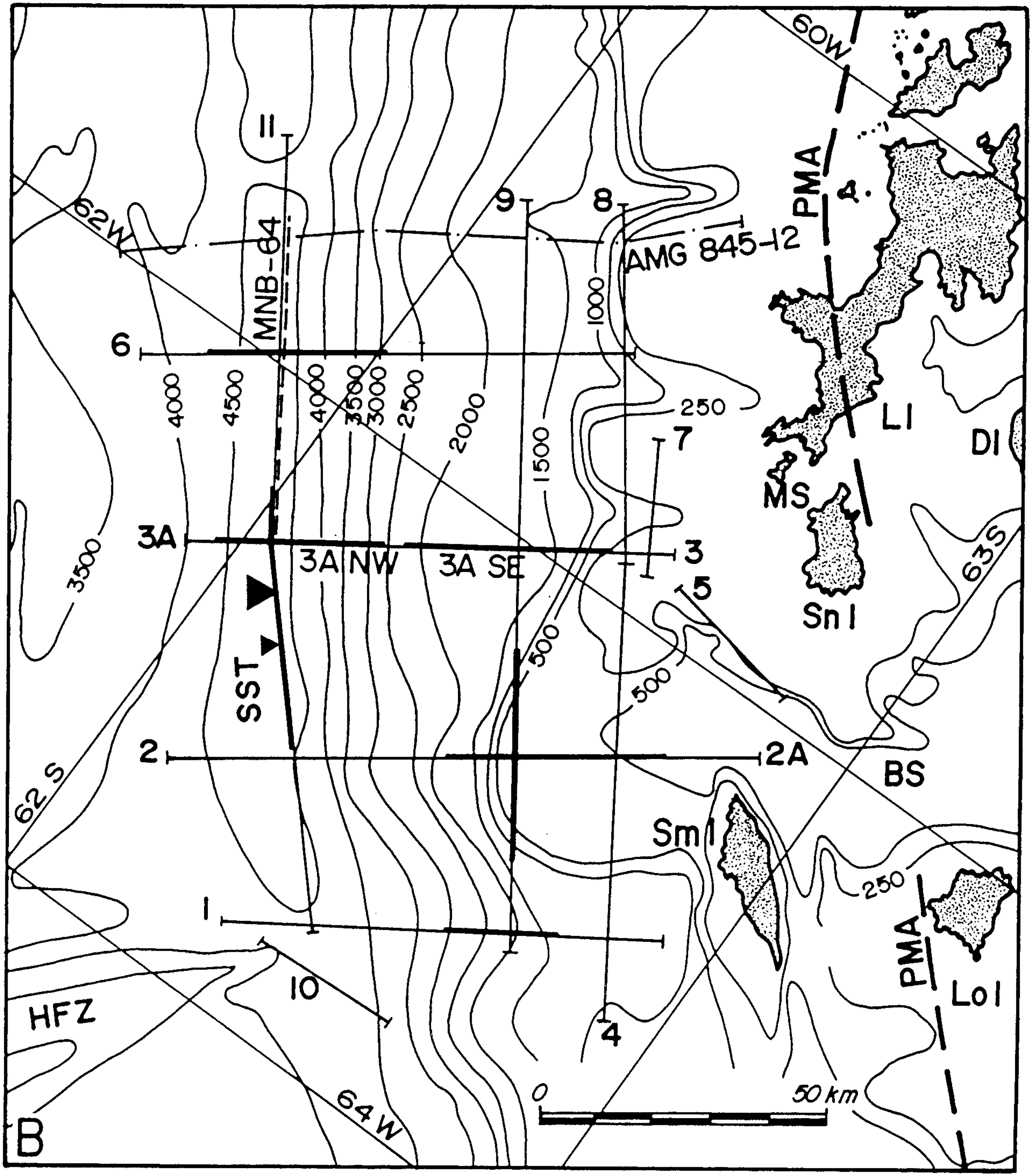
APSSTR
APBRST
APRIS-06A
APRIS-05A
DSDP 35
LOBE 1
LOBE 3
DRIFTS
65°S
80°W
70°W
60°W


80°W
78°W
76°W
66°S
67°S
APRIS-04A
AI95-136
AI95-135A
IT92-109
APRIS-03A
APRIS-02A
APRIS-01A
80°W
78°W
76°W
66°S
67°S



66°W
65°W
64°S
64°S
AMG845-08 / AI95-152
APSHE-01A
-02A
-03A
-04A
-10A
APSHE-11A
AI95-149
66°W
65°W


70°W
69°W
66°S
66°S
AI95-140
APSHE-07A
-08A, -09A
BAS878-19
APSHE-05A
-06A
PD88-04
-12A
70°W
69°W



60W
62W
64W
62S
63S
PMA
PMA
11
9
8
MNB-64
AMG 845-12
1000
6
4000
4500
4000
3500
3000
2500
2000
1500
250
7
LI
DI
MS
3A
3A NW
3A SE
3
3500
5
Sn I
500
500
SST
2
2A
BS
Sm I
250
1
10
Lo I
HFZ
4
0
50 km
B

Table 1. Leg 178 Time Estimates for Primary Sites

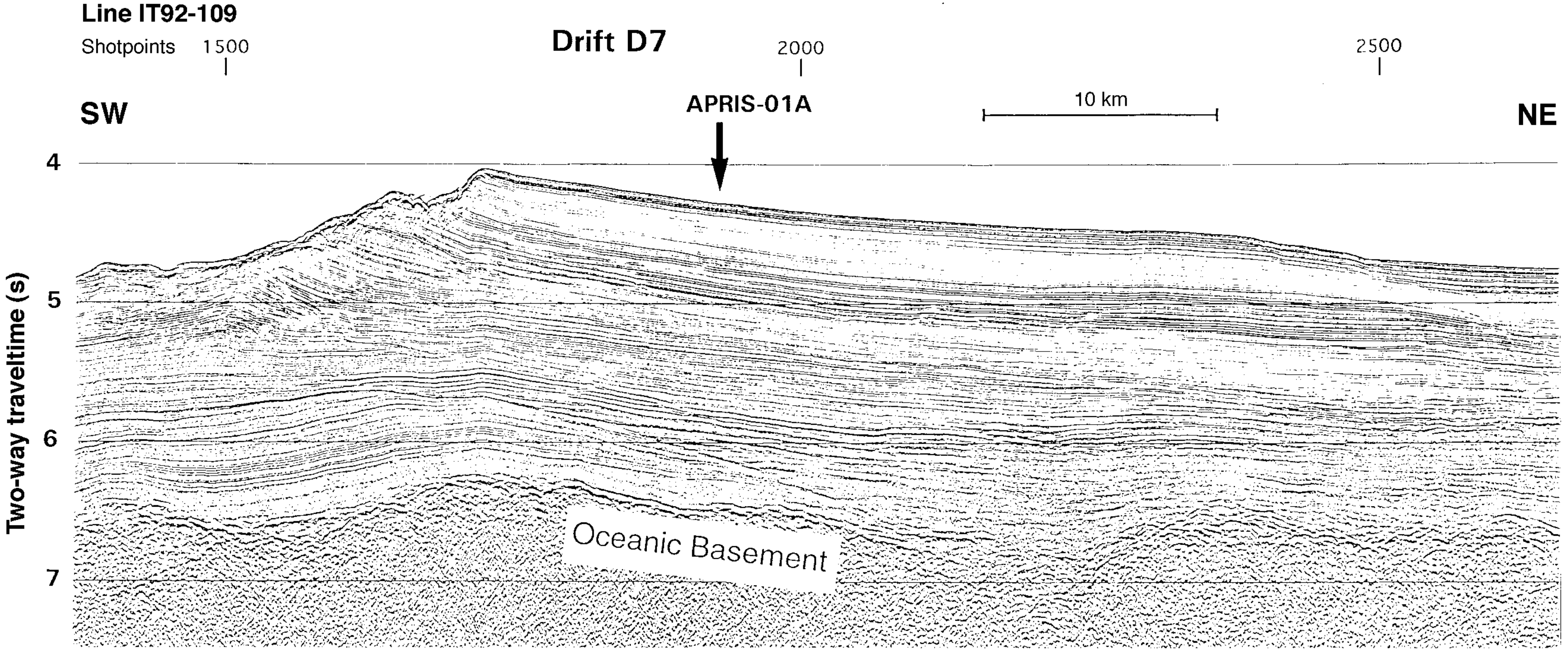
Site Name	Location Lat/Long	Water Depth	Projected Operations Plan	Transit (days)	Drilling (days)	Logging (days)	Total On-site
Punta Arenas			Transit 890.8 nmi from beginning port to Site APRIS-1A @ 10.5 kt	3.5			
APRIS-01A	67° 34.0' S 76° 57.8' W	3200	APC to 200 mbsf, APC/XCB to 400 mbsf, RCB to 700 mbsf. Log Depth objective may be obtained by XCB, then no RCB hole needed.		7.4	1.5	8.9
Transit			Transit 49.1 nmi from APRIS-01A to APRIS-02A @ 10.5 kt	0.2			
APRIS-02A	66° 59.9' S 78° 29.2' W	3850	APC/XCB to 400 mbsf, RCB to 550 mbsf. Log Depth objective may be obtained by XCB, then no RCB hole needed.		5.9	1.4	7.3
Transit			Transit 186.7 nmi from APRIS-02A to APSHE-05A @ 10.5 kt	0.7			
APSHE-05A	66° 23.6' S 70° 45.4' W	600	No APC/XCB. Spud with RCB and core to 785 mbsf. Log		3.7	1.3	5.0
Transit			Transit 186.2 nmi from APSHE-05A to APSHE-13A @ 10.5 kt	0.7			
APSHE-13A	64° 51.7' S 64° 12.5' W	1040	Triple APC to 50 mbsf.		0.8		0.8
Transit			Transit 65.6 nmi from APSHE-13A to APSHE-04A @ 10.5 kt	0.3			
APSHE-04A	63° 56.5' S 65° 34.6' W	490	No APC/XCB. Spud with RCB and core to 785 mbsf. Log		3.6	1.2	4.8
Transit			Transit 5.0 nmi from APSHE-04A to APSHE-03A @ 10.5 kt	0.0			
APSHE-03A	63° 52.9' S 65° 42.7' W	440	No APC/XCB. Spud with RCB and core to 505 mbsf. Log		2.1	1.1	3.1
Transit			DP Offset 1.2 nmi from APSHE-03A to APSHE-02A @ 1 kt	0.0			
APSHE-02A	63° 52.0' S 65° 44.7' W	440	No APC/XCB. Spud with RCB and core to 560 mbsf. Log		2.3	1.1	3.5
Transit			Transit 4.9 nmi from APSHE-02A to APSHE-01A @ 10.5 kt	0.0			
APSHE-01A	63° 48.2' S 65° 51.5' W	450	No APC/XCB. Spud with RCB and core to 505 mbsf. Log		2.1	1.1	3.1
Cape Town			Transit 3609.6 nmi from Site APSHE-01A to ending port @ 10.5 kt	14.3			
			Total	**19.9**	**27.8**	**8.6**	**36.4**
					TOTAL DAYS:		**56.3**

Table 2. Leg 178 Time Estimates for Alternate Sites

Site Name	Latitude	Longitude	Water Depth (m)	*Penetration (mbsf)	Related Primary Site	Drilling *(days)	Logging (days)	Total On-site
APRIS-03A	66° 48.3' S	75° 56.8' W	2960	1150	APRIS-01A	10.7	1.5	12.2
APRIS-04A	65° 55.0' S	77° 13.5' W	3900	700	APRIS-02A	7.8	1.4	9.2
APRIS-05A	64° 35.1' S	69° 24.3' W	2850	1320	APRIS-01A	14.5	1.5	16.0
APRIS-06A	64° 13.7' S	70° 50.4' W	3500	800	APRIS-02A	8.6	1.4	10.0
APSHE-06A	66° 30.0' S	70° 25.8' W	600	505	APSHE-05A	3.4	1.3	4.7
APSHE-07A	65° 54.4' S	70° 30.0' W	420	675	APSHE-01A	4.0	1.1	5.1
APSHE-08A	65° 55.0' S	70° 28.5' W	405	450	APSHE-02A	2.1	1.1	3.2
APSHE-09A	65° 56.0' S	70° 25.8' W	390	450	APSHE-03A	2.1	1.1	3.2
APSHE-10A	64° 00.0' S	65° 27.9' W	510	650	APSHE-05A	3.9	1.3	5.2
APSHE-11A	64° 28.3' S	65° 35.3' W	530	620		3.7	1.3	5.0
APSHE-12A	66° 46.5' S	69° 33.3' W	375	620	alternate for APSHE-11A	3.7	1.3	5.0
APSHE-15A	64° 56.7' S	64° 18.9' W	1425	250	APSHE-13A	1.6		1.6
APSST-01A	62° 07.3' S	62° 40.0' W	4715	630		8.0	1.5	9.5
APSST-02A	62° 13.0' S	62° 53.0' W	4705	720		8.0	1.5	9.5

*assuming penetration to the maximum approved depth

SITE SUMMARIES


Line IT92-109
Shotpoints 1500
Drift D7
2000
2500
SW
APRIS-01A
10 km
NE
4
5
6
7
Two-way traveltime (s)
Oceanic Basement

PRIMARY SITES

Site: APRIS-01A

Priority: 1
Position: 67˚34.00´S, 76˚57.78´W
Water Depth: 3200 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 1450 mbsf
Seismic Coverage: Explora Lines IT92-109 and AI95-130

Objectives: The objectives of Site APRIS-01A are to:

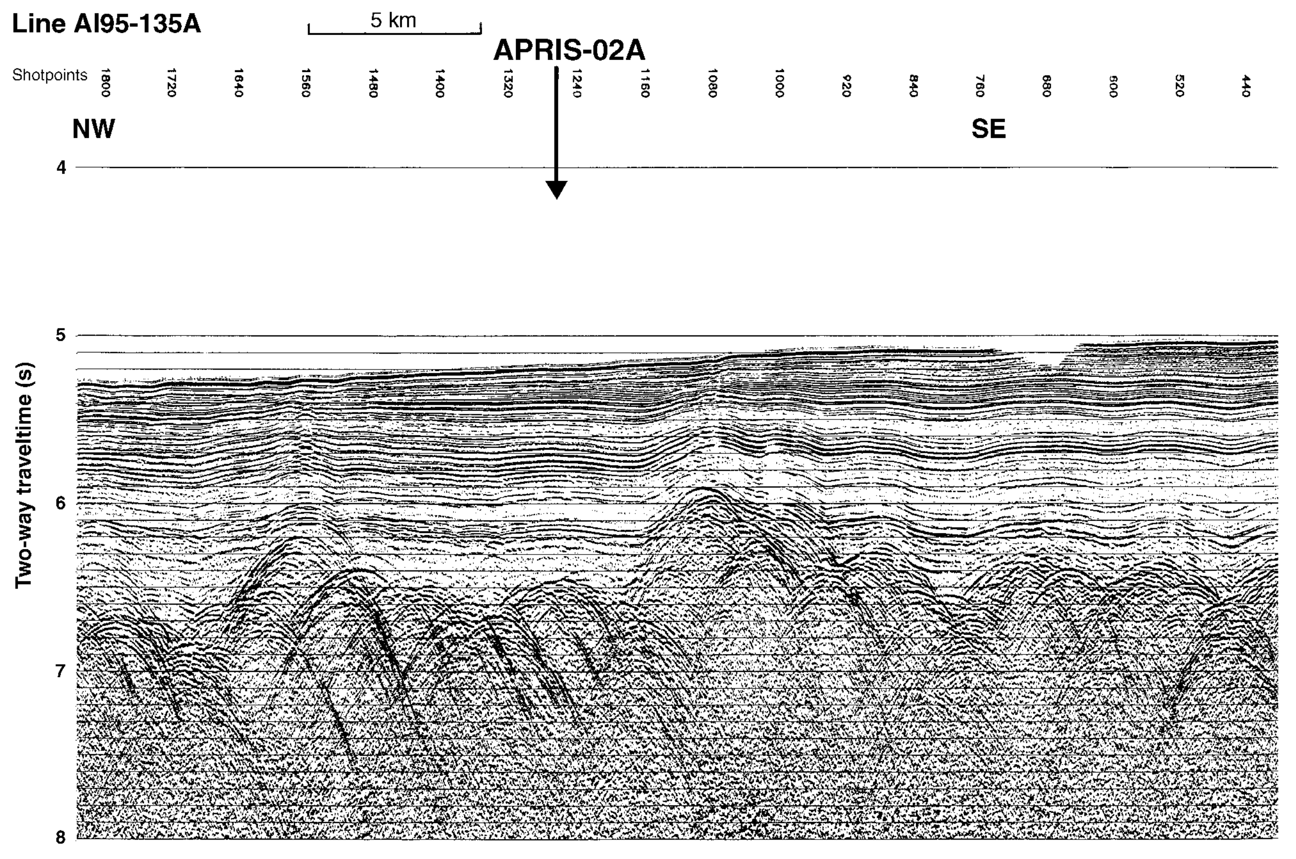
1. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y. from the long continuous sediment succession of the hemipelagic sediment drifts.

2. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Double APC to 200 m and XCB (or RCB if necessary) to 700 m, then either RCB from 700 m to base of 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. Offset is required if stratigraphic control seriously degrades below the silica diagenetic BSR at about 600 m. Alternate sites: APRIS-03A and 05A.

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

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


Line AI95-135A
5 km
APRIS-02A
Shotpoints
1800
1720
1640
1560
1480
1400
1320
1240
1160
1080
1000
920
840
760
680
600
520
440
NW
SE
Two-way traveltime (s)
4
5
6
7
8

Site: APRIS-02A

Priority: 1
Position: 66˚59.91´S, 78˚29.16´W
Water Depth: 3850 m
Sediment Thickness: 1500 m
Approved Maximum Penetration: 700 m
Seismic Coverage: Explora Line AI95-135A

Objectives: The objectives of Site APRIS-02A are to:

1. Sample the deeper part of the stratigraphic section not drilled at Site APRIS-01A.

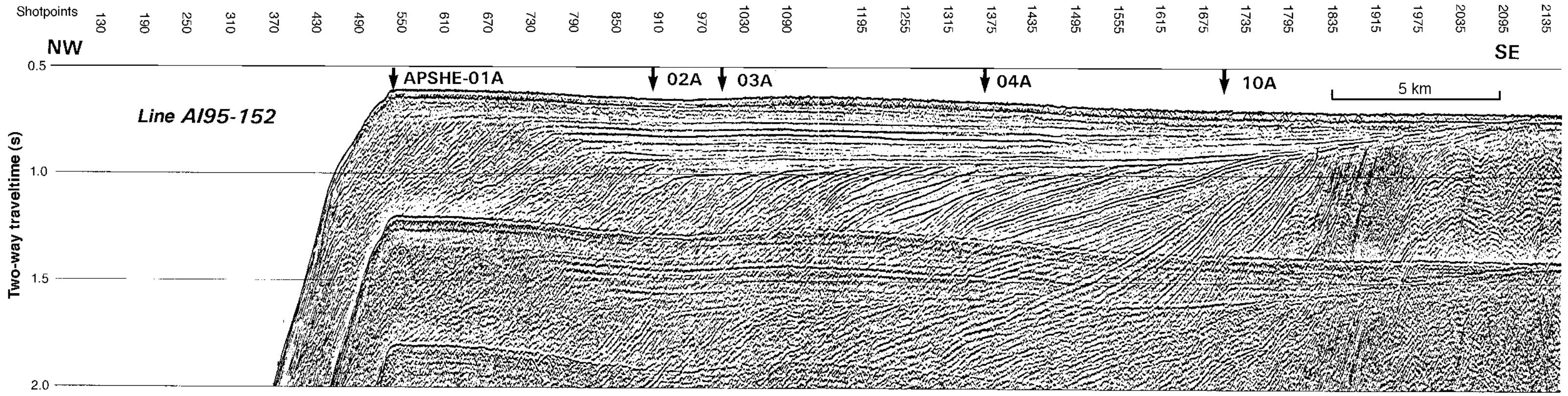
2. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y.

3. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Single APC and XCB to the base of Unit M4 (at ~550 m) where upper section is thinner. A RCB hole may be necessary if the XCB system fails to reach the depth objective. This site is offset by ~50 km from main Site APRIS-01A. Offset will be required if stratigraphic control is seriously degraded below silica diagenetic BSR at 600 m at main site. Alternate Sites: APRIS-04A and 06A.

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

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


Shotpoints
130 190 250 310 370 430 490 550 610 670 730 790 850 910 970 1030 1090 1195 1255 1315 1375 1435 1495 1555 1615 1675 1735 1795 1835 1915 1975 2035 2095 2135
NW
SE
APSHE-01A
02A
03A
04A
10A
5 km
Line AI95-152
Two-way traveltime (s)
0.5
1.0
1.5
2.0

Site: APSHE-01A

Priority: 1
Position: 63˚48.16´S, 65˚51.46´W
Water Depth: 450 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 560 mbsf
Seismic Coverage: Explora Line AI95-152 and Discovery Line AMG845-08

Objectives: The objectives of Site APSHE-01A are to:

1. Identify and date glacial/interglacial transitions in the youngest S1 foreset sequence.

2. Examine foreset lithologies and compare them with the rise drift.

Drilling Program: Single RCB hole to 505 mbsf. Alternate site is 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
Approved Maximum Penetration: 650 mbsf
Seismic Coverage: Explora line AI95-152 and Discovery line AMG845-08

Objectives: The objectives of Site APSHE-02A are to:

1. Identify and date the main changes in wedge geometry during progradation of the glacial wedge (conformable S1/S2 boundary).

2. Examine topset (S1) and foreset (S2) lithologies, and compare with rise drift.

Drilling Program: Single RCB hole to 560 mbsf. Alternate site is APSHE-08A.

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

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

Note: See seismic line for APSHE-01A

Site: APSHE-03A

Priority: 1
Position: 63˚52.93´S, 65˚42.69´W
Water Depth: 440 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 600 mbsf
Seismic Coverage: Explora Line AI95-152 and Discovery Line AMG845-08

Objectives: The objectives of Site APSHE-03A are to:

1. Identify and date the main changes in wedge geometry during the progradation of the glacial wedge (onset of erosional S1/S2 boundary).

2. Examine topset (S1) and foreset (S2) lithologies and compare with the rise drift.

Drilling Program: Single RCB hole to 505 mbsf. Alternate site is 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 in foresets) with thin biosiliceous interbeds.

Note: See seismic line for APSHE-01A

Site: APSHE-04A

Priority: 1
Position: 63˚56.52´S, 65˚34.62´W
Water Depth: 490 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 1050 mbsf
Seismic Coverage: Explora Line AI95-152 and Discovery Line AMG845-08

Objectives: The objectives of Site APSHE-04A are to:

1. Identify and date the main changes in wedge geometry during progradation of the glacial wedge including the "pre-glacial"/glacial transition (conformable boundary between the oldest part of S2 and the youngest "pre-glacial" S3).

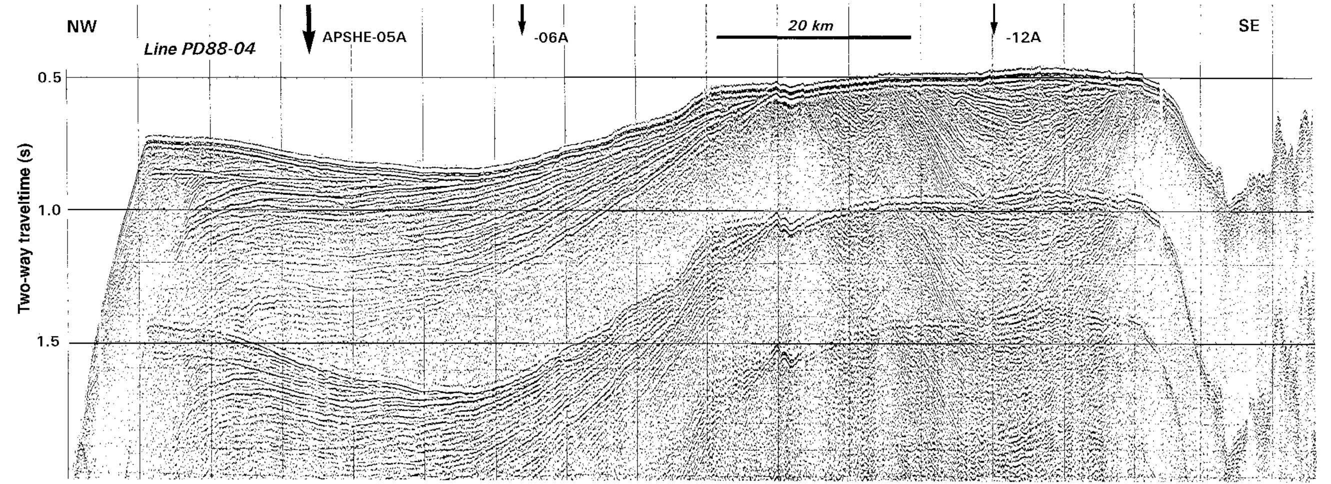
2. Examine topset (S1 and S2) and"pre-glacial" (S3) lithologies and compare with rise drift.

Drilling Program: Single RCB hole to 785 m.

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 of S2, then uncertain lithology (glacial marine diamicton or biosiliceous hemipelagic).

Note: See seismic line for APSHE-01A



NW
Line PD88-04
APSHE-05A
-06A
20 km
-12A
SE
0.5
1.0
1.5
Two-way traveltime (s)

Site: APSHE-05A

Priority: 1
Position: 66˚23.57´S, 70˚45.40´W
Water Depth: 600 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 785 mbsf
Seismic Coverage: Polar Duke Lines PD88-B and PD88-04

Objectives: The objectives of Site APSHE-05A are to:

1. Examine "pre-glacial” (S3) lithologies in detail and test the synchroneity of the conformable S3/S2 boundary along the margin.

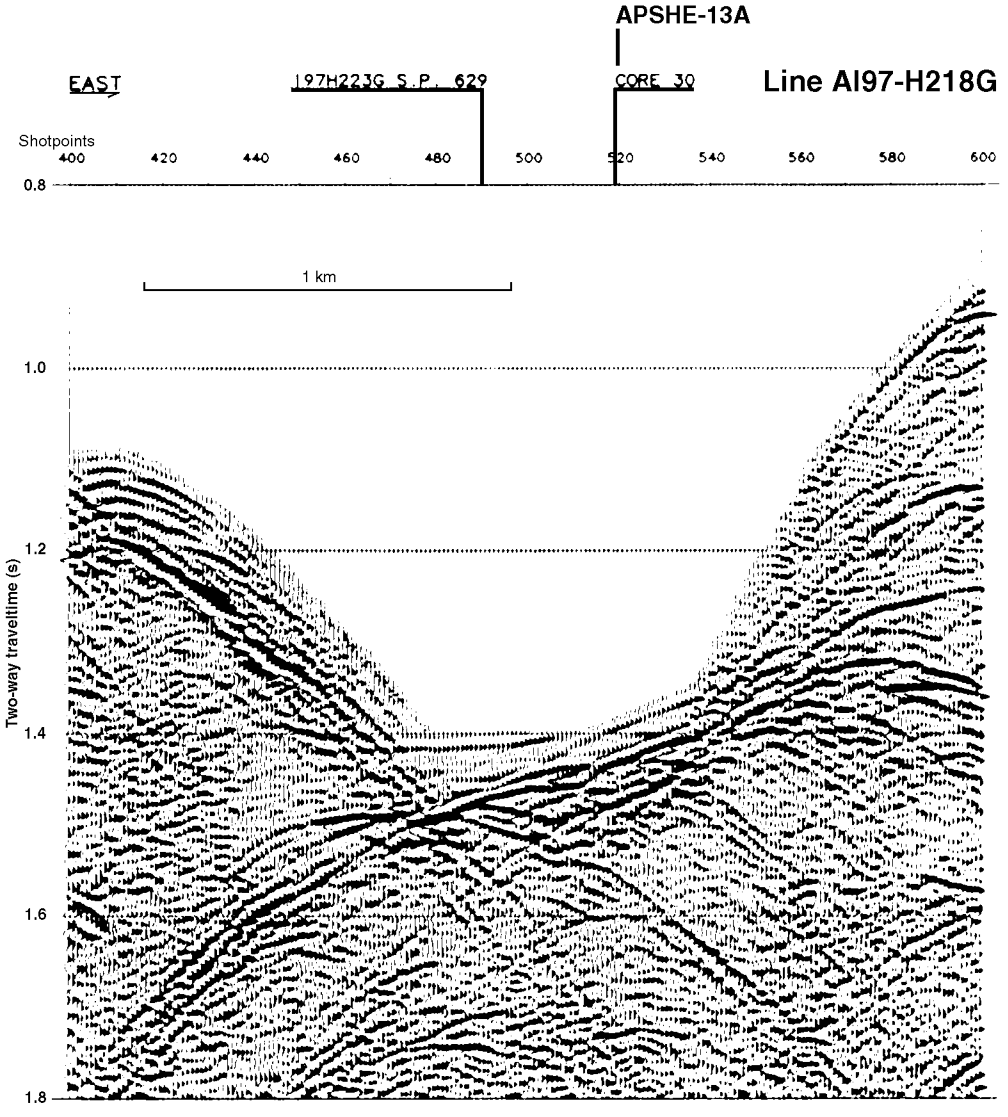
2. Sample the near-conformable (probably tectonic) S3/S4 boundary.

3. Test hypotheses of the "pre-glacial" nature of S3 and of the uplift/subsidence origin of the S4/S3 boundary.

Drilling Program: Single RCB hole to 785 mbsf. Alternate sites are APSHE-06A and 10A.

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

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


APSHE-13A
EAST
I97H223G S.P. 629
CORE 30
Line AI97-H218G
Shotpoints
400
420
440
460
480
500
520
540
560
580
600
1 km
Two-way traveltime (s)
0.8
1.0
1.2
1.4
1.6
1.8

Site: APSHE-13A

Priority: 1
Position: 64˚51.72´S, 64˚12.51´W
Water Depth: 1040 m
Sediment Thickness: ~60 m
Approved Maximum Penetration: 70 mbsf
Seismic Coverage: On site (located on Core 30) at SP 519 of Line AI97-H218G; 375 m off the site, SP 490 of Line AI97-H218G intersects SP 629 of Line AI97-H223G (GI gun source); 400 m off the site SP 490 of Line AI97-H218G intersects SP 930 of Line AI97-H230 (water gun source). Site also located on PD92-2 Huntec D-TB (deep-tow boomer) 540J survey line.

Objectives: The objectives of Site APSHE-13A are to:

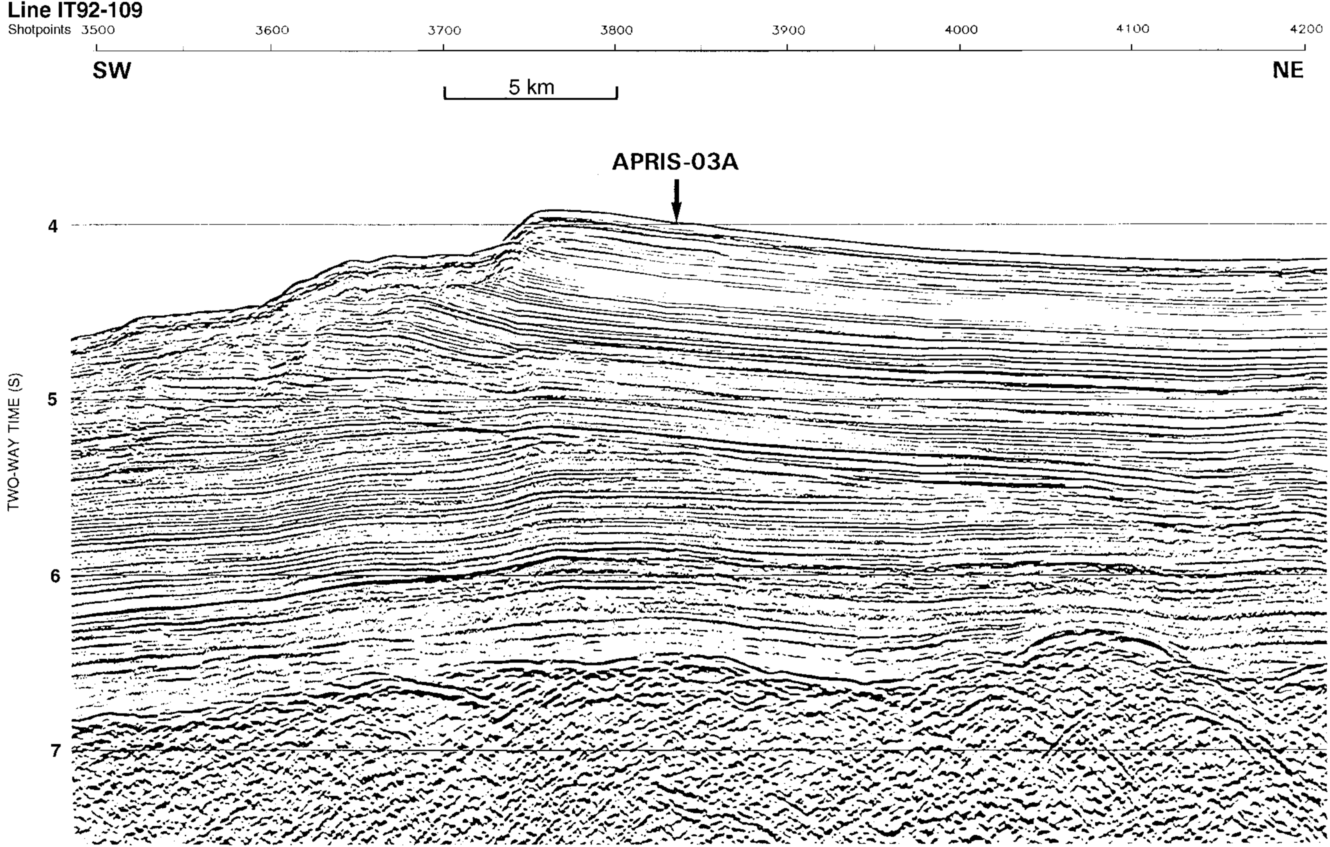
1. Obtain a Holocene ultra-high-resolution record of paleoproductivity in an inner shelf basin.

2. Examine decadal-millennial variability to 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 APSHE-15A.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Pelagic/hemipelagic siliceous ooze and mud, with <1% ice-rafted component (??diamicton at base).


Line IT92-109
Shotpoints 3500
3600
3700
3800
3900
4000
4100
4200
SW
NE
5 km
APRIS-03A
TWO-WAY TIME (S)
4
5
6
7

ALTERNATE SITES

Site: APRIS-03A

Priority: 2 (alternate to APRIS-01A)
Position: 66˚48.33'S, 75˚56.78'W
Water Depth: 2960 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 1150 mbsf
Seismic Coverage: Line IT92-109 SP 3840; intersecting lines are AI95-138A SP 1120 and AI97-243 SP 4767.

Objectives: The objectives of Site APRIS-03A are to:

1. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y.

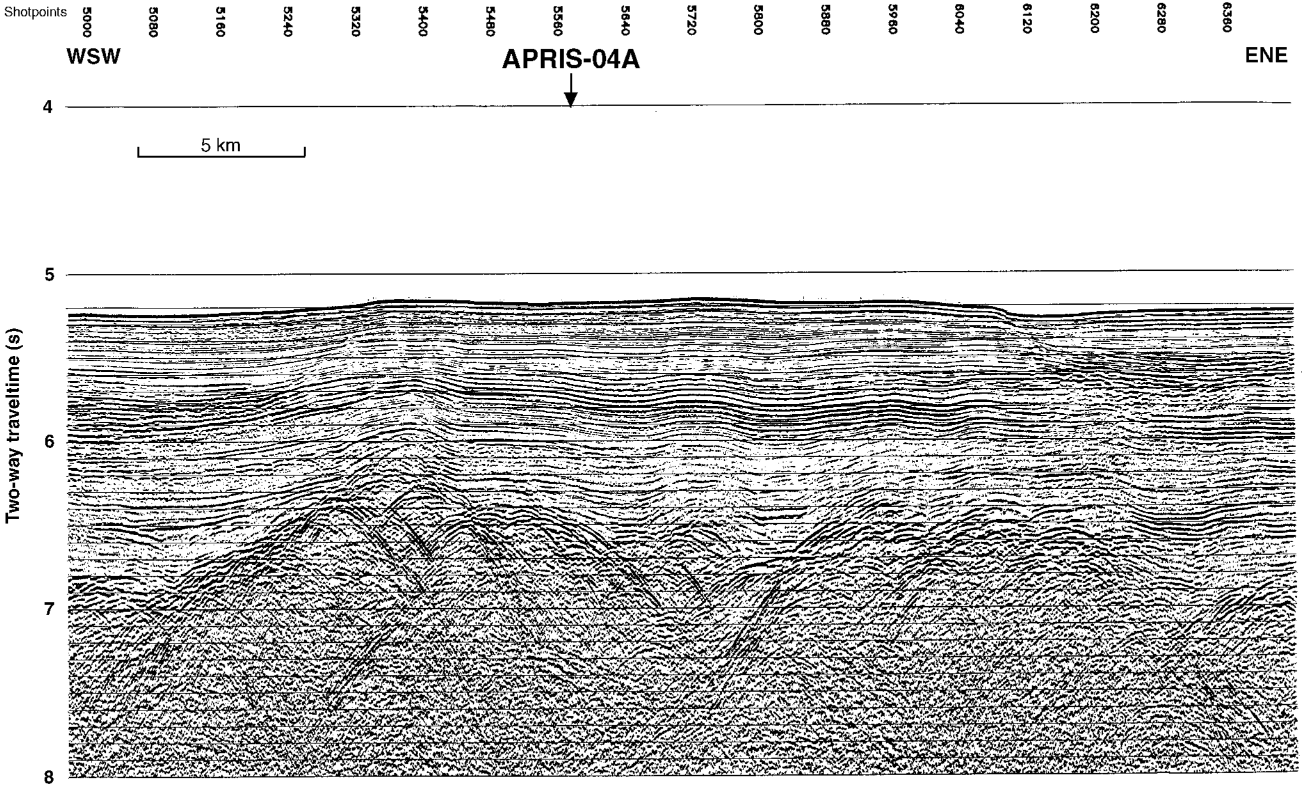
2. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Double APC until refusal (about 200 m), continue with XCB until refusal (about 800 m), and then either RCB from 750 m to base of target section at the same site or single APC and XCB to base of target section at Site APRIS-04. APRIS-04 is offset about 110 km from APRIS-03 and is located where the upper part of the section is thinner and the base of the target section is at only about 700 mbsf. Offset of the site is required if the stratigraphic control seriously degrades below the silica diagenetic BSR at about 670 mbsf at Site APRIS-03A.

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.

Line AI95-136



Site: APRIS-04A

Priority: 2 (alternate to APRIS-02A)
Position: 65˚55.04'S, 77˚13.55'W
Water Depth: 3900 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 700 mbsf
Seismic Coverage: Line AI95-136A SP 5550

Objectives: The objectives of Site APRIS-04A are to:

1. Sample the deeper part of the stratigraphic section not drilled at Site APRIS-03A.

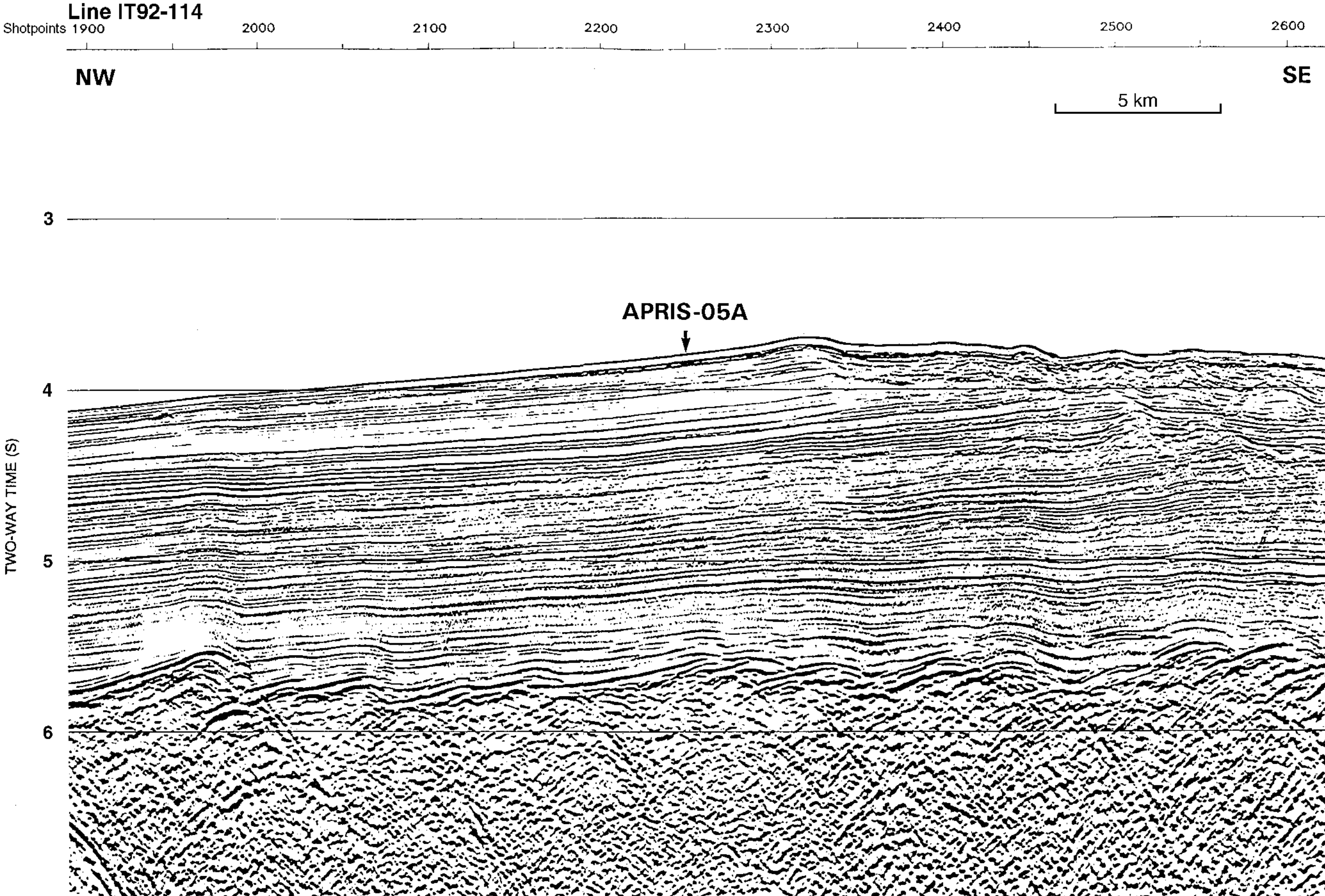
2. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y.

3. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Double APC until refusal (about 200 m) then XCB. The site is offset by ~110 km from main Site APRIS-03A. Offset required if stratigraphic control seriously degraded below silica diagenetic BSR at ~670 m at main site.

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.



Line IT92-114
Shotpoints 1900
2000
2100
2200
2300
2400
2500
2600
NW
SE
5 km
3
4
5
6
TWO-WAY TIME (S)
APRIS-05A

Site: APRIS-05A

Priority: 2 (alternate to APRIS-01A)
Position: 64˚35.06'S, 69˚24.26'W
Water Depth: 2850 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 1320 mbsf
Seismic Coverage: Line IT92-114 SP 2250; Lines intersect at AI97-235A SP 9300 and AI97-236 SP 291

Objectives: The objectives of Site APRIS-05A are to:

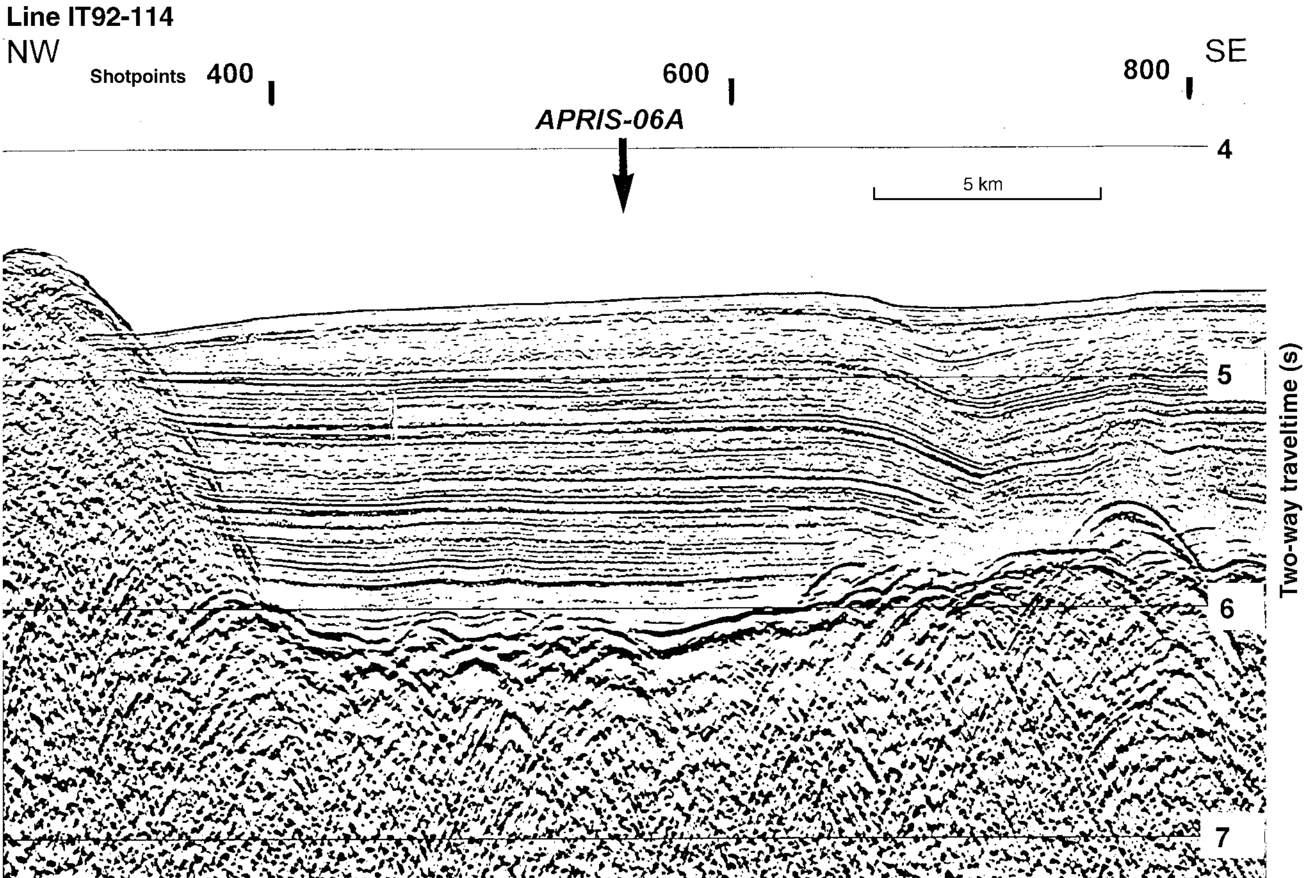
1. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y.

2. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Double APC until refusal (about 200 m), continue with XCB until refusal (about 800 m), and then either RCB from 750 m to base of target section at the same site or single APC and XCB to base of target section at Site APRIS-06A. Site APRIS-06A is offset about 90 km from APRIS-05A and is located where the upper part of the section is thinner and the base of the target section is at only about 800 mbsf. Offset of the site is required if the stratigraphic control seriously degrades below the silica diagenetic BSR at about 590 mbsf at Site APRIS-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.



Line IT92-114
NW
SE
Shotpoints
400
600
800
APRIS-06A
5 km
4
5
6
7
Two-way traveltime (s)

Site: APRIS-06A

Priority: 2 (alternate to APRIS-02A)
Position: 64˚13.72'S, 70˚50.45'W
Water Depth: 3500 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 800 mbsf
Seismic Coverage: Line IT92-114 SP 550

Objectives: The objectives of Site APRIS-06A are to:

1. Sample the deeper part of the stratigraphic section not drilled at Site APRIS-03A.

2. Obtain a high-resolution history of Antarctic Peninsula glaciation for the last 6-10 m.y.

3. Determine the onset of drift formation by sampling the base of Unit M4.

Drilling Program: Double APC until refusal (about 200 m) then XCB. The site is offset by ~90 km from main site, Site APRIS-01A. Offset required if stratigraphic control seriously degraded below silica diagenetic BSR at ~590 m at main site.

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-06A

Priority: 2 (alternate to APSHE-05A)
Position: 66˚30.05'S, 70˚25.8'W
Water Depth: 600 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 505 mbsf
Seismic Coverage: Site located on Line PD88-04 (0500/002). Approximately 3 km from the site, this Line PD88-04 intersects Line BAS878-021 at SP 2430.

Objectives: The objectives of Site APSHE-06A are to:

1. Examine "pre-glacial" (S3) lithologies in detail and test the synchroneity of the conformable S3/S2 boundary along the margin.

2. Sample the near-conformable (probably tectonic) S3/S4 boundary.

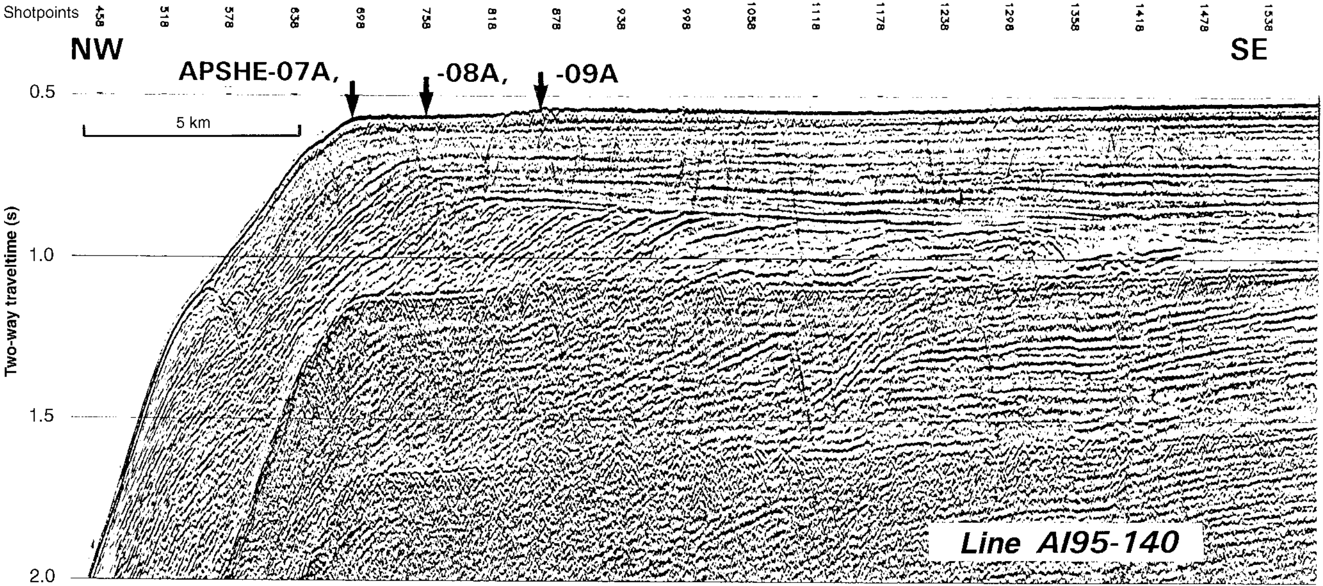
3. Test hypotheses of the "pre-glacial" nature of S3 and of the uplift/subsidence origin of the S4/S3 boundary.

Drilling Program: Single RCB hole.

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 of S2 (i.e., top ~150 m), then uncertain (glacial marine diamicton or biosiliceous hemipelagic) from S3 to base of hole.

Note: See seismic line for APSHE-05A



Shotpoints
458
518
578
638
698
758
818
878
938
998
1058
1118
1178
1238
1298
1358
1418
1478
1538
NW
SE
APSHE-07A,
-08A,
-09A
5 km
Two-way traveltime (s)
0.5
1.0
1.5
2.0
Line AI95-140

Site: APSHE-07A

Priority: 2 (alternate to APSHE-01A)
Position: 65˚54.36'S, 70˚30.00'W
Water Depth: 420 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 675 mbsf
Seismic Coverage: Site located at SP 693 of Line AI95-140; 3175 m off the site, SP 820 of Line AI95-140 intersects SP 610 of Line AI95-142; Line AMG878-19 is nearby.

Objectives: The objectives of Site APSHE-07A are to:

1. Identify and date glacial/intergalcial transitions in the youngest S1 foreset sequence.

2. Examine foreset lithologies and compare them with the rise drift.

Drilling Program: Single RCB hole.

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-08A

Priority: 2 (alternate to APSHE-02A)
Position: 65˚54.98'S, 70˚28.46'W
Water Depth: 405 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 450 mbsf
Seismic Coverage: Site located at SP 758 of Line AI95-140; 1550 m off the site, SP 820 of Line AI95-140 intersects SP 610 of Line AI95-142; Line AMG878-19 is nearby.

Objectives: The objectives of Site APSHE-08A are to:

1. Identify and date the main changes in wedge geometry during progradation of the glacial wedge (conformable S1/S2 boundary).

2. Examine topset (S1) and foreset (S2) lithologies and compare with rise drift.

Drilling Program: Single RCB hole.

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.

Note: See seismic line for APSHE-07A

Site: APSHE-09A

Priority: 2 (alternate to APSHE-03A)
Position: 65˚56.01'S, 70˚25.80'W
Water Depth: 390 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 450 mbsf
Seismic Coverage: Site located at SP 868 of Line AI95-140; 1200 m off the site, SP 820 of Line AI95-140 intersects SP 610 of Line AI95-142; Line AMG878-19 is nearby.

Objectives: The objectives of Site APSHE-09A are to:

1. Identify and date the main changes in wedge geometry during progradation of the glacial wedge (onset of erosional S1/S2 boundary).

2. Examine topset (S1) and foreset (S2) lithologies and compare with rise drift.

Drilling Program: Single RCB hole.

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.

Note: See seismic line for APSHE-07A

Site: APSHE-10A

Priority: 2 (alternate to APSHE-05A)
Position: 63˚59.97'S, 65˚27.92'W
Water Depth: 510 m
Sediment Thickness: >2000 m
Approved Maximum Penetration: 650 mbsf
Seismic Coverage: Site located at SP 1707 of Line AI95-152; also on Line AMG 845-08; 7675 m off the site, SP 1400 of Line AI95-152 intersects SP 1500 of Line AMG 845-10. Intersect on site AI97-H231 SP 3491.

Objectives: The objectives of Site APSHE-10A are to:

1. Examine "pre-glacial" (S3) lithologies in detail and test the synchroneity of the conformable S3/S2 boundary along the margin.

2. Sample the near-conformable (probably tectonic) S3/S4 boundary.

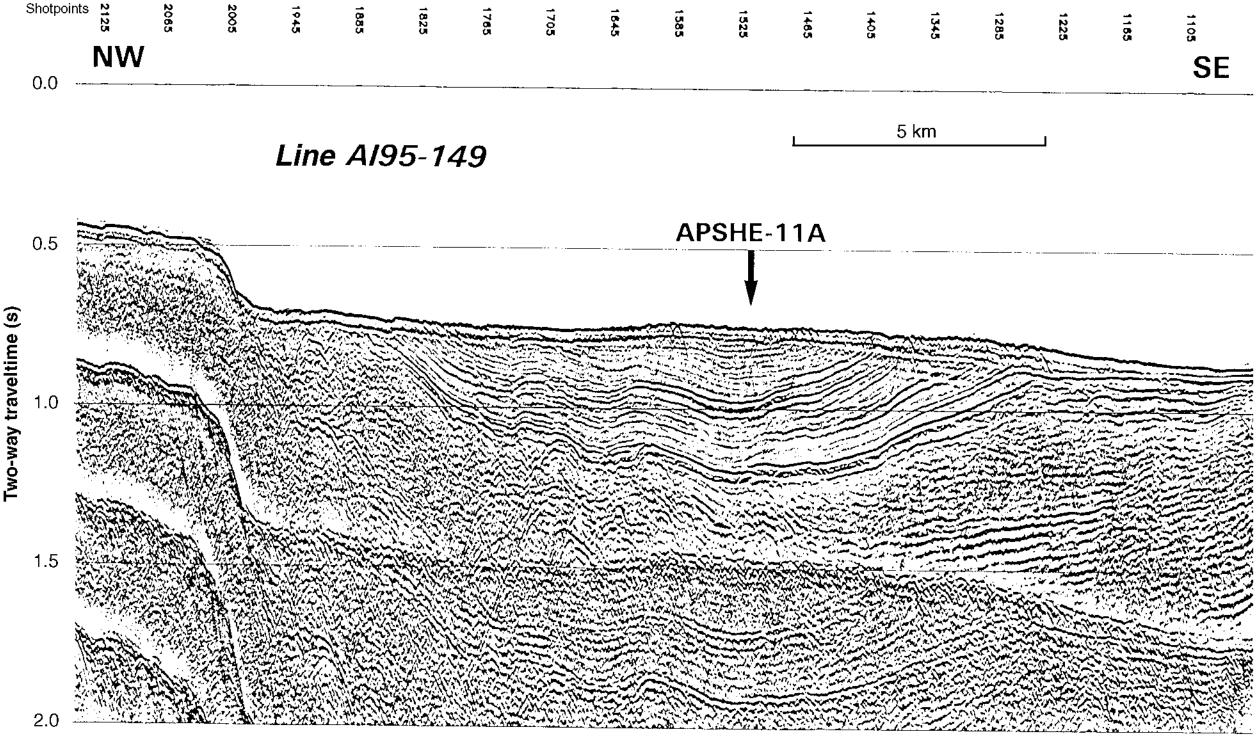
3. Test hypotheses of the "pre-glacial" nature of S3 and of the uplift/subsidence origin of the S4/S3 boundary.

Drilling Program: Single RCB hole.

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

Nature of Rock Anticipated: Diamicton intercalated with thin hemipelagic layers down to S1/S3 boundary. Hemipelagic or terrigenous sediments down to S3/S4 boundary. Volcaniclastics below S3/S4 boundary.

Note: See seismic line for APSHE-01A



Shotpoints
2125
2065
2005
1945
1885
1825
1765
1705
1645
1585
1525
1465
1405
1345
1285
1225
1165
1105
NW
SE
0.0
5 km
Line AI95-149
APSHE-11A
0.5
1.0
1.5
2.0
Two-way traveltime (s)

Site: APSHE-11A

Priority: 2
Position: 64˚28.32'S, 65˚35.27'W
Water Depth: 530 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 620 mbsf
Seismic Coverage: Site located on Line AI95-149 SP 1520; Line AMG845-03 SP 1290; intersect Line BAS878-18 SP 3380; Intersect at 1900 m off site Ewing SAP1.

Objectives: The objectives of Site APSHE-11A are to:

1. Obtain a record of "pre-glacial" sedimentation in the inner shelf basin.

2. Provide constraints on the history of vertical motion associated with ridge-crest collision.

Drilling Program: Single RCB hole. The alternate site is APSHE-12A.

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

Nature of Rock Anticipated: Diamicton intercalated with thin hemipelagic layers down to IS1/IS2 boundary. Volcaniclastics sandstones and mudstones below IS1/IS2 boundary.

Site: APSHE-12A

Priority: 2 (alternate to APSHE-11A)
Position: 66˚46.55'S, 69˚33.35'W
Water Depth: 375 m
Sediment Thickness: >1000 m
Approved Maximum Penetration: 620 mbsf
Seismic Coverage: Line PD88-04 (0830/002). Intersection: Line IT92-111 SP 1125.

Objectives: The objectives of Site APSHE-12A are to:

1. Obtain a record of "pre-glacial" sedimentation in the inner shelf basin.

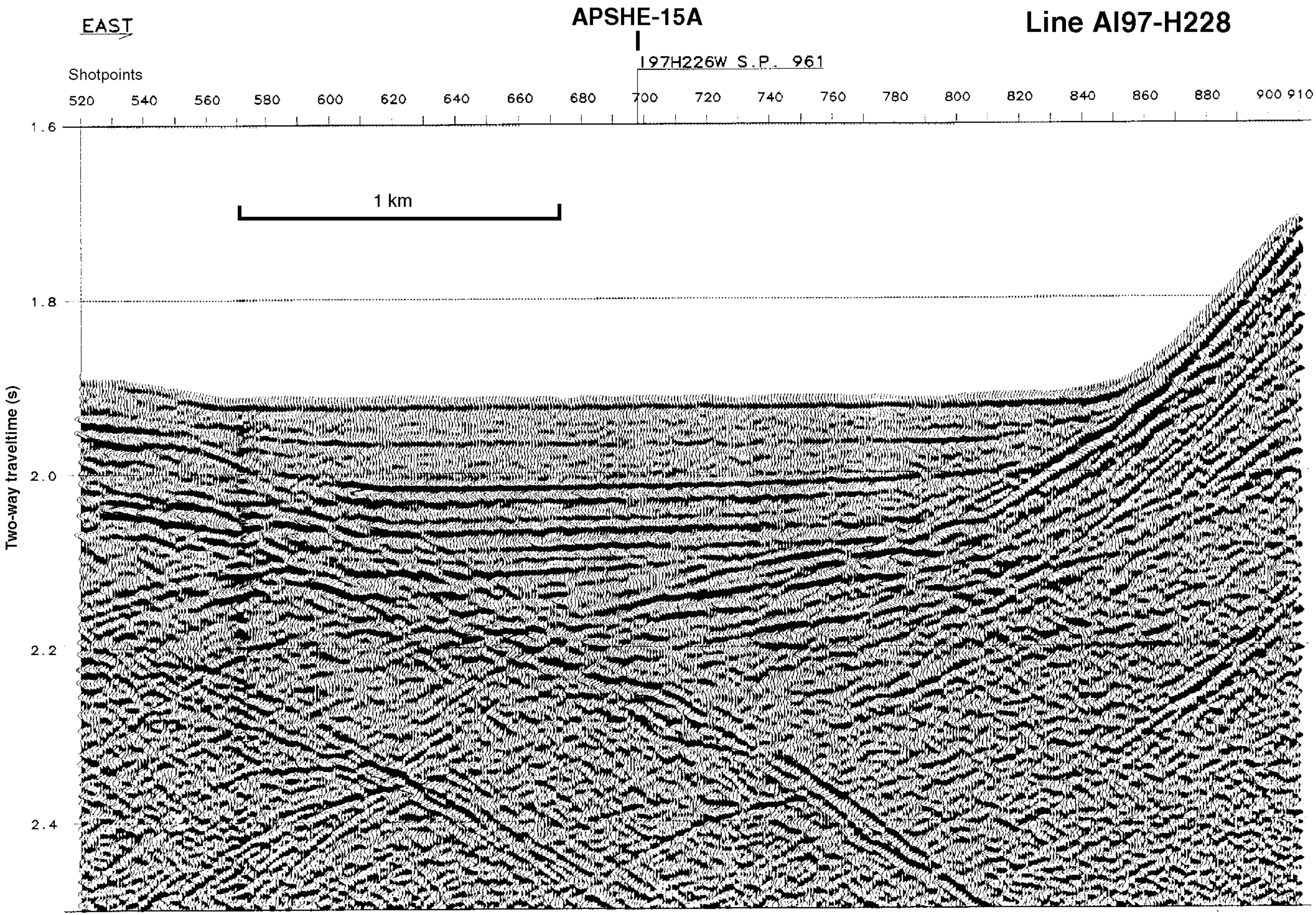
2. Provide constraints on the history of vertical motion associated with ridge-crest collision.

Drilling Program: Single RCB hole.

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

Nature of Rock Anticipated: Diamicton intercalated with thin hemipelagic layers down to IS1/IS2 boundary. Volcaniclastic sandstones and mudstones below IS1/IS2 boundary.

Note: See seismic line for APSHE-05A



EAST
APSHE-15A
Line AI97-H228
I97H226W S.P. 961
Shotpoints
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
860
880
900 910
1 km
Two-way traveltime (s)
1.6
1.8
2.0
2.2
2.4

Site: APSHE-15A

Priority: 2 (alternate to APSHE-13A)
Position: 64˚56.68'S, 64˚18.92'W
Water Depth: 1445 m
Sediment Thickness: ~200 m
Approved Maximum Penetration: 250 mbsf
Seismic Coverage: On Site: Lines AI97-H219G SP 1962 and AI97-H221 SP 800 (G.I. Gun source). Intersection on site: Line AI97-H228 SP 698 (water gun source). PD92-2 Huntec D-TB 540J survey.

Objectives: The objectives of Site APSHE-15A are to:

1. Obtain a Holocene ultra-high-resolution record of paleoproductivity in an inner shelf basin.

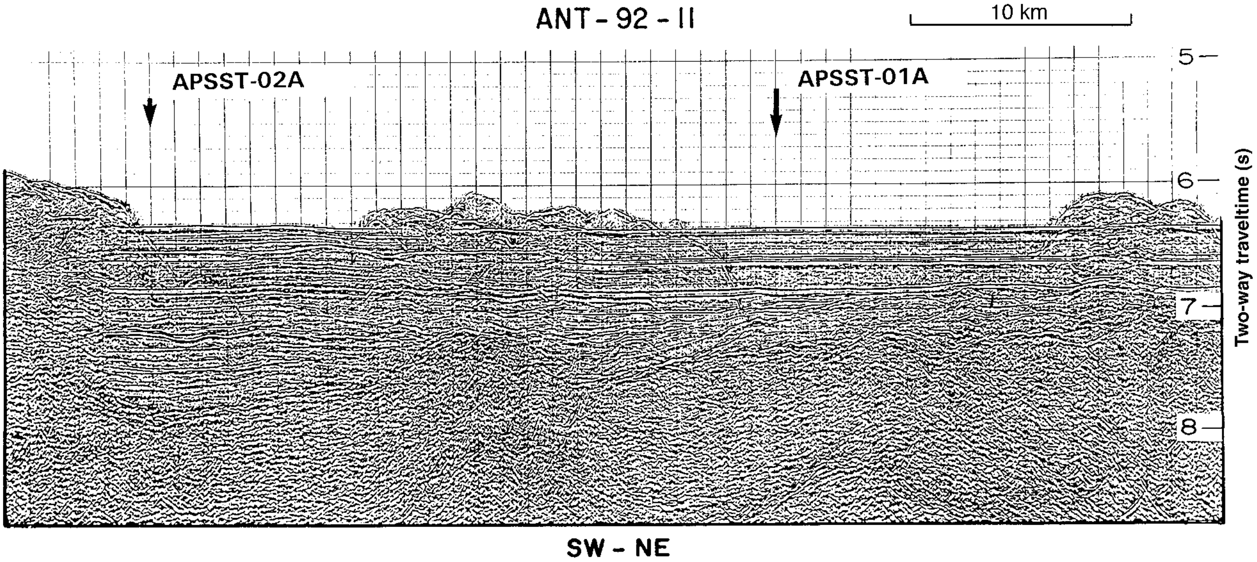
2. Examine decadal-millennial variability to compare with low-latitude and ice-core records.

3. Test the hypothesis that Palmer Deep was a subglacial lake during the latest episodes of ice grounding on the Antarctic Peninsula continental shelf.

Drilling Program: Quadruple APC coring to base of transparent unit. XCB coring into the lower unit.

Logging and Downhole Operations: None

Nature of Rock Anticipated: Pelagic/hemipelagic siliceous ooze and mud, with <1% ice-rafted component (??diamicton at base).


ANT - 92 - II
10 km
APSST-02A
APSST-01A
5
6
7
8
Two-way traveltime (s)
SW - NE

Site: APSST-01A

Priority: 2
Position: 62˚07.30'S, 62˚40.00'W
Water Depth: 4715 m
Sediment Thickness: ~900 m
Approved Maximum Penetration: 630 mbsf
Seismic Coverage: Line HESP92-11 SP 39300, part of coarse grid of MCS lines (cruise ANT-92).

Objectives: The objectives of Site APSST-01A are to:

1. Obtain a high-resolution Pliocene-Quaternary stratigraphy of cyclic sedimentation in the South Shetland Trench.

2. Date glacial events and paleoceanographic processes.

Drilling Program: Double APC until refusal (about 200 m) then XCB. The alternate site is APSST-02A.

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

Nature of Rock Anticipated: Turbidites.

Site: APSST-02A

Priority: 2 (alternate to APSST-01A)
Position: 62˚13.00'S, 62˚53.00'W
Water Depth: 4705 m
Sediment Thickness: ~1500 m
Approved Maximum Penetration: 720 mbsf
Seismic Coverage: Line HESP92-11 SP 38900, part of coarse grid of MCS lines (cruise ANT-92).

Objectives: The objectives of Site APSST-02A are to:

1. Obtain a high-resolution Pliocene-Quaternary stratigraphy of cyclic sedimentation in the South Shetland Trench.

2. Time glacial events and paleoceanographic processes.

Drilling Program: Double APC until refusal (about 200 m) then XCB.

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

Nature of Rock Anticipated: Turbidites.

Note: See seismic line for APSST-01A

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