1. INTRODUCTION[1]

Shipboard Scientific Party[2]

Leg 119 along with Leg 120 of the Ocean Drilling Program (ODP) constitute a latitudinal transect in the Southern Ocean between Kerguelen Island (49°S) and Prydz Bay, Antarctica (67°S). Along this transect we studied the Late Cretaceous to Holocene paleoclimatic history of East Antarctica, the origin and tectonic history of the Kerguelen Plateau, and the Late Mesozoic rifting history of the Indian plate from East Antarctica.

Kerguelen Plateau

Strategically situated for high-latitude paleoceanographic studies, the Kerguelen Plateau stretches approximately 2500 km between 46°S and 64°S in a northwest-southeast direction as a basement depth anomaly on the Antarctic plate. The feature is between 200 and 600 km wide and stands 2–4 km above the adjacent ocean basins. The plateau is bounded to the northeast by the Australian-Antarctic Basin, to the south by the Antarctic continental rise, to the southwest by the African-Antarctic Basin, and to the northwest by the Crozet Basin (Fig. 1).

The Kerguelen Plateau has been divided into two distinct domains (Schlich, 1975; Houtz et al., 1977). The northern portion, the Kerguelen-Heard Plateau, generally lies in water depths less than 1000 m and includes the feature's only subaerial manifestations, Kerguelen, Heard, and McDonald islands. The southern portion, the southern Kerguelen Plateau, is deeper, generally lying in water depths between 1500 and 2000 m. The transition zone, between 54°S and 58°S, exhibits a complex bathymetry with a large east-trending spur, the Elan Bank, extending westward from the main plateau over a distance of 600 km.

The age of the oceanic crust abutting the plateau varies and has been analyzed since 1966 by various authors (Fig. 2). The Kerguelen Plateau and Broken Ridge form a symmetric pair of "aseismic ridges" separated by the Southeast Indian Ridge. Fracture zones and magnetic lineations related to this spreading center have been mapped and analyzed by Schlich and Patriat (1967, 1971), Le Pichon and Heirtzler (1968), McKenzie and Sclater (1971), and Houtz et al. (1977). The seafloor close to the plateau has been dated by the observed magnetic lineations (Fig. 2). Le Pichon and Heirtzler (1968) identified anomalies 13, 16, and 17 (40 Ma) east of Heard Island. Schlich and Patriat (1971) recognized anomalies 1–11 (32 Ma) to the east and the north of Kerguelen Island (ages from magnetic time scale of Berggren et al., 1985). Further south, eastward of Heard Island, Houtz et al. (1977) also identified anomalies 1–18 (42 Ma). Thus, the isochrons close to the northeastern margin of the ridge are not parallel to this boundary but vary in age from 32 Ma (to the north) to 42 Ma (to the south). Northwest and west of the Kerguelen Plateau, magnetic anomalies 23, 24, 26, and 28 (65 Ma) and magnetic anomalies 33 and 34 (84 Ma) have been identified (Schlich, 1975, 1982). No seafloor-spreading magnetic anomalies have been observed adjacent to the southwestern flank of the Kerguelen Plateau.

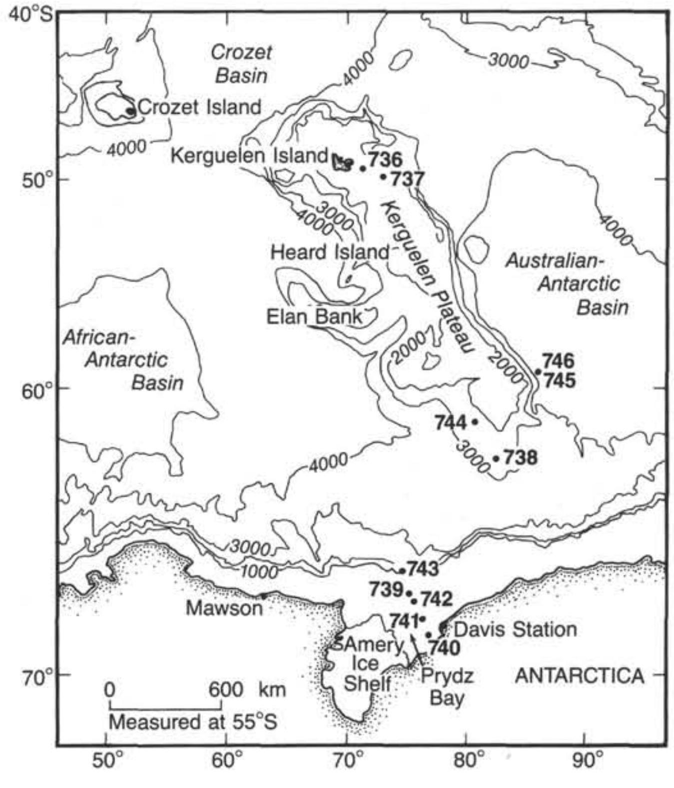

Figure 1. The Kerguelen Plateau and Prydz Bay with the Leg 119 and Leg 120 sites. Bathymetry in meters is from GEBCO (Hayes and Vogel, 1981; Fischer et al., 1982).

According to Le Pichon and Heirtzler (1968), the Kerguelen Plateau and Broken Ridge were separated in Eocene time. The reconstructions proposed by Houtz et al. (1977) and Goslin (1981) to allow for total closure of Australia and Antarctica by anomaly 20 time show an unacceptable overlap of Broken Ridge and the Kerguelen-Heard Plateau. Mutter and Cande (1983) and Mutter et al. (1985), using a revised chronology for the breakup of Australia and Antarctica (Cande and Mutter, 1982), partially resolved the overlap problem. However, the resulting reconstruction does not exclude overlap of the northern portion of the Kerguelen Plateau with Broken Ridge.

The origin and crustal structure of the Kerguelen Plateau have remained obscure despite geophysical and geological investigations. Three possibilities, each geochemically distinguishable, may explain the feature's origin and crustal nature: (1) it is a continental fragment left over from the breakup of India and Antarctica; (2) it is a product of excessive on- or off-axis oceanic volcanism, possibly hot-spot-related; (3) it is a thermally or tectonically uplifted and possibly thickened block of oceanic crust. It is possible, given the apparent structural complexities of the Kerguelen Plateau, that different parts of the feature have different origins (Coffin et al., 1986; Bassias et al., 1987). Petrological (Giret, 1983) and geochemical studies (Dosso et al.,

[1] Barron, J., Larsen, B., et al., 1989. *Proc. ODP, Init. Repts.*, 119: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of Participants preceding the contents.

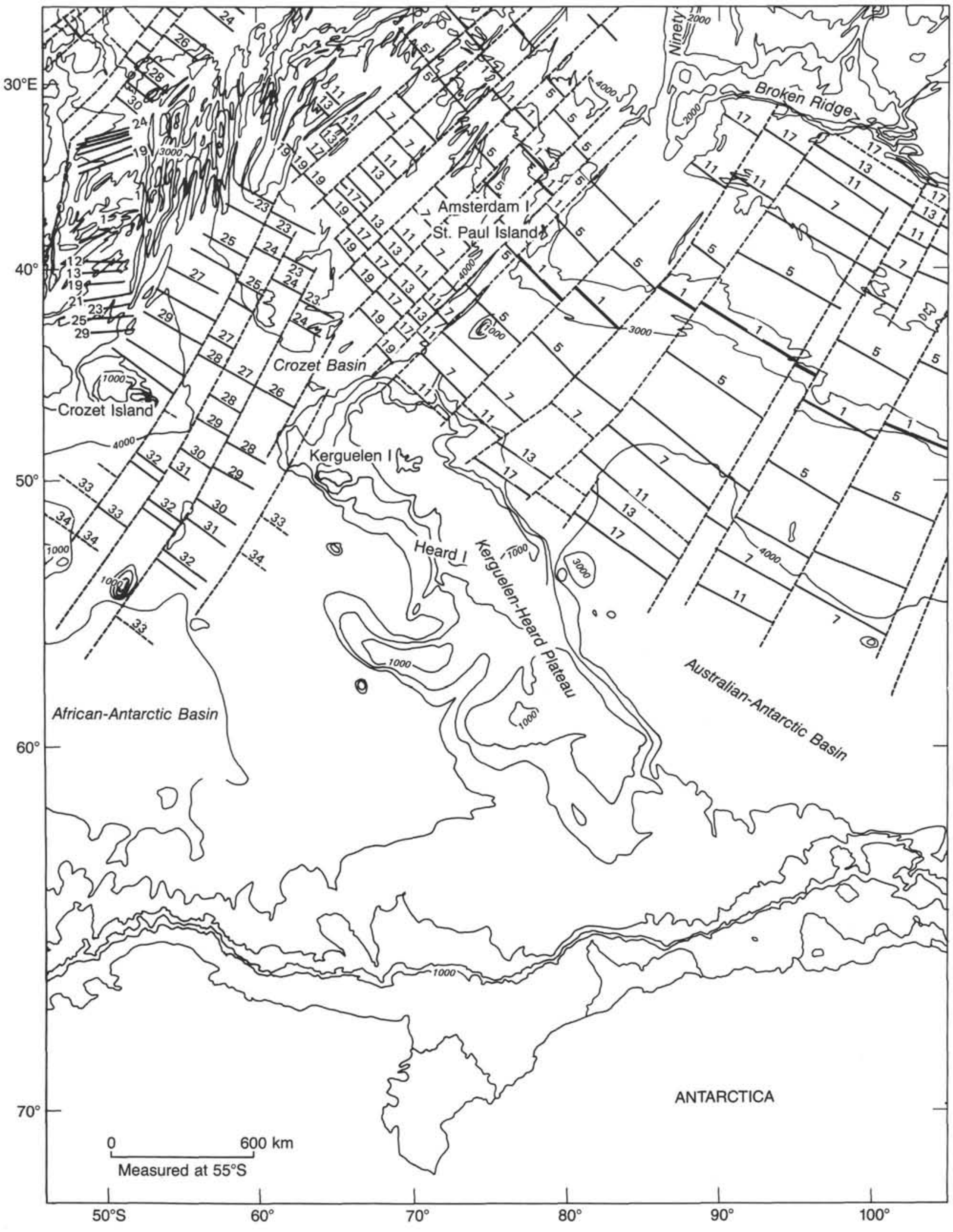

Figure 2. The Kerguelen Plateau in the south-central Indian Ocean. Bathymetry in meters is from GEBCO (Hayes and Vogel, 1981; Fischer et al., 1982). Fracture zones and numbered magnetic anomalies are from Schlich and Patriat (1967, 1971), Le Pichon and Heirtzler (1968), Schlich (1975, 1982), Houtz et al. (1977), and Tilbury (1981).

1979; Mahoney et al., 1983) on Kerguelen Island igneous rocks show clear similarities with the observations derived from other oceanic islands.

The crustal structure of the southern Kerguelen Plateau was modeled by Houtz et al. (1977) using gravimetric and seismic reflection/refraction data, and of the Kerguelen-Heard Plateau by Recq et al. (1983) and Recq and Charvis (1986) using two seismic refraction profiles shot on Kerguelen Island. The maximum thickness of the crust was determined to lie between 15 and 23 km. Furthermore, the seismic velocity vs. depth distribution is similar to that of typical oceanic islands (e.g., Crozet) or plateaus (e.g., Madagascar).

Coffin et al. (1986) concluded that the southern Kerguelen Plateau may be an amalgamation of different structural elements, including broad continental uplifts, trapped oceanic crust, possible continental fragments, and possible fracture zone ridges and troughs. Dredging along a major graben (77° graben of Houtz et al., 1977) recovered the first significant assemblage of basement rocks from the southern Kerguelen Plateau. The horst samples are basaltic, suggesting an oceanic or oceanic island origin for the southern Kerguelen Plateau. Shallow-water limestones of probable Cretaceous and Paleogene age were also recovered by dredging the basin, and Eocene and Cretaceous sediments were sampled on the faulted eastern flank of the southern Kerguelen Plateau (Bassias et al., 1987). The recent sampling supports the previous interpretation of Houtz et al. (1977) that the Neogene section on the southern Kerguelen Plateau, although perhaps thick locally in the Raggatt Basin, is generally thin. Furthermore, it is separated from older sediments by a major unconformity of Eocene age.

Munschy and Schlich (1987) divide the sediments on the Kerguelen-Heard Plateau into two major seismic sequences (S and I) that are separated by a major discordance (A). Discordance A is a major event in the sedimentary section. According to Munschy and Schlich (1987), it marks a hiatus separating the middle Eocene from the lower Miocene and also separates pre-rifting from breakup and post-breakup sequences. The evolution of the Kerguelen Plateau, chiefly postulated from basin stratigraphy, is summarized by Munschy and Schlich (1987) as follows:

1. In early Late Cretaceous time (about 100 Ma), the Kerguelen Plateau was faulted and elevated to shallow depths. Normal faulting occurred along the present limit of the sedimentary basin and along the present eastern margin of the Kerguelen Plateau. This tectonic event corresponds to the first pre-rift faulting episode between the Kerguelen Plateau and Broken Ridge (Fig. 3).
2. From Late Cretaceous to Eocene the Kerguelen Plateau remained a shallow marine structure, continuously subsiding at a rate of about 20 m/m.y., and was covered essentially by shelf pelagic sediments (Units I2 and I1) without obvious sedimentary hiatuses (Fig. 3).
3. During the Eocene, the eastern part of the Kerguelen Plateau was uplifted, probably close to sea level, and Unit I1 was partially eroded (Fig. 3).
4. By magnetic anomaly 18 time, the Kerguelen Plateau and Broken Ridge were clearly separated by spreading at the Southeast Indian Ridge. The breakup occurred at 45–42 Ma, and newly rifted margins subsequently subsided.
5. During Miocene and possibly Oligocene time, the plateau was covered by calcareous ooze containing siliceous biogenic components. The clastic component of the post-rift deposits is significant and is derived essentially from Kerguelen Island. The first clastic deposits are probably Oligocene in age (Fig. 3).
6. Sedimentation continued throughout the late Miocene, Pliocene, and Quaternary and consists of diatomaceous ooze, glauconitized sand with ice-rafted debris, and ash layers corresponding to explosive volcanic activity (Fig. 3).

It should be noted that this interpretation does not entirely agree with the results of Legs 119 and 120.

Drilling Objectives On The Kerguelen Plateau

Drilling at the northern Kerguelen Plateau (Site 736; 49°24.125′S, 71°39.61′E, water depth 631 m) was aimed at the recovery of an expanded section of Neogene calcareous and biosiliceous oozes at the northern end of the paleoceanographic transect. The site lies very near the present-day Antarctic Convergence (or Polar Front), which separates subantarctic waters from Antarctic waters (Fig. 4). The Antarctic Convergence approximates the boundary between dominantly calcareous sediments to the north and dominantly siliceous sediments to the south. However, Site 736 sediments should contain considerable carbonate, as the site lies above the carbonate compensation depth (CCD).

This expanded Neogene section should be an excellent stratigraphic section for high-resolution biostratigraphic and paleoceanographic studies. Kemp et al. (1975) used sedimentary evidence from DSDP Leg 28 to the east to suggest that the Antarctic Convergence moved northward to its present location at the beginning of the Pliocene. Brewster (1980) observed that biosiliceous sediment-accumulation rates in the Southern Ocean increased dramatically at this same time, further supporting a northward expansion of the convergence. A major objective of paleoceanographic studies at Site 736 was to trace the movement of the Antarctic Convergence through time both with sediments and with microfossil assemblages.

A second objective at Site 736 was to date the reflector at 910 m below seafloor (mbsf), which presumably represents the major middle Cenozoic uplift and separation of the Kerguelen Plateau and Broken Ridge (reflector A of Munchy and Schlich, 1987).

The objective at the southern Kerguelen Site 738 (62°44.0′S, 83°05.2′E; water depth 2700 m) was to obtain an Upper Cretaceous through Cenozoic reference section for the southern plateau, to determine the nature and age of basement there, and to provide evidence of the rifting and subsidence of the Kerguelen Plateau. Site 738 lies at the southern end of the Kerguelen Plateau transect, north of the Antarctic Divergence and beneath the southern part of the eastward-flowing Antarctic Circumpolar Current. We believed that sediments at Site 738 would record the initial northward expansion of Antarctic water masses, presumably in the late Paleogene (Barker, Kennett, et al., 1988). Furthermore, Site 738 would provide a valuable Upper Cretaceous and lower Paleogene high-latitude, pelagic reference section.

Prydz Bay

Prydz Bay lies at the oceanward end of the graben occupied by the Lambert Glacier and Amery Ice Shelf (Fig. 5). The Lambert Glacier drains a large part of the East Antarctic ice sheet, including the 3000-m-high subglacial Gamburtsev Mountains. The glacier follows the line of the Lambert Graben, which extends 700 km or more inland and is probably of Permian or Early Cretaceous age. The present ice-drainage basin is believed to be long-lived because of this structural control, and Prydz Bay sediments should reflect all stages of Antarctic glaciation and the pre-glacial continental climate.

Today, the East Antarctic ice cover terminates in the Amery Ice Shelf, forming the southern shore of the bay (Fig. 1). During glacial maxima, however, the ice appears to have grounded right across Prydz Bay, as demonstrated by the eroded, over-deep-

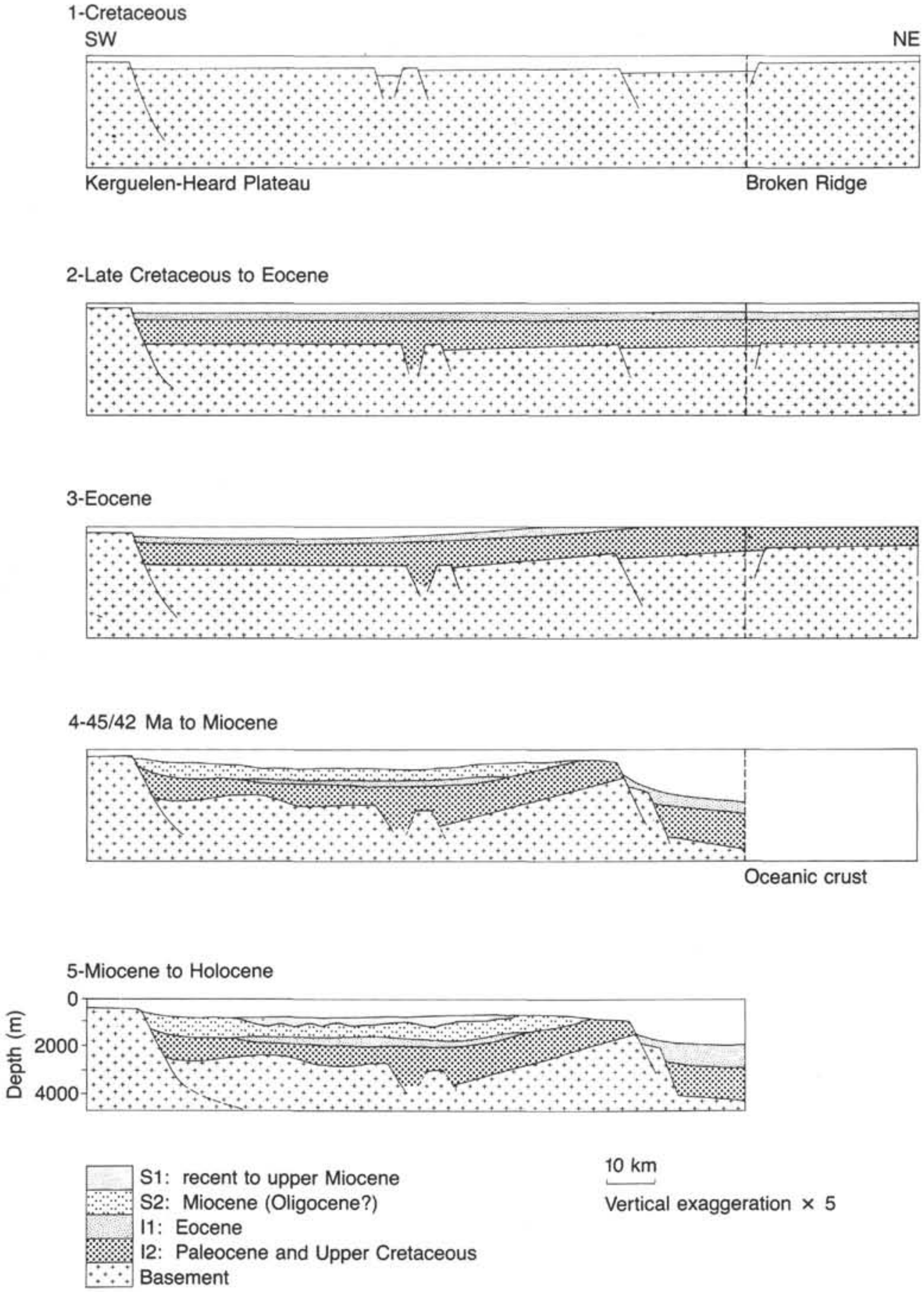

Figure 3. Schematic representation of the geological evolution of the Kerguelen-Heard Plateau from Cretaceous to Holocene time according to Munschy and Schlich (1987); see text for discussion. The results of Leg 119 have not been included in the chronology.

ened shelf topography (Fig. 6) seen most prominently at the southern end of the profiles (the shelf on profile PB-021; Fig. 9, for example, is 900 m deep inshore, shallowing to 400 m offshore). A very broad transverse channel across the shelf in front of the Amery Ice Shelf, the Prydz Channel, is probably erosional also (Stagg, 1985). A thick prograding sequence of sediments deposited at the shelf edge at the outlet of this channel indicates that the younger Prydz Bay sediments will reflect the glacial processes of the East Antarctic margin.

The morphology of the Prydz Bay continental shelf is thus typical of Antarctic continental shelves, with relatively shallow banks landward of the shelf break, deeper channels in the inner part of the shelf, and one broad transverse channel.

Bedrock in the Prydz Bay region is almost entirely formed of Precambrian igneous and metamorphic rocks (Fig. 5; Collerson and Sheraton, 1986; Grew, 1982). The metamorphic rocks are a diverse assemblage of rocks with igneous and sedimentary precursors. They include quartzofeldspathic and basic gneisses and schists, pelitic schists and amphibolites, quartzites, marble and calc-silicate rocks, and banded ironstone. Plutonic rocks range from gabbro to granite in composition and include large tracts of charnockite. Geochronologic and structural data allow

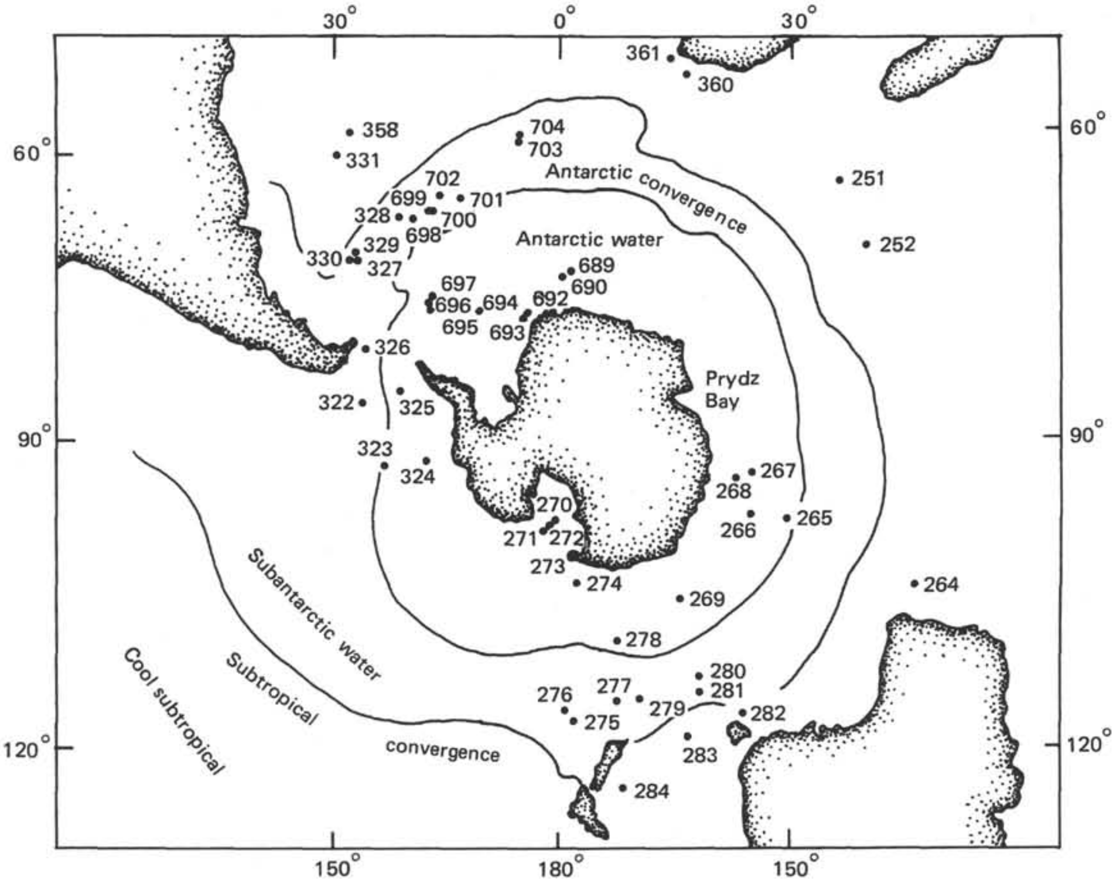

Figure 4. Present-day location of surface-water masses of the Southern Ocean (from Kennett, 1978), and DSDP/ODP drill site locations prior to Leg 119.

subdivision into Archean (>2500 Ma terrain of granulite-facies metamorphic rocks and younger Proterozoic 2500–600 Ma) belts of generally lower metamorphic facies (Tingey, 1982). Scattered intrusive bodies of Cambrian age cut the Precambrian rocks.

Geophysical surveys have established that the Lambert Glacier–Amery Ice Shelf region, the southward extension of Prydz Bay, is a rift structure in which depth to Moho is 22–23 km in contrast to 30–34 km on the rift flanks (Federov et al., 1982). A very substantial thickness of sediment is present in the rift, and the age of rifting is poorly constrained. A restricted locality of Permian nonmarine, coal-bearing, clastic strata is exposed along the southwestern margin of the Amery Ice Shelf (Mond, 1972). The Permian strata may have been deposited in the early stages of rifting and, therefore, in a similar tectonic setting to the Gondwana sequence in the Mahanadi and Godovari Valley of Peninsular India. The rift has been interpreted by Stagg (1985) as the failed arm of a triple (or quadruple) junction developed on the separation of Antarctica and India, in which case it dates from the Early Cretaceous. The alkaline mafic igneous rocks are likely to be associated with such rifting. The seaward end of the graben opens out into Prydz Bay. Palynological data from surface sediments indicate the presence of Lower Cretaceous nonmarine beds and Upper Cretaceous to Eocene marine strata (Truswell, 1982).

Seismic data from Prydz Bay have been interpreted by Stagg (1985) in terms of several sedimentary packages, separated by seismic reflectors, on both the shelf and slope (Figs. 7–9). On the shelf an older sequence showing minor folding and faulting is interpreted as a continental to possibly shallow-marine sequence that pre-dates breakup. The younger sequence is interpreted as a post-breakup sequence of shallow-marine sediments. A thin sequence at the seafloor is clearly disconformable on older strata and indicates that ice advance has removed parts of the underlying sequences. Stagg (1985) tentatively assigned ages to these sequences: (1) acoustic basement in southeastern Prydz Bay, adjacent to the Vestfold Hills, is Cambrian or older; (2) pre-breakup strata (PS 3, 4, and 5) are continental clastic sediments and coal; and (3) post-breakup strata (PS 2) are Early Cretaceous to ?Miocene, whereas the thin veneer at the seafloor (PS 1) is post-middle Miocene.

There is no direct age control on any of the sediments. Stagg (1985) interprets the section proposed for drilling to be of Permian to Holocene age, but this is based on (1) a Permian age for the Lambert Graben, (2) a Neocomian age for the faulting on the western profiles (Indian-Antarctic breakup), and (3) speculative correlation of sequences eastward, without cross lines. For profile PB-021, on which the proposed sites lie (Figs. 7 and 9), this interpretation has the consequence that the Neocomian separation of East Antarctica from India, which created the northern margin of Prydz Bay, produced no major unconformity. However, another equally likely explanation is that eastern Prydz Bay was not directly on the line of the Lambert Graben, whatever its age, and that the sequences shown on PB-021 and adjacent lines are all of Neocomian and younger age.

Paleoclimatic Background

Scientific drilling in Prydz Bay is aimed mainly at understanding the Late Cretaceous to Holocene climatic evolution of East Antarctica and the growth of the continental ice sheet. The history of climate change through the Cenozoic has been obtained from a variety of sources, but primarily from Deep Sea

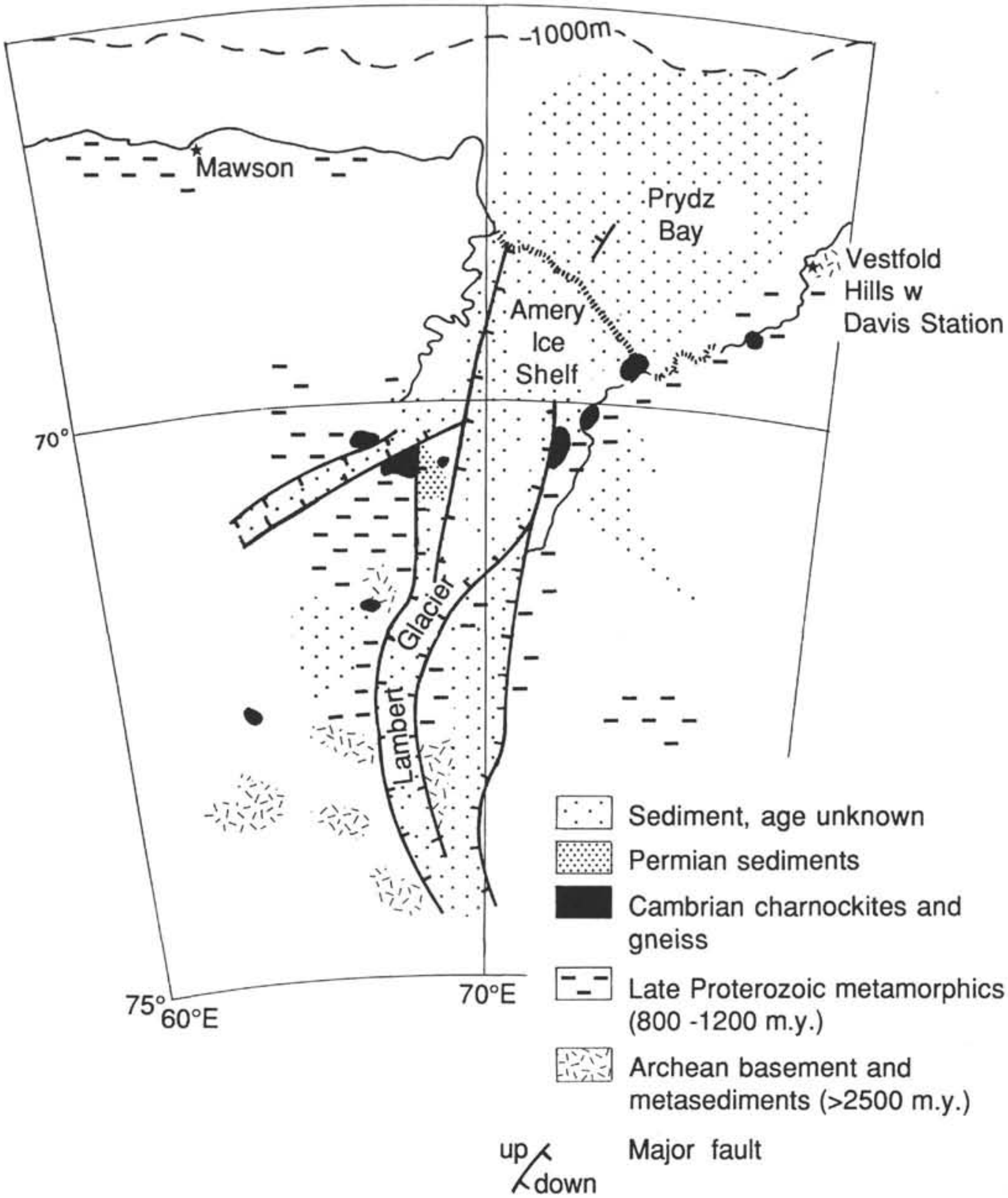

Figure 5. Schematic geologic map of Prince Charles Mountains region and the adjacent coast (modified from Tingey, 1982).

Drilling Project (DSDP), ODP, and other cores taken from the subantarctic parts of the South Pacific and South Atlantic and from the continental margin of Antarctica in the western Ross Sea and eastern Weddell Sea. The commonly accepted interpretation of the oxygen isotopic record of climate trends is that the abrupt increase in ^{18}O at the Eocene/Oligocene boundary reflects the first formation of sea ice and the consequent establishment of cold bottom water. The second abrupt enrichment in the middle Miocene reflects the establishment of full ice-sheet conditions (Shackleton and Kennett, 1975; Kennett, 1978). ODP Leg 113 results from Site 693 have been interpreted in the same manner (Barker et al., 1987). There is no other Antarctic site to corroborate that interpretation.

In the Ross Sea region, DSDP Leg 28 results demonstrated the existence of glacial deposits as old as 25 Ma, which overlie Oligocene glauconite sandstone dated at 26.7 Ma (Hayes and Frakes, 1975). The glacial deposits indicate the existence of outlet glaciers, not ice-sheet conditions. Drilling in the western Ross Sea has extended the record of glacially-related deposition back to the early Oligocene (Barrett et al., in press). Unfortunately, the record is complicated by proximity to the Transantarctic Mountains, which were uplifted during the Cenozoic to their present elevation of over 4000 m (Gleadow et al., 1984).

The earliest terrestrial record of glaciation in Antarctica is based on interpretation of Cenozoic hyaloclastite deposits in Marie Byrd Land as the products of subglacial eruption (LeMasurier and Rex, 1983). The maximum age inferred is 27 Ma. Most of the other records do not bear directly on either of the two major cooling events that are inferred through interpretation of the oxygen isotopic record or on ice-sheet fluctuations. The principal exception is the postulated Pliocene deglaciation of Antarctica that is based on the physical and paleontological

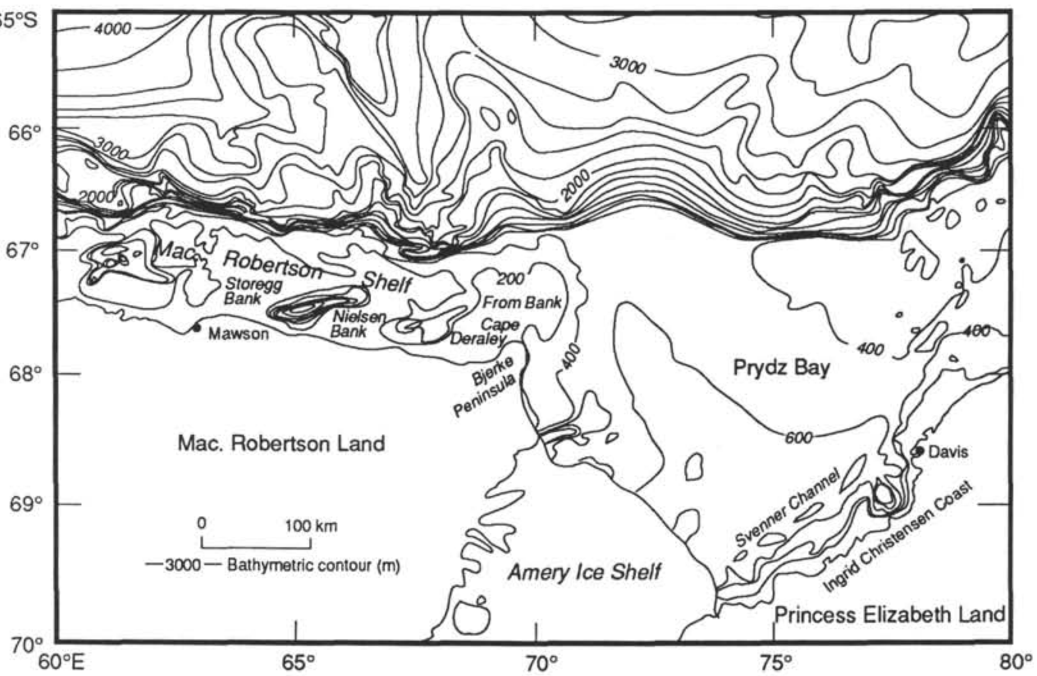

Figure 6. Bathymetry of Prydz Bay. Contour interval in meters (from Stagg, 1985).

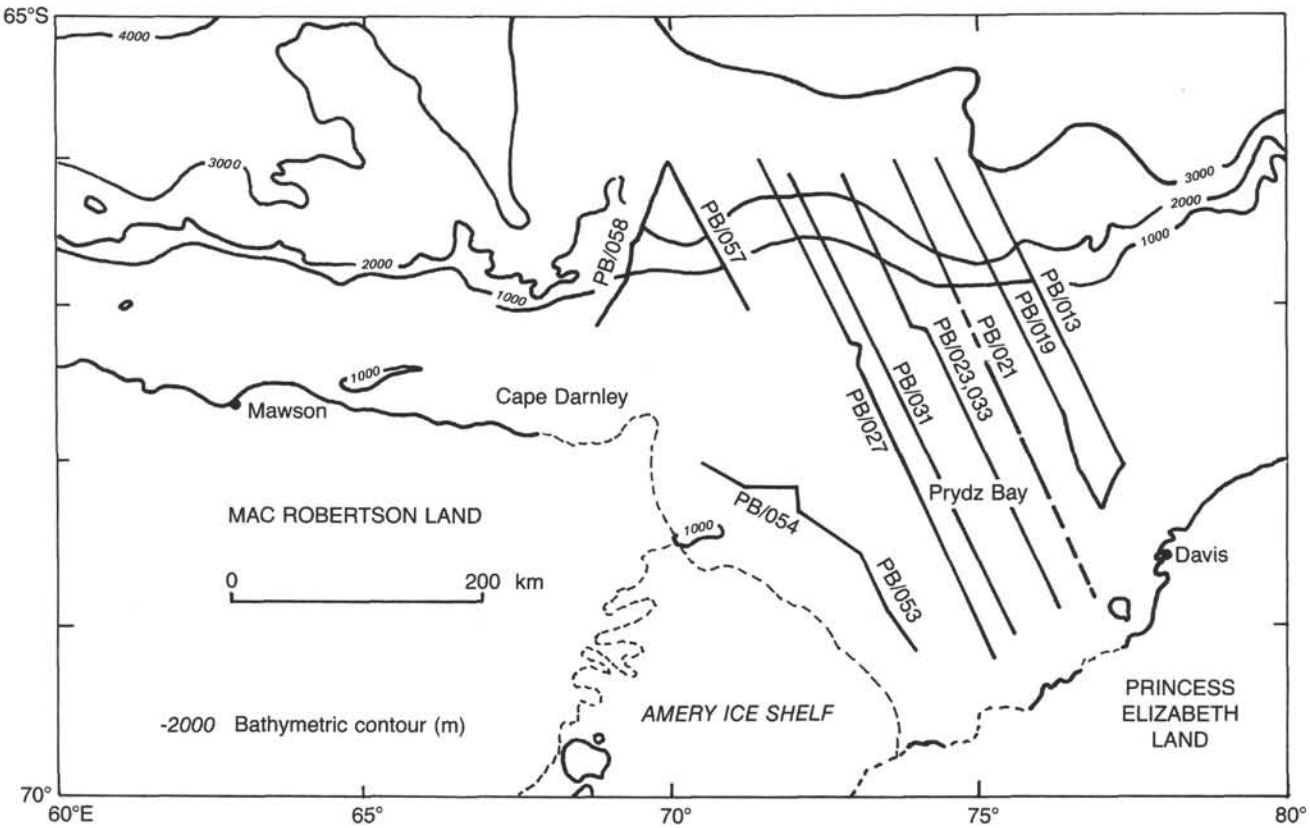

Figure 7. Seismic survey lines from cruise *Nella Dan* (1982) in Prydz Bay. Proposed sites are located on line PB-021.

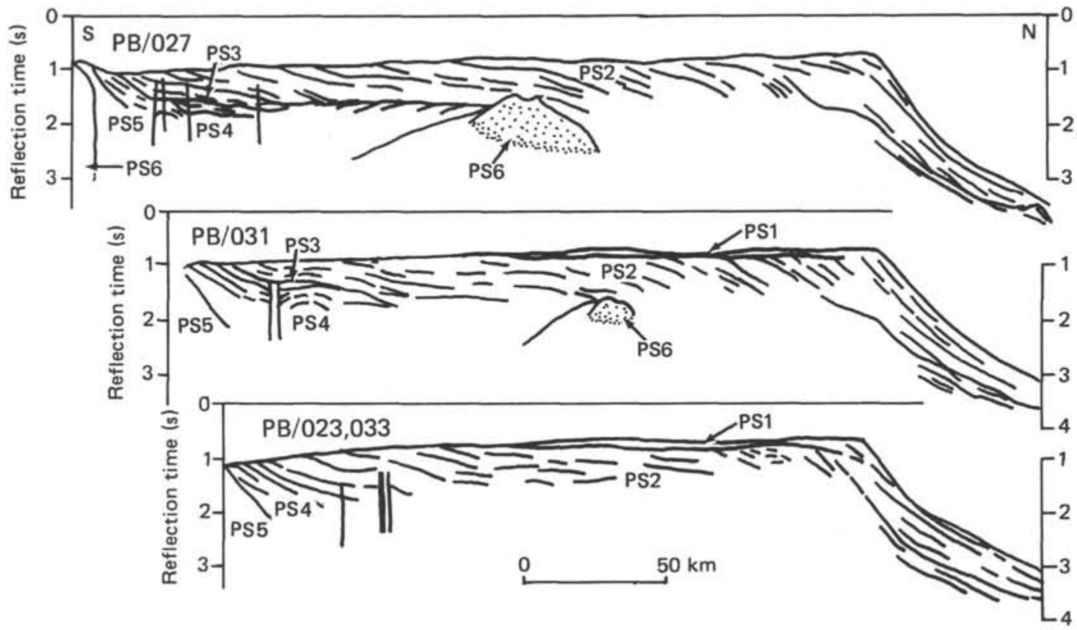

Figure 8. Line drawings of seismic sections along lines PB-023–033, PB-031, and PB-027 (from Stagg, 1985; see text for discussion).

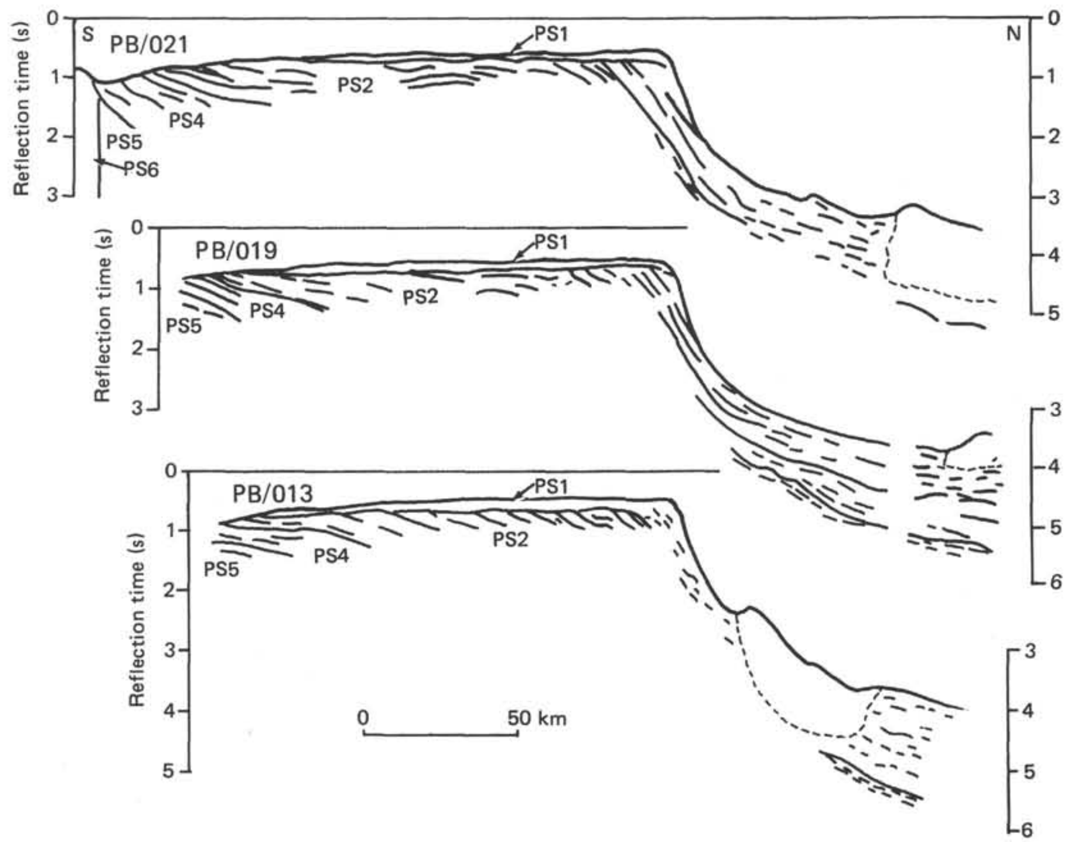

Figure 9. Line drawings of seismic sections along lines PB-013, PB-019, and PB-021 (from Stagg, 1985; see text for discussion).

characteristics of the Sirius Formation (Webb et al., 1984). The possibility of such an event has been challenged by Leg 113 results.

Drilling Objectives In Prydz Bay

The primary objective at Prydz Bay was to obtain the Mesozoic through Holocene climatic and glacial history of Antarctica as recorded in the sediments of the broad and deep continental shelf. In addition, Prydz Bay drilling provided the southern tie point for a latitudinal transect from Prydz Bay to the northern Kerguelen Plateau that will aid in understanding the role of changing climates in the meridional and vertical evolution of water masses and their associated biota in the Southern Ocean. Specific objectives in Prydz Bay include:

1. To establish the evolution from pre-glacial to glacial continental climate (East Antarctica), particularly through the Late Cretaceous and Paleogene.
2. To determine the development of the East Antarctic ice sheet through the Oligocene and early Neogene.
3. To investigate the history of glacial erosion of the shelf, which is itself an indication of ice-sheet volume changes and has implications for bottom-water formation.
4. To document other changes in the shelf environment (depth, temperature, sea-ice cover) before and during glaciation, providing secondary indications of climatic change.
5. To determine the timing of the East Antarctica-India separation in the Early Cretaceous and the Mesozoic record of Antarctic continental climate.

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