OCEAN DRILLING PROGRAM

LEG 177 SCIENTIFIC PROSPECTUS

SOUTHERN OCEAN PALEOCEANOGRAPHY

Dr. David Hodell
Co-Chief Scientist, Leg 177
Department of Geology
University of Florida
1112 Turlington Hall
Gainesville, FL 32611
U.S.A.

Dr. Rainer Gersonde
Co-Chief Scientist, Leg 177
Alfred Wegener Institut für
Polar und Meeresforschung
Postfach 120161
D-27515 Bremerhaven
Germany

Dr. Peter Blum
Staff Scientist, Leg 177
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.

Timothy J.G. Francis
Deputy Director
of Science Operations
ODP/TAMU

Peter Blum
Leg Project Manager
Science Services
ODP/TAMU

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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 177 will core sediments in the southeast Atlantic sector of the Southern Ocean to study the paleoceanographic history of the Antarctic region on short (millennial) to long (Cenozoic) time scales. Six primary sites are located along a latitudinal transect across the Antarctic Circumpolar Current (ACC) from 41° to 53°S, including two sites (TSO-6A/B, TSO-7C/B) within the circum-Antarctic siliceous belt. The sites are also arranged along a bathymetric transect ranging from 2100 to 4600-m water depths, intersecting all of the major deep- and bottom-water masses in the Southern Ocean.

The general goals of Leg 177 are two-fold: (1) to augment the biostratigraphic, biogeographic, and paleoceanographic history of the earlier Cenozoic, a period marked by the establishment of the Antarctic cryosphere and the ACC; and (2) to target expanded sections of late Neogene sediments, which can be used to resolve the timing of Southern Hemisphere climatic events on orbital and suborbital time scales and which can be compared with similar records from other ocean basins and with ice cores from Greenland and Antarctica. Drilling the proposed sites will provide the sedimentary sequences needed to address a number of first-order objectives and questions in southern high-latitude paleoclimatology and stratigraphy, including (1) the evolution of the ACC and past changes in the position of the Polar Front Zone and the Antarctic sea-ice field; (2) the evolutionary history and stability of the Antarctic cryosphere; (3) changes in Southern Ocean productivity, nutrient cycling, and pCO_2 and their role in global biogeochemical cycles and climate evolution; (4) changes in the mixing ratio of various deep- and bottom-water masses in the Antarctic (e.g., North Atlantic Deep Water); (5) the response of the Southern Ocean to orbital forcing and the phase relationships to climatic changes in low and northern high latitudes; (6) documentation of abrupt climate change on millennial time scales in the Southern Ocean and their correlation with ice and sediment core records from other areas; and (7) recovery of the first continuous sequences from the circum-Antarctic siliceous belt that will provide insight into early low-temperature chert diagenesis.

INTRODUCTION

Leg 177 will core sediments in the southeast Atlantic sector of the Southern Ocean to study the paleoceanographic history of the Antarctic region on tectonic (10^6 yrs, Cenozoic), orbital (10^4 to 10^5 yrs, Milankovitch), and suborbital (10^2 to 10^3 yrs, millennial) time scales. Six primary sites are located along a latitudinal transect across the Antarctic Circumpolar Current (ACC) from 41° to 53°S (Fig. 1), which should encompass the dynamic range of past frontal boundary movements within the ACC. Two of the sites (TSO-6A, TSO-7C) are located south of the Polar Front within the circum-Antarctic siliceous belt. Leg 177 sites are also arranged along a bathymetric transect ranging from 2100 to 4600-m water depths, intersecting all of the major deep (Circumpolar Deep Water [CPDW], North Atlantic Deep Water [NADW]) and bottom (Antarctic Bottom Water [AABW]) water masses in the Southern Ocean (Fig. 2). Two deep holes (TSO-2B, TSO-6A) are planned that will recover Cenozoic sequences. Several sites (SubSAT-1B, TSO-6A, and TSO-7C) exhibit average sedimentation rates exceeding 20 cm/k.y. during the late Neogene, offering an opportunity for paleoclimatic studies on millennial time scales.

Paleoceanographers, climatologists, and geochemists have recognized over the last decade that processes occurring in the Southern Ocean have played a major role in defining the Earth's climate system. The Southern Ocean is an extraordinarily important region because

1. The Antarctic cryosphere represents the largest accumulation of ice on the Earth's surface. The development and evolution of the Antarctic ice sheets and sea-ice field has had a profound influence on global sea-level history, the Earth's heat budget, atmospheric circulation, surface and deep-water circulation, and the evolution of Antarctic biota.

2. The Southern Ocean is one of the primary sites of intermediate-, deep-, and bottom-water formation. For example, almost two-thirds of the ocean floor is bathed by AABW that mainly originates in the Weddell Sea region. AABW depresses the temperature of at least 55-60% of the world's ocean volume to below 2°C (Gordon, 1988). In addition, the Southern Ocean represents the "junction box" of deep-water circulation where mixing occurs among water

masses from other ocean basins (Fig. 3). As such, the Southern Ocean is perhaps the only region where the relative mixing ratios of deep-water masses can be monitored (e.g., fluxes of NADW production). As one of the primary sites of deep- and intermediate-water mass formation, the geochemical and climatic fingerprint of Southern Ocean processes is transmitted throughout the world's deep oceans.

3. The Antarctic continent is thermally and biogeographically isolated from the subtropics by the Antarctic Circumpolar Current, a circum-global ring of cold water that contains complex frontal features and upwelling/downwelling cells. The zonal temperature, sea-ice distribution, and nutrient structure within the ACC control the biogenic sedimentary provinces that are characteristic of the Southern Ocean. Upwelling of deep, nutrient-rich water in the Southern Ocean results in significant primary productivity and constitutes nearly one-third of total marine productivity (Berger, 1989). As a result, about two-thirds of the silica supplied annually to the ocean is removed as hard parts of planktonic siliceous microorganisms in the Southern Ocean. This leads to high accumulation rates of biogenic opal and the formation of a circum-Antarctic biogenic silica belt, located between the Polar Frontal Zone (PFZ) and the northern seasonally sea-ice covered Antarctic Zone of the ACC (e.g., DeMaster, 1981; Lisitzin, 1985). Surface waters in the circum-Antarctic are also important globally because upwelling of deep water and sea-ice formation link the thermal and gas composition of the ocean's interior with the atmosphere through air-sea exchange. As a result, most paleogeochemical models of atmospheric CO_2 are highly sensitive to changes in nutrient utilization and/or alkalinity of Antarctic surface waters. Variations in the export of organic matter from the Southern Ocean and its associated drawdown of atmospheric CO_2 have been proposed as a forcing mechanism for past global climate change on both short (Kumar et al., 1995) and long (Pollock, 1997) time scales.

Although Antarctica and the adjacent Southern Ocean represent one of the most important components of the Earth’s climate system, significant gaps exist in our knowledge of its paleoceanographic and paleoclimatic history. The main hindrance for improving our knowledge of Southern Ocean paleoceanography has been the lack of continuous deep-sea sedimentary sequences from the region. To improve the present latitudinal and bathymetric coverage in the Southern Ocean, Leg 177 will drill six primary sites in the high latitudes of the southeast Atlantic Ocean (Fig. 1). Specific sites have been targeted that contain expanded Quaternary, Neogene, and Paleogene sequences not adequately recovered at these depths and latitudes by past drilling. On the basis of previous drilling in the region, Leg 177 is expected to recover predominantly calcareous sediments at the northern sites of the transect. At the southern sites, sediments are expected to be biosiliceous during the Quaternary and late Neogene, grading into biogenic calcareous sequences prior to the late Pliocene (Fig. 4). Because of the general paucity of high-quality sedimentary sequences available from the Southern Ocean, Leg 177 is expected to fill a critical gap in the distribution of drilled ocean sites.

BACKGROUND

Previous deep-sea drilling in the Southern Ocean, especially cores recovered with the hydraulic piston corer (HPC), advanced hydraulic piston corer (APC), and extended core barrel (XCB) systems (Deep Sea Drilling Project [DSDP] Leg 71, Ocean Drilling Program [ODP] Legs 113, 114, 119, and 120, Fig. 5), have provided a basic understanding of the paleoceanographic and paleoclimatic evolution of the southern high latitudes during the Cenozoic. The history of this region is closely related to paleogeographic changes (i.e., Gondwana breakup) that opened the Tasman Seaway and Drake Passages and permitted the establishment of the Antarctic Circumpolar Current (Kennett, 1977). Isotopic and microfossil evidence suggests that ice sheets were established and sea ice expanded during the earliest Oligocene (Kennett, 1982; Webb, 1990), but little agreement exists on the presence of ice sheets during the Eocene, particularly during the early-middle Eocene (Barron et al., 1991, Wise et al., 1992). Prior to the growth of large Northern Hemisphere ice sheets during the late Pliocene, the Southern Hemisphere cryosphere is implicated as a major driving force for global climate and sea level fluctuations. There are large differences of opinion, however, regarding the details of Antarctic cryospheric evolution, arising primarily from differences in the interpretation of continental, marine isotopic, and sea-level records (Fig. 6). For example, the cause of a rapid fall in sea level ~30 Ma is enigmatic because it was not accompanied by a significant increase in benthic oxygen isotopic values. Major differences also exist in the interpretation of the extent and volume of the Antarctic ice sheet during the early-late Pliocene (during the Gauss Chron). There are those who assume an essentially stable, combined East and West Antarctic ice sheet since the early Pliocene (Kennett and Barker, 1990; Clapperton and Sugden, 1990), and those who envision a highly dynamic Antarctic ice sheet during the early and early-late Pliocene (Webb and Harwood, 1991; Hambrey and Barrett, 1993). Strongly related to these controversies is the unresolved question of how to partition the temperature, salinity, and ice-volume signals embedded in the Cenozoic oxygen isotopic record (see discussion in Wise et al., 1992) and how these signals are related to sea-level changes inferred from sequence stratigraphic analysis (Fig. 6). The former problem might be addressed by the reconstruction of latitudinal oxygen isotopic gradients across the Southern Ocean (see Zachos et al., 1992) in conjunction with patterns of biogeographic distribution of microfossil assemblages, which reflect changes in water-mass properties. In addition, tandem measurements of oxygen isotopes in diatoms and foraminifers may deconvolve the temperature from the ice-volume signal in oxygen isotopic records, although this novel approach has only been attempted thus far in the latest Pleistocene (Shemesh et al., 1992). The main stumbling block for reconstructing latitudinal gradients in the Southern Ocean has been the lack of suitable core material. Drilling during ODP Legs 113, 119, and 120 was concentrated in the Antarctic Zone south of the Polar Front, and most of the ODP Leg 114 and previous DSDP sites that used modern drilling techniques are aligned around 50°S in the Atlantic sector of the Southern Ocean (Fig. 5). As a result, a true latitudinal transect of cores does not exist to study the response of surface water masses in the Southern Ocean to the glacial evolution on the Antarctic continent.

Another deficiency in the distribution of ocean-drilled cores is the lack of Quaternary, Neogene, and older sequences from the southern high latitudes that would permit the generation of high-resolution stratigraphic and paleoenvironmental signals. Compared to the superb records now available from the North Atlantic Ocean (ODP Legs 94, 154, 162, and 172), the Southern Ocean has relatively few sites that are suitable for high-resolution paleoclimatic studies. One of the fundamental tasks in paleoclimatology today is documenting and explaining phase relationships between climatic proxies from different oceanographic regions. Cores with high sedimentation rates are needed to study the timing and response of the southern high latitudes to orbital forcing and the phase relationships to climatic changes in the high-latitude Northern Hemisphere (Imbrie et al., 1989, 1992). Targeting ultra-high-resolution sequences is also important to study rapid climate change on suborbital (millennial) time scales and to understand the nature of abrupt triggering and feedback processes in the ocean/sea-ice/atmosphere system.

Previous ODP drilling in the Southern Ocean has resulted in only a few sites that recovered Pleistocene and Neogene sections with high-sedimentation rates (Site 704, Meteor Rise; Site 594, Chatham Rise; Site 695, east of South Orkney; Site 514, Subantarctic southwest Atlantic). Sediment drifts and the region of the circum-Antarctic biogenic silica belt in the South Atlantic are ideal targets for the recovery of sediments deposited at high and ultra-high sedimentation rates. On Leg 177, we expect to recover expanded late Neogene sections with good biocalcareous and biosiliceous preservation at several sites (SubSAT-1B, TSO-6A, and TSO-7C) between 41° and 53°S. Piston cores at these sites indicate sedimentation rates in excess of 20 cm/k.y. In addition, the high flux of organic materials to the seafloor in the circum-Antarctic biogenic silica belt may lead to the formation of laminated biosiliceous sediments, which develop when oxygen is depleted periodically in sediment pore waters. Biosiliceous sediments deposited above the carbonate compensation depth (CCD) in the biogenic silica belt also generally contain sufficient calcareous microfossils (foraminifers) for stable isotopic analysis. Together with quantitative reconstructions of paleoenvironmental conditions using statistical methods developed recently for diatoms (Pichon et al., 1987; Zielinski, 1993; Zielinski and Gersonde, 1997) and radiolarians (Brathauer, 1996; A. Abelmann, pers. comm., 1997), these records can be used to reconstruct surface water hydrography, nutrients, and productivity. In addition, sea-ice distribution can be deciphered using diatom taxa that are indicative of sea ice (Gersonde et al., 1996; Zielinski and Gersonde, 1997).

SCIENTIFIC OBJECTIVES

The broad scientific themes of Leg 177 are two-fold:

1. To augment the biostratigraphic, biogeographic, paleoceanographic, and paleoclimatic history of the Southern Ocean during the Cenozoic, including the evolution and stability of the Antarctic cryosphere; and
2. To construct high- and ultra-high-resolution records during the Quaternary and late Neogene to better understand the role of the Southern Ocean in climate change on orbital and suborbital time scales.

Specific paleoceanographic and biogeochemical problems to be addressed within the context of these broad themes include

- *Evolutionary history and stability of the Antarctic cryosphere.* The Leg 177 transect will permit reconstruction of latitudinal isotopic gradients and analysis of biogeographic distribution and abundance patterns of microfossil assemblages that should lead to improved understanding of the growth and stability of the Antarctic ice sheets and help address existing discrepancies between land-based, marine isotopic, and sea-level records (Fig. 6).

- *Thermal isolation of Southern Ocean surface waters by development of the ACC and its associated frontal systems.* Thermal isolation of the Antarctic continent was intimately linked to tectonic and paleoceanographic changes that led to the establishment of a zonal circulation system, the ACC. Knowledge of the timing and strength of thermal isolation is important for understanding polar heat transport and its effect on the development and stability of the Antarctic ice sheets. The establishment and expansion of the ACC has also influenced intermediate-, deep-, and bottom-water formation in the Southern Ocean. Accurate reconstruction of frontal boundaries requires a latitudinal transect of sites that encompass the dynamic range of the frontal movements. Leg 177 sites will permit us to reconstruct the changes in the paleolatitudinal position of frontal boundaries, similar to studies carried out on piston cores from the late Quaternary (Prell et al., 1979; Morley, 1989; Howard and Prell, 1992).

- *History and distribution of sea ice and its seasonal variation to better understand its role in the global climate system.* Sea ice is a fast changing environmental parameter, which is presently characterized by strong seasonal variations. Changes in sea-ice distribution have been among the most important controls on the Southern Hemisphere climate during the late Pleistocene and affect gas and heat exchange between ocean and atmosphere, ocean circulation and the formation of water masses by the rejection of salt, atmospheric circulation and wind speeds, surface albedo, and the biological production and distribution of organisms.

- *History of primary productivity in the Southern Ocean and evolution of the Antarctic biogenic silica belt.* Since about 36 Ma, the Southern Ocean has acted as a major sink for biogenic opal, reflecting increased surface-water productivity as a result of polar cooling and upwelling in the circum-Antarctic (Baldauf et al., 1992). Changes in Southern Ocean productivity and the expansion of the biogenic silica belt have significantly influenced the distribution of nutrients in the World Ocean and have probably played a role in atmospheric pCO_2 variation (Keir, 1988). Differences of opinion exist, however, regarding the role that changing primary productivity in the Southern Ocean has had on atmospheric CO_2 and global climate (Kumar et al., 1995, Frank et al., 1996, Pollock, 1997).

- *Early low-temperature chert diagenesis in sediment from the Antarctic biogenic silica belt.* Leg 177 will provide the first continuous Neogene records from the Antarctic biogenic silica belt, which is comprised of nearly pure diatom ooze that accumulates at high sedimentation rates. Very early transformation of silica from opal-A to opal-CT (strongly cemented porcellanites) has been observed at shallow burial depth in a low-temperature environment in cores recovered near TSO-6A and TSO-7C (Bohrmann et al., 1990, 1994). At these sites, it will be possible to study the nature and rates of silica diagenetic reactions in a sediment type that is ubiquitous in the geological record (e.g., Eocene cherts), but rare in the contemporaneous ocean.

- *Southern high-latitude calcareous and siliceous biozonations.* ODP Legs 113, 114, 119, and

120 provided an enormous improvement in southern high-latitude stratigraphy, but further refinement of these biozonations is desirable. Leg 177 will provide the opportunity to improve dating of Neogene biostratigraphic markers by correlation with orbital-tuned paleoenvironmental signals. In addition, Leg 177 sequences will permit study of evolutionary processes (patterns, modes, and timing of speciation and diversification), the development of Southern Hemisphere bioprovinces (e.g., endemism), and the response of the biota to long- and short-term environmental changes.

- *Changes in the production and the mixing ratios of various deep -and bottom-water masses, and their role in affecting the global climate system.* The Southern Ocean is unique in that its deep water (mainly Circumpolar Deep Water) is a mixture of deep-water masses from all ocean basins. As such, monitoring changes in the chemistry of Southern Ocean deep water provides an opportunity to reconstruct changes in the mean composition of the deep ocean. The Southern Ocean is perhaps the only region where fluctuations in the production rate of NADW can be monitored unambiguously (Oppo and Fairbanks, 1987; Charles and Fairbanks, 1992). The South Atlantic sector of the Southern Ocean represents the initial point of entry of NADW into the Circumpolar Current and, therefore, is highly sensitive to changes in the strength of the NADW conveyor. The Leg 177 depth transect will be ideal for reconstructing the long-term evolution of the dominant subsurface water masses in the Southern Ocean (Fig. 2).

- *Timing and response of Southern Ocean surface and deep waters to orbital forcing, including the phase relationships to climatic changes in the Northern Hemisphere.* Relatively little is known about the interhemispheric phase response (lead, lag, or in-phase) between the high-latitude Northern and Southern Hemispheres. Based upon limited data from the Southern Ocean, Imbrie et al. (1989, 1992) suggested an early response of surface and deep waters in the Southern Ocean relative to other regional proxy data. This early response has also been observed by other studies (Charles et al., 1996; Bender et al., 1994; Sowers and Bender, 1995), implying that the Antarctic region plays a key role in the driving mechanism of glacial-to-interglacial climate change during the last climatic cycle. It is not known, however, if this early response of the Southern Ocean was characteristic of the entire 100-k.y. world of the late Pleistocene or whether this phase relationship also extended to the 41-k.y. world of the early Pleistocene and Pliocene. Leg 177 sediments (e.g., from TSO-3C and TSO-5C) will provide the material needed to study the response of the Southern Ocean to orbital forcing and the phase relationships to climatic changes in other regions.

- *Rapid (suborbital) climate change in the Southern Ocean by correlation and comparison of millennial signals from the Southern Hemisphere with polar ice cores and marine records.* Leg 177 will recover cores with highly expanded sections at three sites (SubSAT-1B, TSO-6A, TSO-7C), which will permit the study of climatic variations in the Southern Ocean at suborbital (millennial) time scales. These targets will serve as the Southern Hemisphere analogs to the North Atlantic drift deposits recovered by ODP Legs 162 and 172. These cores will allow us to determine whether abrupt climate changes similar to those documented in Greenland ice cores (Dansgaard et al., 1993) and marine records from the high-latitude North Atlantic (Bond et al., 1993; Bond and Lotti, 1995) have occurred in the southern high latitudes. If high-frequency oscillations can be identified in the Southern Ocean, as recently claimed by A. Hoffmann (per. comm., 1997), then were they synchronous with changes in North Atlantic climate? Expanded sections will also permit study of the structure of glacial and interglacial cycles in the Southern Ocean, including the trajectories of deglacial meltwater from the Antarctic continent (Labeyrie et al., 1986). For example, did pulse-like surges occur in the Antarctic Ice Sheet during the late Pleistocene, similar to Heinrich events in the North Atlantic? What was the nature and structure of terminations in the Southern Hemisphere during the late Pleistocene? Lastly, correlation between Antarctic sediment cores and ice cores from Greenland and Antarctica, which now span the last 400 k.y. at Vostok (Antarctica) (Petit et al., 1997), will reveal the phase relationships between various variables in the atmosphere and ocean systems, and may contribute to identifying the mechanisms responsible for rapid climate change.

- *Geomagnetic paleointensity.* U-channel sampling of cores collected on Leg 177 will be used to construct continuous records of variations in the intensity of Earth's magnetic field. Comparison of these signals from the high-latitude Southern Hemisphere with similar results obtained from the North Atlantic will test whether these observed variations are reflecting changes in the intensity of the Earth's dipole field. If so, then these dipolar paleointensity changes will provide a powerful stratigraphic tool that can be used to correlate cores globally.

- *Tectonic history of Agulhas Ridge.* Drilling a depth transect on the Agulhas Ridge may shed light on the tectonic evolution of this fracture zone ridge. The ridge also has paleoceanographic implications because of its role as an impediment to deep-water flow in the South Atlantic, as well as its topographic influence on the location of oceanic frontal systems.

DRILLING STRATEGY

The drill plan includes six primary sites that span water depths from 2100 to 4600 m (Tables 1, 2). Targets will be drilled from north to south (TSO-2B, SubSAT-1B, TSO-3C, TSO-5C, TSO-6A, and TSO-7C). Alternate sites were selected for TSO-6A and TSO-7C in the event an iceberg is sitting atop the primary target. Because of time constrains, three alternate sites (TSO-4B, SubSAT-3B, and SubSAT-4B/C) cannot be included in the proposed one-leg effort of 56 days; however, these alternate sites will serve as backups to the primary targets. If time is saved as a result of early departure from port or conservative drilling time estimates, additional time will be used to enhance the scientific objectives with the following priorities: (1) insure continuous sections at high-resolution triple-cored intervals (i.e., recover a fourth hole if needed to complete a composite section), (2) maintain the latitudinal transect composed of four high-resolution sites, (3) deepen site TSO-7C, and (4) deepen other sites to approved target depth or drill alternate sites.

Successful recovery at the primary sites will provide the following:

- Two deep holes (700 m) at Sites TSO-2B and TSO-6A that will complete a Cenozoic latitudinal transect between 35° and 72°S when combined with ODP Site 704 (Meteor Rise, as well as other Leg 114 sites), Sites 689 and 690 (Leg 113, Maud Rise), and DSDP Site 360 (South African Continental Rise, Leg 40).

- A depth transect on the Agulhas Ridge around 43°S that includes Sites TSO-2B (2104 m), TSO-3C (3718 m), SubSAT-1B (4620 m) and one site on the Meteor Rise around 47°S when Site TSO-5C (4418 m) is combined with Site 704 (2532 m).

- Complete composite sections of the late Neogene with moderate sedimentation rates by triple APC/XCB penetration to 200 m at Sites TSO-3C (3 cm/k.y.) and TSO-5C (8 cm/k.y.).

- One ultra-high-resolution transect between 41° and 53°S (SubSAT-1B, TSO-6A, and TSO-7C) recovered by triple APC/XCB.

Criteria for discontinuing operation at a particular site will include poor recovery, inability to construct a composite section at high-resolution sites, massive sediment disturbance (i.e., mass flows, turbidites, etc.), extremely slow penetration rate, drilling into sediment ages that are beyond the scope of the scientific objectives, and persistent heavy weather that prevents drilling or leads to unproductive operations.

PROPOSED PRIMARY SITES

Site TSO-2B

Proposed Site TSO-2B is located on the northern Agulhas Ridge in a water depth of 2104 m near the boundary between the upper CPDW and the NADW (Figs. 1, 5). The Agulhas Ridge in this region is a narrow feature that trends approximately northeast/southwest, and is covered by a thick (>1000 m) package of sediments. Quaternary and Neogene sediments in the region consist of biogenic calcareous oozes that have sedimentation rates of 1-3 cm/k.y. and are not disturbed by turbidites. We plan to drill an 700-m-thick Cenozoic calcareous sequence at Site TSO-2B to gain information from an upper mid-water depth (2104 m) site that is presently located near the northern boundary of the ACC. Because of the low sedimentation rates at Site TSO-2B, it is doubtful that a complete Pliocene-Pleistocene sequence can be recovered. Consequently, only a single APC hole is planned at this site. This is not a major compromise, however, because surface water signals at this latitude will be captured at Site SubSAT-1B.

The primary objective at Site TSO-2B is to recover a Cenozoic carbonate record that can be used to reconstruct long-term changes in

- surface-water parameters and the evolution of the Subtropical Front (STF) and its response to southern-high latitude climate variability;
- paleoproductivity north of the PFZ;
- the mixing ratio between lower upper CPDW and upper NADW properties and the evolution of these water masses during the Cenozoic; and
- the paleodepth history of the Agulhas Ridge.

Site SubSAT-1B

Proposed Site SubSAT-1B is located on the northern flank of the Agulhas Ridge (Fig. 1) where a thick package of sediment overlies topographically irregular basement consisting of normal oceanic crust. This site was targeted because of the remarkably high-resolution isotopic record of the last climatic cycle obtained from nearby Core RC11-83 (Fig. 7, Charles et al., 1996), which has sedimentation rates of about 20 cm/k.y. Although the site is deep (4622 m), the high rain rate and quick burial of sediment promote the preservation of calcium carbonate, which averages 35% in Core RC11-83. Site SubSAT-1B will be cored by triple APC/XCB to a depth of 300 m to recover a complete Pleistocene section at sedimentation rates of >20 cm/k.y. The primary objective is to recover an expanded Pleistocene section north of the present-day PFZ that can be used to study

- the response of the Southern Ocean to orbital forcing and the phase relationships to climatic events occurring in low and northern high latitudes;
- rapid climate change on suborbital time scales in the Southern Ocean and its relation to climate signals from ice cores recovered from Greenland, Antarctica, and tropical glaciers;
- glacial-to-interglacial variations in the physical and chemical properties of bottom-water masses in the South Atlantic Ocean and their relation to high-latitude climate change; and

- glacial-to-interglacial variations in Southern Ocean productivity, nutrient cycling, and pCO_2 and their role in global biogeochemical cycles.

Site TSO-3C

Proposed Site TSO-3C is located in the central part of the Subantarctic Zone on the southern flank of the Agulhas Ridge (Fig. 1). The topography of the ridge is more intricate here compared with its northern component. The water depth at Site TSO-3C is ~3700 m, which is close to the boundary between NADW and underlying lower CPDW (Fig. 2). Site TSO-3C will recover carbonate sediments at sedimentation rates averaging 3 cm/k.y. from the Subantarctic Zone of the ACC. Oxygen isotope stratigraphy of a 13-m piston core (TN057-6) taken at the location of TSO 3C revealed a complete record back to marine isotope Stage 12 (Fig. 8, Hodell et al., in prep.). Together with Sites TSO-2B (2104 m) on the Agulhas Ridge and SubSAT-1C (4620 m) north of the ridge, the sites form a depth transect that intersects most of the major water masses of the South Atlantic Ocean (Fig. 2). Site TSO-3C will be cored by APC to a depth of 200 m, which should penetrate to the late Miocene (~7 Ma), assuming a constant sedimentation rate. Specific objectives at Site TSO-3C include the recovery of a continuous Pliocene-Pleistocene composite section at moderate sedimentation rates to study

- past migrations in the position of the PFZ;
- changes in the mixing ratios of lower NADW and CPDW in the Southern Ocean and its relation to high-latitude climate change;
- response of the Southern Ocean to orbital forcing and the phase relationships (leads and lags) to climatic changes in the low and high northern latitudes; and
- stability of the Antarctic cryosphere during "warmer-than-present" climate during the Pliocene prior to the initiation of Northern Hemisphere glaciation.

Site TSO-5C

Proposed Site TSO-5C is located on the western flank of the Meteor Rise in the Polar Frontal Zone of the ACC (Fig. 1). It is located at about the same latitude as ODP Site 704, drilled on the Meteor Rise, but is significantly deeper (4418 m) than Site 704 (2532 m). Late Pleistocene sediments at

Site TSO-5C consist of alternating diatom ooze with calcareous intercalations and an average sedimentation rate of 8 cm/k.y. It will be cored by triple APC to a depth of 200 m to obtain a continuous late Pliocene-Pleistocene record within the PFZ. Comparison of the deeper water record of Site TSO-5C with shallower results from ODP Site 704 on the Meteor Rise will be useful to study the history of lower CPDW/AABW and mid- to upper NADW, respectively (Fig. 2). Specific objectives at Site TSO-5B include the reconstruction of

- surface-water parameters and the evolution of the PFZ;
- paleoproductivity changes in the present PFZ region; and
- lower CPDW and AABW properties and their response to high-latitude climate and the changes in flux of NADW during glacial and interglacial cycles.

Site TSO-6A

Proposed Site TSO-6A is located to the north of Shona Ridge (water depth 3680 m) close to the present-day Polar Front (Fig. 1). This area also represents the southernmost extension of the southward spreading tongue of the NADW, which mixes with cold Antarctic waters to form the CPDW (Fig. 2). This site is located in the northern part of the biogenic silica belt, which is characterized by high biosiliceous accumulation rates. Cores recovered at and near the location of Site TSO-6A are marked by high biosiliceous accumulation with sedimentation rates as high as 80 cm/k.y. during the Holocene. These rates decrease greatly, however, during glacial periods. Today, Site TSO-6A is located about 5° north of the average winter sea-ice edge, but diatoms from glacial-aged sediments indicate that Site TSO-6A was covered by sea ice during late Quaternary glaciations (Gersonde, unpublished). Sediments consist of late Quaternary diatom ooze and diatomaceous mud, but foraminifers are present throughout the core for the establishment of stable isotopic stratigraphies. Site TSO-6A will be triple APC cored to 200 m, followed by single XCB coring to approximately 400 m, and RCB coring to a depth of 700 m to recover late Cenozoic biosiliceous and calcareous high-resolution sediments in mid-water depths on the Shona Ridge. Specific objectives include the study of

- surface-water parameters and the evolution of the Polar Front;
- sea-ice distribution in the Southern Ocean;
- paleoproductivity changes (e.g., silica, carbon export rates) and the history of the circum-Antarctic biogenic silica belt in relation to surface-water mass changes, deep-water circulation, and sea-ice distribution;
- deep-water circulation, including changes in the physical and chemical properties of CPDW; and
- silica diagenesis (see also Site TSO-7C).

Site TSO-7C

Proposed Site TSO-7C is located in a small sedimentary basin north of Bouvet Island at a water depth of 2850 m. The site is located in the center of the ice-free Antarctic Zone and is bounded to the north by the Polar Front and to the south by the Weddell Gyre/ACC Boundary (Fig. 1). During glacial times, however, the site was covered by winter sea ice as indicated by the occurrence of sea-ice diagnostic diatoms. TSO-7C is one of two sites located in the biogenic silica belt south of the present-day Polar Front. Sedimentation rates in the late Quaternary range between 15 and 60 cm/k.y. An interesting feature of Site TSO-7C is the occurrence of a very early porcellanite in Marine Isotopic Stage 11 (Bohrmann et al., 1994). The occurrence of early porcellanites at TSO-7C will permit geochemical studies of low-temperature silica diagenesis in sediments and pore waters. The porcellanite beds in the sediment cores are only a few centimeters thick and thus should not impede APC penetration. Site TSO-7C will be cored by triple APC to a depth of 200 m to obtain an ultra-high-resolution record of biosiliceous sediments south of the present-day position of the Polar Front. Any time remaining at the end of Leg 177 will be used to deepen TSO-7C to a maximum depth of 730 m. The paleoclimatic record from this site will be used to study rapid climate change on suborbital time scales in Antarctic surface waters and will be correlated to similar ultra-high-resolution records from other marine cores, as well as to Antarctic and Greenland ice core records. Specific objectives include the reconstruction of

- surface-water parameters south of the present PFZ;
- sea-ice distribution in the Southern Ocean;
- paleoproductivity changes (e.g., silica, carbon export rates) in relation to surface-water mass

changes and sea-ice distribution;
- deep-water circulation, including changes in the physical and chemical properties of CPDW; and
- early low-temperature silica diagenesis.

PROPOSED ALTERNATE SITES

Site TSO-4B

Proposed Site TSO-4B is located in the deep northern Agulhas Basin (water depth 4630 m), and is situated in the central part of the Subantarctic Zone of the ACC (Fig. 1). The site is close to magnetic anomaly 32 according to Raymond and LaBrecque (1988), which indicates an early Maastrichtian basement age (~73 Ma, Cande and Kent, 1992). Site TSO-4B is positioned near an extinct spreading center in the Agulhas Basin that was abandoned ~65 Ma when the spreading axis jumped 825 km to the west. Late Quaternary sediments at Site TSO-4B consist of diatom ooze with calcareous intercalations. Site TSO-4B has been approved for single APC coring to 200 m, followed by XCB coring to 400 m, and RCB coring to 500 m. In addition to the reconstruction of surface-water parameters and paleoproductivity, Site TSO-4B will be used to study the history of deep- and bottom-water masses related to the establishment of the Southern Hemisphere cryosphere and its variability through time. The site will also permit a comparison and calibration of stratigraphic and paleoceanographic records based on both calcareous and siliceous microfossils in the present Subantarctic Zone. If basement is reached during drilling, the age will be useful for understanding plate reconstruction in the central South Atlantic.

Site SubSAT-3B

Proposed Site SubSAT-3B is located on the northern Meteor Rise in 2008 m water depth, approximately 34 nmi to the northwest of Site 704. During ODP Leg 114, a 500-m-thick Neogene sequence was recovered from Site 704, but significant core disturbance (e.g., missing and double-cored sections) is evident in Holes 704A and B during some intervals, and the core breaks occur at almost the same depth in the two holes, making it impossible to retrieve missing or disturbed sections in the companion hole. Site SubSAT-3B is expected to provide an identical record to Site

704 in terms of age, sedimentation rate, and lithology, but will be far superior in terms of coring disturbance, gaps, and turbidites. Sediments at Site SubSAT-3B should be composed of alternating calcareous and siliceous ooze during the Pleistocene, grading into dominantly calcareous ooze with a significant biosiliceous component during the Pliocene. Average sedimentation rates are expected to be 3 cm per tens of years during the Brunhes Chron, increasing to an average of 7 cm per tens of years during the Matuyama Chron, and decreasing again to 2 cm per tens of years during the Gauss and Gilbert Chrons. Site SubSAT-3B is approved to be cored by triple APC in the upper 200 m. Because 672 m of sediment was drilled in Hole 704B to the early Oligocene, recovery beyond the depth of APC penetration (>200 m) at Site SubSAT-3B is not warranted. Site SubSAT-3B should penetrate to the early Pliocene (~4.0 Ma) according to the section recovered at Site 704. Specific objectives at Site SubSAT-3B include the recovery of a continuous composite section of the Pliocene-Pleistocene ~2.5°N of the present-day position of the PFZ in 2008 m of water.

Site SubSAT-4B

Site SubSAT-4B is located to the south of the Davis Seamounts in a region where high sedimentation rates occur, and is south of the present-day position of the Polar Front of the ACC in a water depth of 3661 m (Fig. 1). This site is located at 52°S between Sites TSO-6A and TSO-7C and serves as a good backup to either of these sites in the event that weather or icebergs prevent us from occupying either of them. Site SubSAT-4B is approved to be drilled using triple APC to 200 m, XCB to 400 m, and RCB to 800 m to recover late Cenozoic biosiliceous and calcareous sediments at high resolution south of the present-day position of the PFZ. The objectives are essentially the same as those outlined for Sites TSO-6A and TSO-7C.

SubSAT-4C

Site SubSAT-4C has been selected as an alternate to Site SubSAT-4B in the unlikely event that an iceberg prevents occupation of the primary site. The objectives and drilling strategy at SubSAT-4C are identical to those described for SubSAT-4B.

Site TSO-6B

Site TSO-6B is an alternate to Site TSO-6A in the unlikely event that an iceberg prevents occupation of the primary site. The objectives and drilling strategy at TSO-6B are identical to those described for TSO-6A.

Site TSO-7B

Site TSO-7B is an alternate to Site TSO-7C in the unlikely event that an iceberg prevents occupation of the primary site. The objectives and drilling strategy at TSO-7B are identical to those described for TSO-7C.

SAMPLING STRATEGY

During Leg 177, the upper sections (approximately 200 m) at each site will be recovered by APC in three holes (except for Site TSO-2B). The archive halves (permanent and temporary) in all holes will not be sampled aboard ship, and the permanent archive will be designated post-cruise. Sampling for high-resolution isotopic, sedimentologic, and micropaleontologic studies will be conducted after construction of the spliced composite section. Most of the high-resolution sampling will be deferred until after the cruise; however, the upper few cores in each hole that contain high-porosity sediments that may be disturbed during transport to the Bremen repository will be sampled on board ship. High-resolution sampling is anticipated for most of the upper APC and XCB cores (5-cm intervals), with 10 to 20 cm^3 needed for each sample, depending on the abundance of microfossils (especially benthic foraminifers). Whenever possible, whole-round samples for pore-water geochemical analyses will be taken from intervals in holes that are not critical for constructing the composite section. U-channel sampling for paleomagnetic and rock magnetic studies will be conducted in the archive half along the composite sampling splice where appropriate. There is a possibility that diatom mats will be encountered in some sites south of the Polar Front. These mats will be sampled by taking a continuous slab of sediment from the working half. The sampling plan for Leg 177 must be approved by the sampling allocation committee (SAC), consisting of the Co-chiefs, Staff Scientist, and Curatorial representative. The initial sampling plan is preliminary and can be modified depending upon actual material recovered and collaborations that may evolve between scientists during the leg.

LOGGING PLAN

This leg offers an opportunity to reconstruct continuous records of Southern Ocean paleoclimate variability using core and log data. Sediments encountered at these sites will consist of periodically alternating layers of biosiliceous and carbonate sediments, with variable amounts of fine (clays) and coarse (ice-rafted debris) terrigenous clastics. Because of the strong density and porosity variations associated with this lithologic variability, core and log physical property indices will very likely be extremely valuable proxy measurements for reconstructing sediment composition time series. Some sites have very high sedimentation rates, so there is great potential for generating very high-resolution records of regional paleoclimatic and paleoceanographic variability. Previous ODP logging in the region (e.g., Site 704) indicate that strong physical property variability related to the paleoclimatic opal-carbonate-terrigenous bedding cycles will be observed.

Downhole logging is scheduled for all holes deeper than 400 m, which currently includes Sites TSO-2B and TSO-6A. At these sites, the Triple Combo, Formation MicroScanner (FMS), and Geological High-resolution Magnetometer (GHMT) will be deployed to develop continuous high-resolution paleoclimate records and augment the results of coring. The Triple Combo tool string provides measurements of spectral gamma ray, porosity, density, and electrical resistivity. The FMS tool string produces high-resolution electrical resistivity images of the borehole wall that can be used to study the structure of bedding, diagenetic features, hiatuses, and cyclicity recorded by sediments. A sonic tool will be run with the FMS to provide acoustic data useful in establishing synthetic seismograms and seismic line calibration. The GHMT provides both continuous in situ magnetic susceptibility and the vertical component of the total magnetic field data. If the remnant magnetization of the sediments is sufficiently stong, the total field measurement of the GHMT can provide magnetic reversal stratigraphy.

REFERENCES

Baldauf J.G., Barron, J.A., Ehrmann, W.U., Hempel, P., and Murray, D., 1992. Biosiliceous sedimentation patterns for the Indian ocean during the last 45 million years. *Geophys Monogr.*, 70:335-349.

Barrett, P.J., 1994. Progress towards a Cenozoic Antarctic glacial history. *Terra Antarctica*, 1:247-248.

Barron, J., Larsen, B., and Baldauf, J.G., 1991. Evidence for late Eocene to early Oligocene Antarctic glaciation and observations on late Neogene glacial history of Antarctica: Results from Leg 119. *In* Barron, J., Larsen, B., et al., *Proc. ODP Sci. Results*, 119: College Station, TX (Ocean Drilling Program), 869-891.

Bender, M., Sowers, T., Dickson, M., Orchardo, J., Grootes, P., Mayewski P., and Messe, D., 1994. Climate teleconnections between Greenland and Antarctica throughout the last 100,000 years. *Nature*, 372:663-666.

Berger, W.H., 1989. Global maps of ocean productivity. *In* Berger, W.H., Smetacek, V.S. and Wefer, G. (Eds.), *Productivity in the ocean: Present and Past*. Dahlem Workshop Reports LS44, Wiley & Sons, pp. 429-456.

Bohrmann, G., Abelmann, A., Gersonde, R., Hubberten, H., and Kuhn, G., 1994. Pure siliceous ooze, a diagenetic environment for early chert formation. *Geology*, 22:207-210.

Bohrmann, G., Kuhn, G., Abelmann, A., Gersonde, R., and Fütterer, D., 1990. A young porcellanite occurrence from the Southwest Indian Ridge. *Marine Geology*, 92:155-163

Bond, G.C. and Lotti, R., 1995. Detailed record of iceberg discharges into the northern Atlantic. *Science*, 267:1005-1010.

Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., and Bonani, G., 1993. Correlation between the climatic record in northern Atlantic marine sediment and in Greenland ice. *Nature*, 365:143-147.

Brathauer, U., 1996. Radiolarians as indicators for Quaternary climatic changes in the Southern Ocean (Atlantic sector). *Rept. on Polar Research*, 216, 163 p.

Cande, SC. and Kent, D.V., 1992. A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.*, 97:13,917-13,951.

Charles, C.D., Lynch-Stieglitz, J., Ninnemann, U.S., and Fairbanks, R.G., 1996. Climate connections between the hemispheres revealed by deep sea sediment core/ice core correlations. *Earth Planet. Sci. Letts.*, 142:19-27.

Charles, C.D., and Fairbanks, R.G., 1992. Evidence from Southern Ocean sediments for the effect of North Atlantic deep-water flux on climate. *Nature*, 355:416-419.

Clapperton, C.M., and Sugden, D.E., 1990. Late Cenozoic glacial history of the Ross Embayment, Antarctica. *Quat. Sci. Reviews*, 9:253-272.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjörnsdottir, A.E., Jouzel, J., and Bond, G., 1993. Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature*, 364:218-220.

DeMaster, D.J., 1981. The supply and accumulation of silica in the marine environment. *Geochim., Cosmochim. Acta*, 45:1715-1735.

Frank, M., Gersonde, R., Rutgers van der Loeff, M., Kuhn, G., and Mangini, A., 1996. Late Quaternary sediment dating and quantification of lateral sediment redistribution applying $^{230}Th_{ex}$: A study from the eastern Atlantic sector of the Southern Ocean. *Geol. Rundschau*, 85:554-566.

Gersonde, R., Abelmann, A., Brathauer, U., Sieger, R., and Zielinski, U., 1996. Das Südpolarmeer - ein Schlüsselgebiet für Klimaänderungen in vergangener Zeit. *Geowissenschaften*, 14:17-21.

Gordon, A.L., 1988. The Southern Ocean and global climate. *Oceanus*, 31:39-46.

Hambrey, M.J., and Barrett, P.J., 1993. Cenozoic sedimentary and climatic record, Ross Sea Region, Antarctica. *In* Kennett, J.P., and Warnke, D.A., (Eds.), *The Antarctic Paleoenvironment: A Perspective on Global Change, 2.* Antarct. Res. Ser., 60:91-124.

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

Imbrie, J., McIntyre, A., and Mix., A., 1989. Oceanic response to orbital forcing in the late Quaternary: observational and experimental strategies. *In* Berger, A., Schneider, S., and Duplessy, J.C. (Eds.), *Climate and Geo-Sciences*: Dordrecht (Kluwer Academic), 121-164.

Imbrie, J., Boyle, E.A., Clemens, S.C., Duffy, A., Howard, W.R., Kukla, G., Kutzbach, J., Martinson, D.G., McIntyre, A., Mix, A.C., Molfino, B., Morley, J.J., Peterson, L.C., Pisias, N.G., Prell, W.L., Raymo, M.E., Shackleton, N.J., and Toggweiler, J.R., 1992. On the structure and origin of major glaciation cycles 1. Linear responses to Milankovitch forcing. *Paleoceanography*, 7:701-738.

Keir, R. S., 1988. On the late Pleistocene ocean geochemistry and circulation. *Paleoceanography*, 3:413-445.

Kennett, J.P., 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic ocean, and their impact on global paleoceanography. *J. Geophys. Res.*, 82:3843-59.

Kennett, J.P., 1982. *Marine Geology*. Prentice Hall, Englewood Cliffs.

Kennett, J.P., and Barker, P.F., 1990. Latest Cretaceous to Cenozoic climate and oceanographic developments in the Weddell Sea, Antarctica: An ocean-drilling perspective. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 937-962.

Kumar, N., Anderson, R.F., Mortlock, R.A., Froelich, P.N., Kubik, P., Dittrich-Hannen, B. and Suter, M., 1995. Increased biological productivity and export production in the glacial Southern ocean. *Nature*, 378, 675-680.

Labeyrie, L., Pichon, J.-J., Labracherie, M., Ippolito, P., Duprat, J., and Duplessy, J.-C., 1986. Melting history of Antarctica during the past 60,000 years. *Nature*, 322:701-706.

Lisitzin, A.P., 1985. The silica cycle during the last ice age. *Paleogeography, Paleoclimatology, Paleoecology*, 50:241-270.

Morley, J.J., 1989. Variations in high-latitude oceanographic fronts in the southern Indian Ocean: an estimation based on faunal changes. *Paleoceanography*, 4:547-554.

Oppo, D.W., and Fairbanks, R.G., 1987. Variability in the deep and intermediate water circulation of the Atlantic Ocean during the past 25,000 years: Northern Hemisphere modulation of the Southern Ocean. *Earth Planet. Sci. Letts.*, 86:1-15.

Petit, J.R., Basile, I., Leruyuet, A., Raynaud, D., Lorius, C., Jouzel, J., Stievenard, M., Lipenkov, V.Y., Barkov, N.I., Kudryashov, B.B., Davis, M., Saltzman, E., and Kotlyakov, V., 1997. Four climate cycles in Vostok ice core. *Nature*, 387:359-360.

Pichon, J.J., Labracherie, M., Labeyrie, L.D., and Duprat, J., 1987. Transfer functions between diatom assemblages and surface hydrology in the Southern Ocean. *Palaeogeography,* *Palaeoclimatology, Palaeoecology*, 61:79-95.

Pollock, D.E., 1997. The role of diatoms, dissolved silicate and Antarctic glaciation in glacial/interglacial climate change: a hypothesis. *Global and Planetary Change*, 14:113-125.

Prell, W.L., Huston, W.H., and Williams, D.F., 1979. The Subtropical Convergence and late Quaternary circulation in the southern Indian Ocean. *Mar. Micropaleontol.*, 4:225-234.

Raymond, C., and LaBrecque, J., 1988. Geophysical signatures of the Agulhas Ridge and Meteor Rise, Indo-Atlantic Basin. *In* Ciesielski, P.F., Kristoffersen, Y., et al., *Proc. ODP, Init. Repts*., 114: College Station, TX (Ocean Drilling Program), 27-43.

Shemesh, A., Charles, C.D., and Fairbanks, R.G., 1992. Oxygen isotopes in biogenic silica: global changes in ocean temperature and isotopic composition. *Science*, 256:1434-1436.

Sowers, T., and Bender, M., 1995. Climate records covering the last deglaciation. *Science*, 269:210-214.

Webb, P.-N., 1990. The Cenozoic history of Antarctica and its global impact. *Antarctic Sci.*, 2:3-21.

Webb, P.-N., and Harwood, D.M., 1991. Late Cenozoic glacial history of the Ross Embayment, Antarctica. *Quat. Sci. Reviews*, 10:215-223.

Whitworth III, T., 1988. The Antarctic Circumpolar Current. *Oceanu*s, 31:53-58

Wise, S.W., Breza, J.R., Harwood, D.M., Wei, W., and Zachos, J.C., 1992. Paleogene glacial history of Antarctica in light of Leg 120 drilling results. *In* Wise, S.W., Schlich, R., et al., *Proc. ODP, Sci. Results*, 120: College Station, TX (Ocean Drilling Program), 1001-1030.

Zachos, J.C., Berggren, W.A., Aubry, M.-P., and Mackensen, A., 1992. Isotope and trace element geochemistry of Eocene and Oligocene foraminifers from Site 748, Kerguelen Plateau. *In* Wise, S.W., Schlich, R., et al., *Proc. ODP Sci. Results*, 120: College Station, TX (Ocean Drilling Program), 839-854.

Zielinski, U., 1993. Quantitative estimation of paleoenvironmental parameters of the Antarctic surface water in the Late Quaternary using transfer functions with diatoms. *Rept. on Polar Research*, 126, 148 p.

Zielinski, U., and Gersonde, R., 1997. Diatom distribution in Southern Ocean surface sediments: Implications for paleoenvironmental reconstructions. *Palaeogeography,Palaeoclimatology, Palaeoecology*, 129:213-250.

FIGURE CAPTIONS

Figure 1. Location of Leg 177 drilling targets and previous DSDP/ODP sites in the South Atlantic. Primary sites are underlined. Circle indicates 200 nmi zone off Bouvet Island (Norway).

Figure 2. The vertical distribution of potential temperature on a transect in the eastern Atlantic sector of the Southern Ocean (from Agulhas Ridge to Bouvet Island) relative to the proposed Leg 177 sites. The ratio numbers at the top of the figure indicate the hydrographic station used to contour the potential temperature. PF = Polar Front. SAF = Subantarctic Front.

Figure 3. Schematic representation of present ocean circulation and interocean exchange. Not shown are the deep Indian and Pacific reservoirs (flux in Sv, from Keir, 1988).

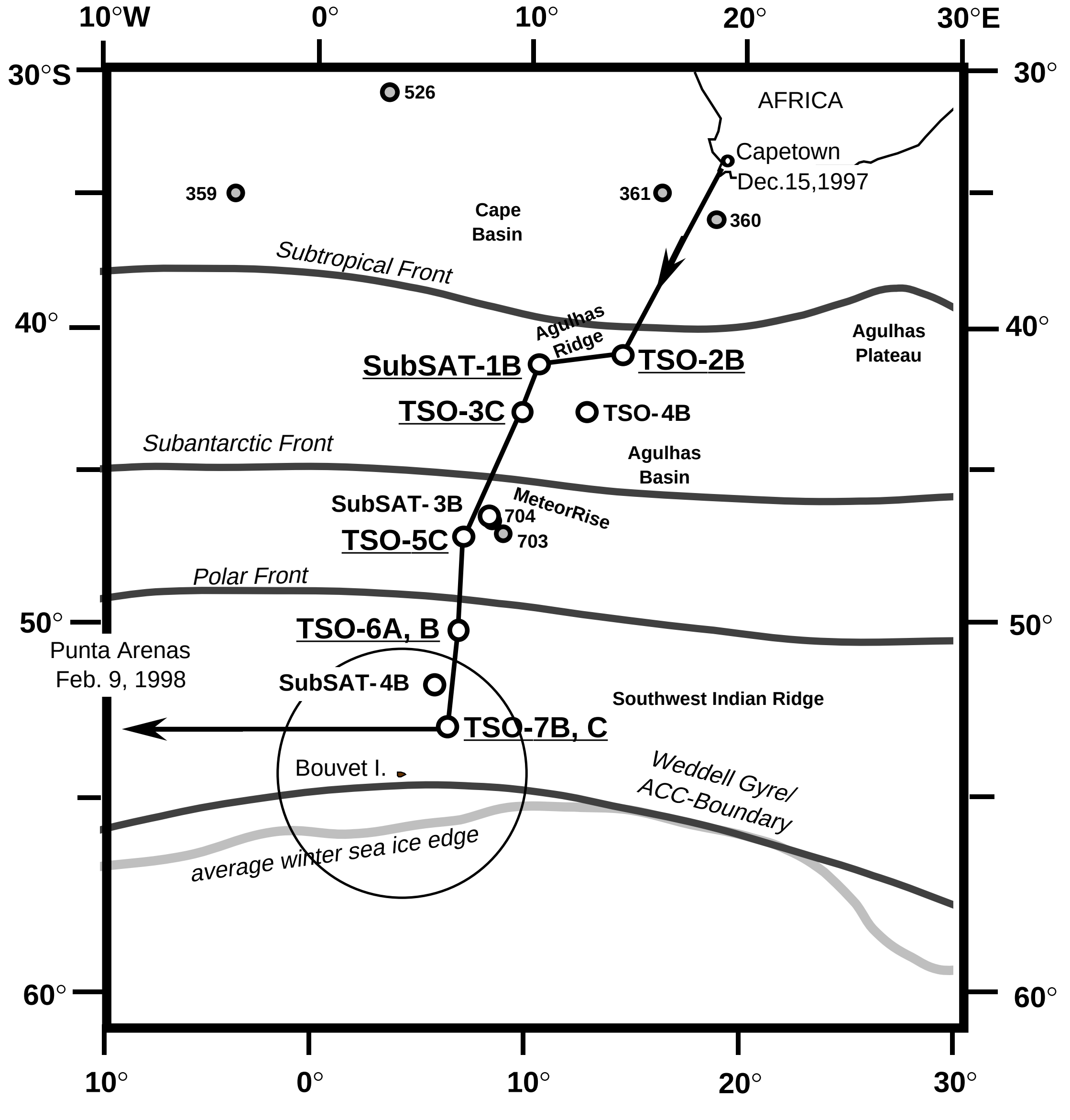
Figure 4. Lithologies and sediment ages expected at the proposed primary and secondary drill sites on a latitudinal and depth transect across the Atlantic sector of the Southern Ocean. Also indicated are locations of previous DSDP and ODP drill sites (compare Fig. 5).

Figure 5. Schematic representation of the Southern Ocean, its oceanic frontal systems and sea-ice distribution (according to Whitworth 1988 and other sources), including existing DSDP and ODP sites and the drilling transect planned for Leg 177.

Figure 6. Comparison of Cenozoic variations in benthic oxygen isotope ratio with the global sea-level curve inferred from sequence stratigraphy.

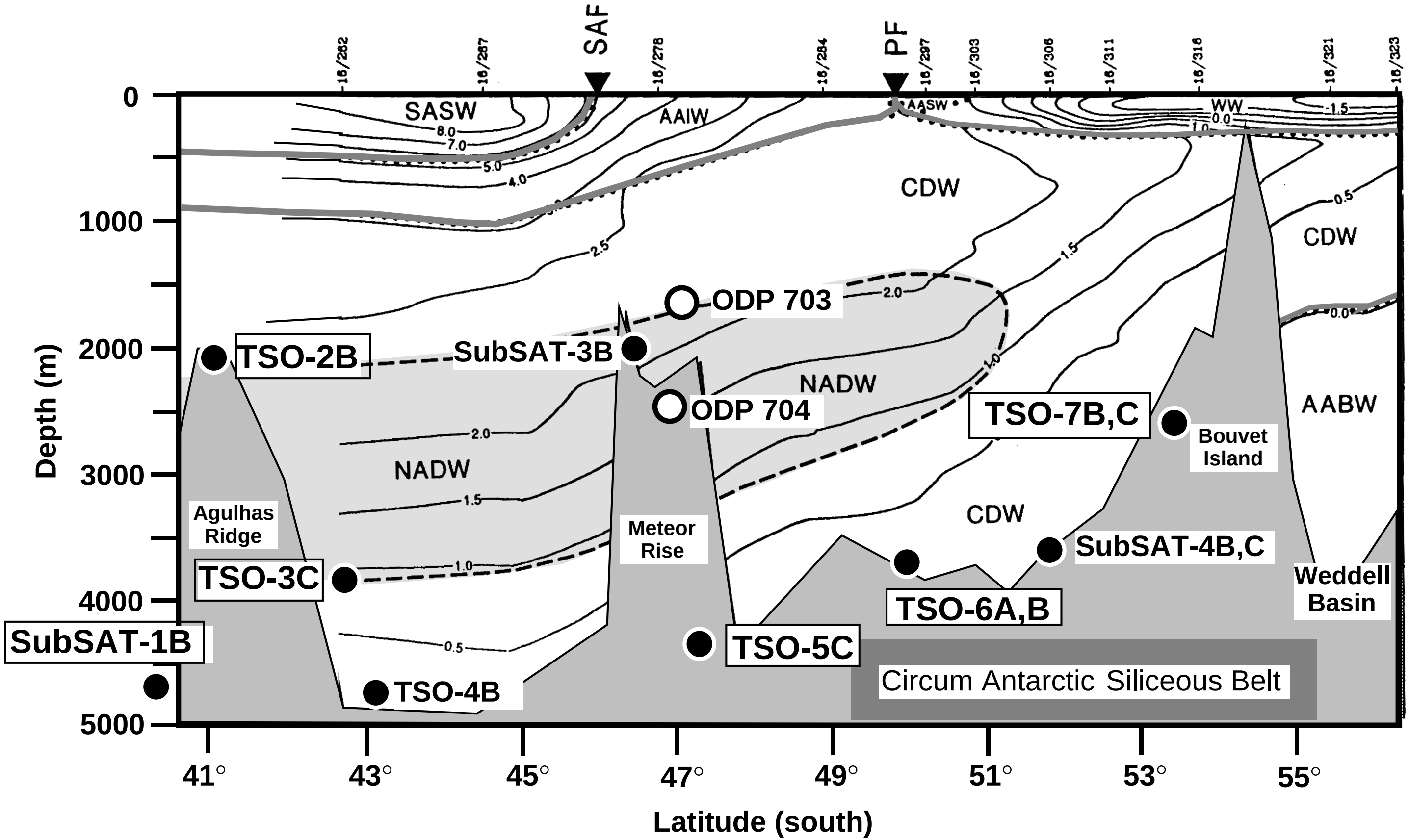
Figure 7. Oxygen isotopic record of Core RC11-83 (located near SubSAT-1C) compared with hydrogen isotopic record from Vostok ice core (Charles et al., 1996).

Figure 8. Oxygen isotopic record of Core TN057-6-PC3 (located near TSO-3C) that demonstrates a complete record through Marine Isotope Stage 12 with average sedimentation rates of 3 cm 10^{-3} yrs (Hodell et al., in prep.).



10°W
0°
10°
20°
30°E
30°S
30°
40°
50°
60°
526
359
361
360
AFRICA
Capetown
Dec.15,1997
Cape Basin
Subtropical Front
Agulhas Ridge
Agulhas Plateau
SubSAT-1B
TSO-2B
TSO-3C
TSO-4B
Subantarctic Front
Agulhas Basin
SubSAT-3B
704
703
MeteorRise
TSO-5C
Polar Front
TSO-6A, B
Punta Arenas
Feb. 9, 1998
SubSAT-4B
Southwest Indian Ridge
TSO-7B, C
Bouvet I.
Weddell Gyre/
ACC-Boundary
average winter sea ice edge
10°
0°
10°
20°
30°

Figure 1



SAF
PF
18/282
18/287
18/278
18/284
18/297
18/303
18/306
18/311
18/316
18/321
18/323
SASW
AAIW
AASW
WW
CDW
NADW
AABW
Agulhas Ridge
Meteor Rise
Bouvet Island
Weddell Basin
ODP 703
ODP 704
TSO-2B
TSO-3C
TSO-4B
TSO-5C
TSO-6A,B
TSO-7B,C
SubSAT-1B
SubSAT-3B
SubSAT-4B,C
Circum Antarctic Siliceous Belt
Depth (m)
0
1000
2000
3000
4000
5000
41°
43°
45°
47°
49°
51°
53°
55°
Latitude (south)

Figure 2

Leg 177

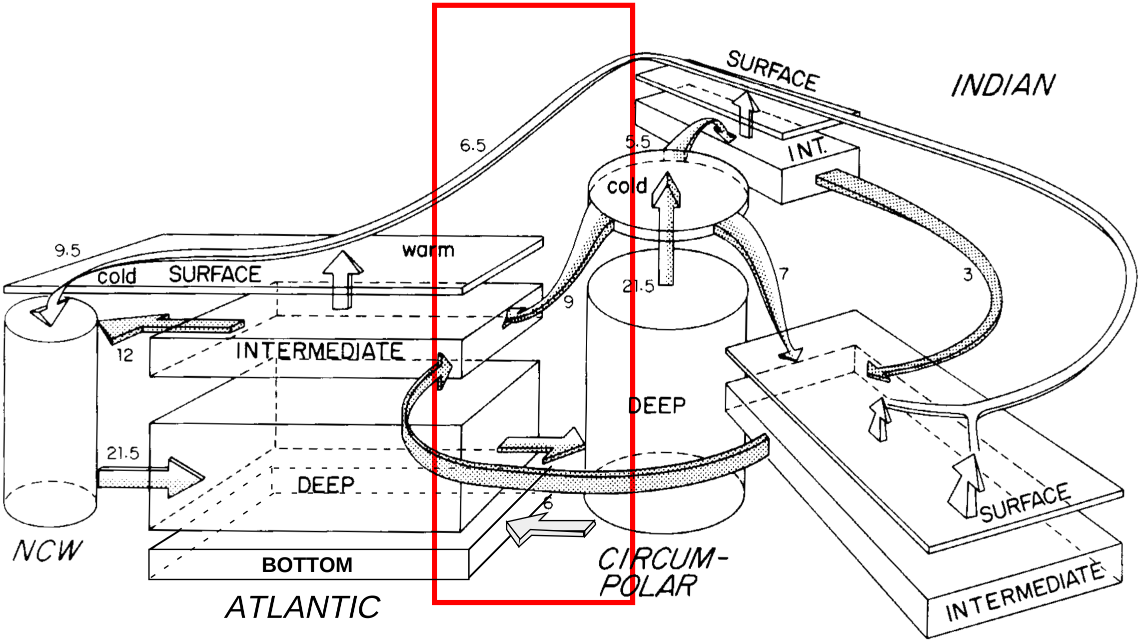
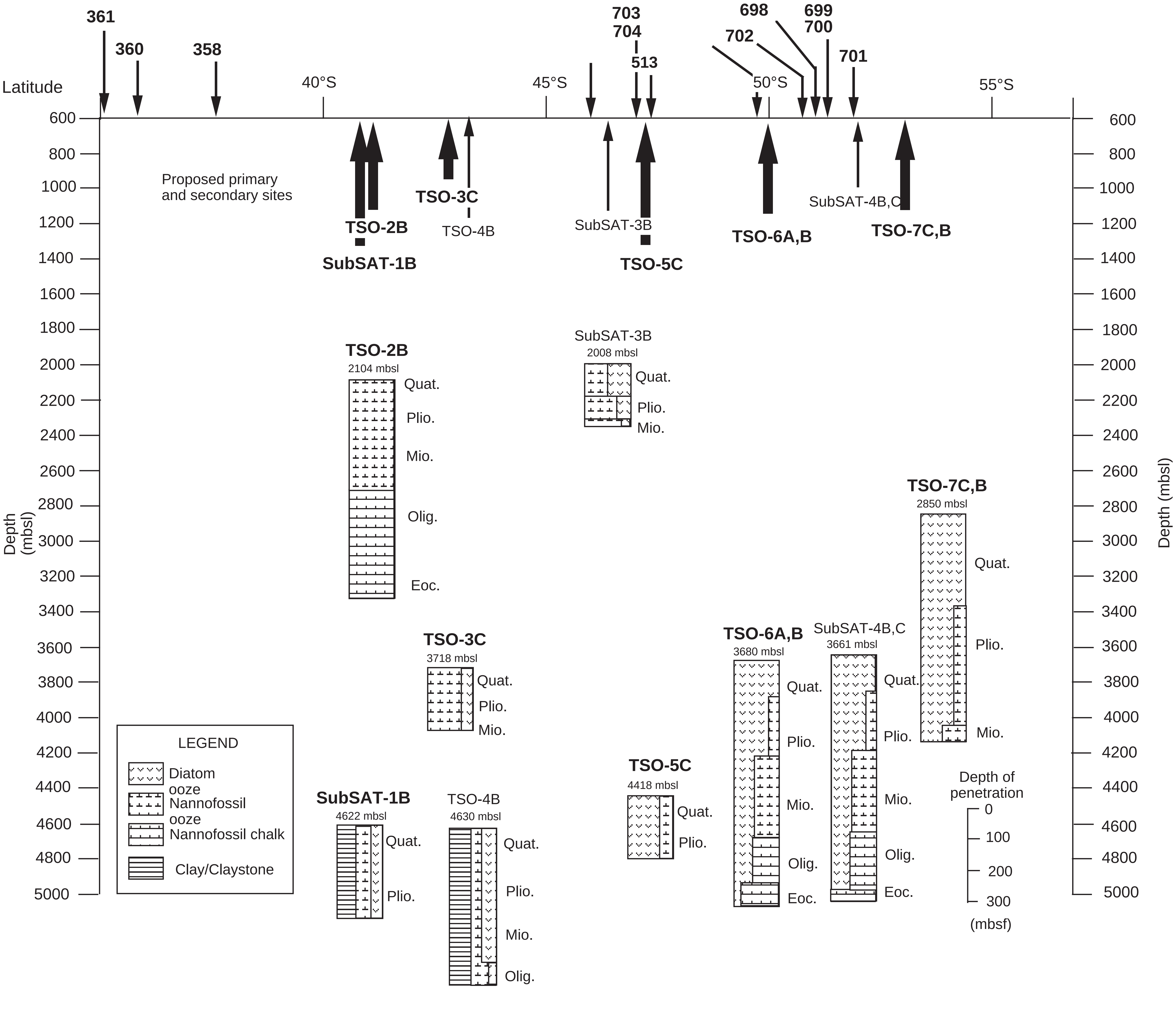


Figure 3



361
360
358
703
704
513
698
702
699
700
701
Latitude
40°S
45°S
50°S
55°S
Depth (mbsl)
Proposed primary and secondary sites
TSO-2B
SubSAT-1B
TSO-3C
TSO-4B
SubSAT-3B
TSO-5C
TSO-6A,B
SubSAT-4B,C
TSO-7C,B
TSO-2B 2104 mbsl
SubSAT-3B 2008 mbsl
TSO-3C 3718 mbsl
SubSAT-1B 4622 mbsl
TSO-4B 4630 mbsl
TSO-5C 4418 mbsl
TSO-6A,B 3680 mbsl
SubSAT-4B,C 3661 mbsl
TSO-7C,B 2850 mbsl
Quat.
Plio.
Mio.
Olig.
Eoc.
LEGEND
Diatom ooze
Nannofossil ooze
Nannofossil chalk
Clay/Claystone
Depth of penetration
0
100
200
300
(mbsf)

Figure 4

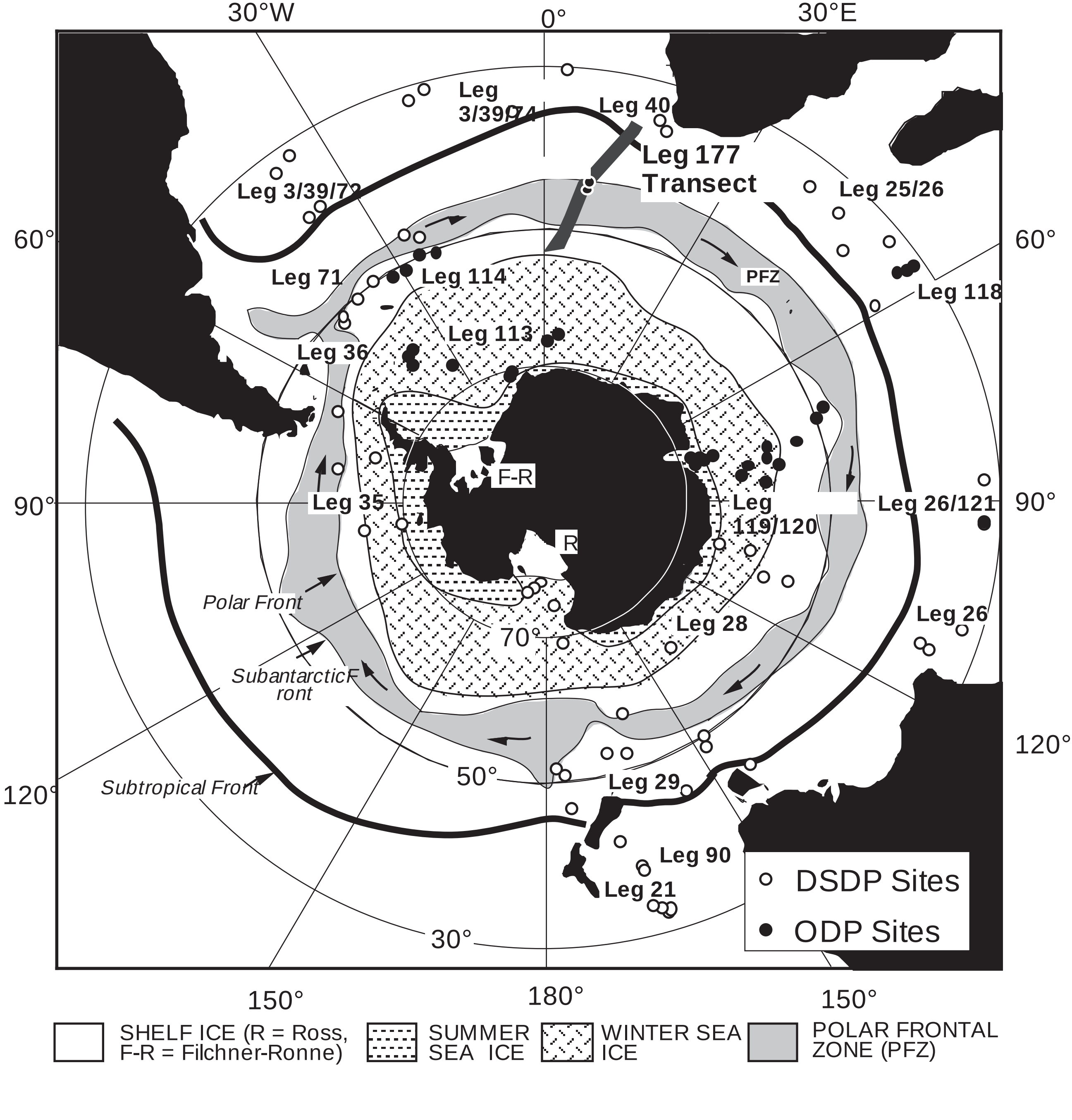
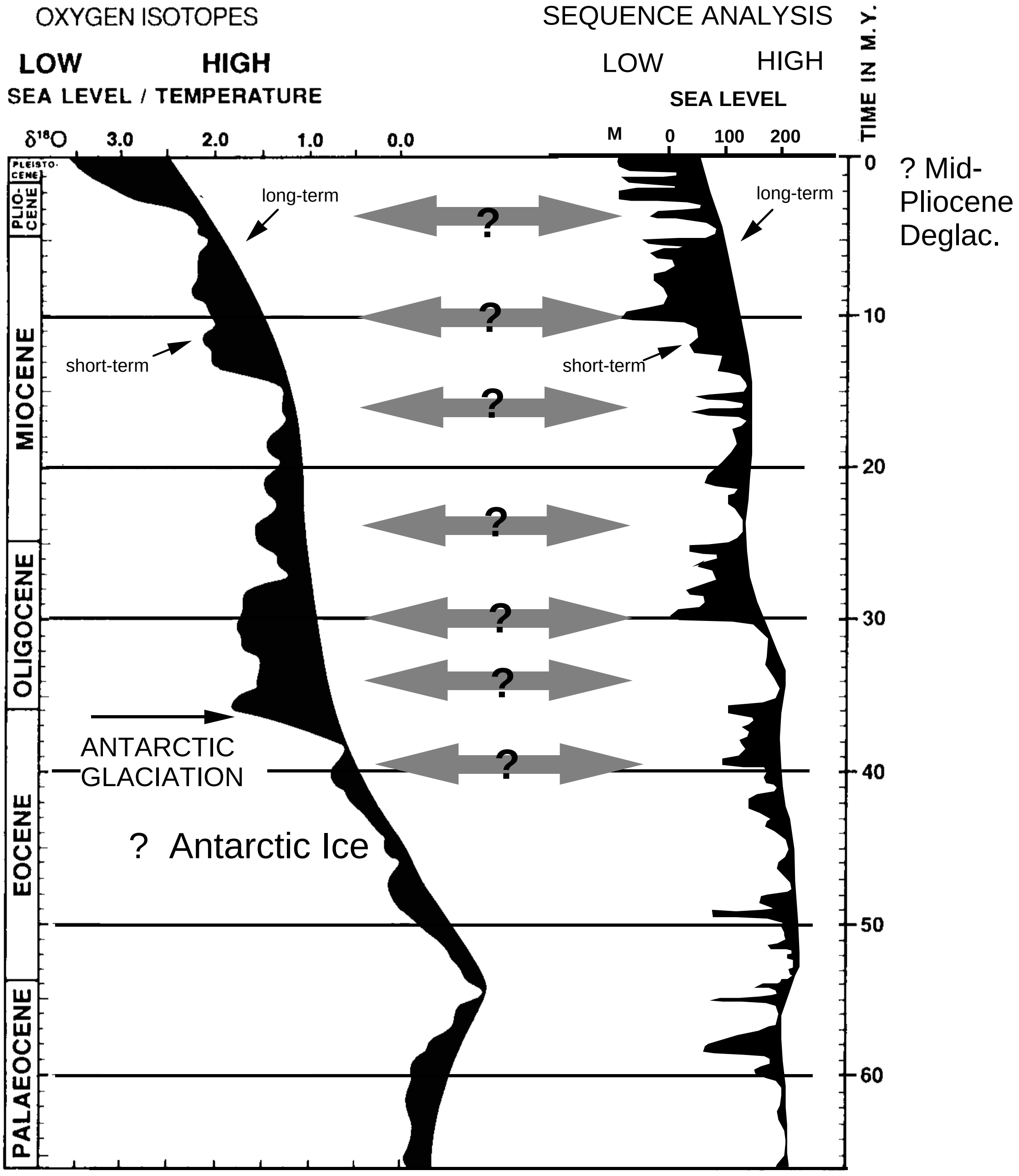

30°W
0°
30°E
Leg 3/39/74
Leg 40
Leg 177 Transect
Leg 3/39/72
Leg 25/26
60°
60°
PFZ
Leg 71
Leg 114
Leg 118
Leg 113
Leg 36
F-R
Leg 35
Leg 119/120
Leg 26/121
90°
90°
R
Polar Front
Leg 28
Leg 26
70°
Subantarctic front
120°
120°
Subtropical Front
50°
Leg 29
Leg 90
Leg 21
DSDP Sites
ODP Sites
30°
150°
180°
150°
SHELF ICE (R = Ross, F-R = Filchner-Ronne)
SUMMER SEA ICE
WINTER SEA ICE
POLAR FRONTAL ZONE (PFZ)

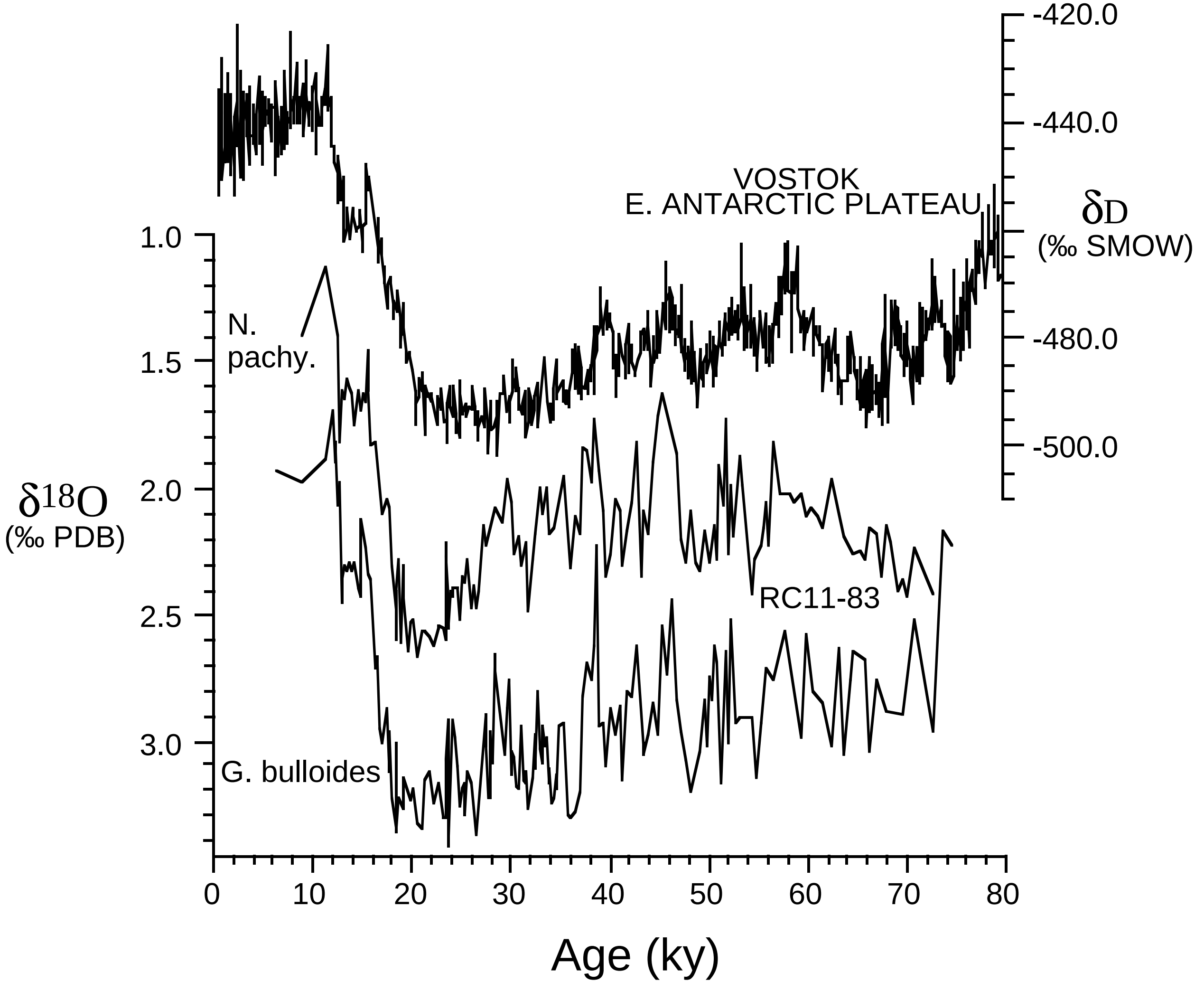
Figure 5

Oxygen isotope and sea level records



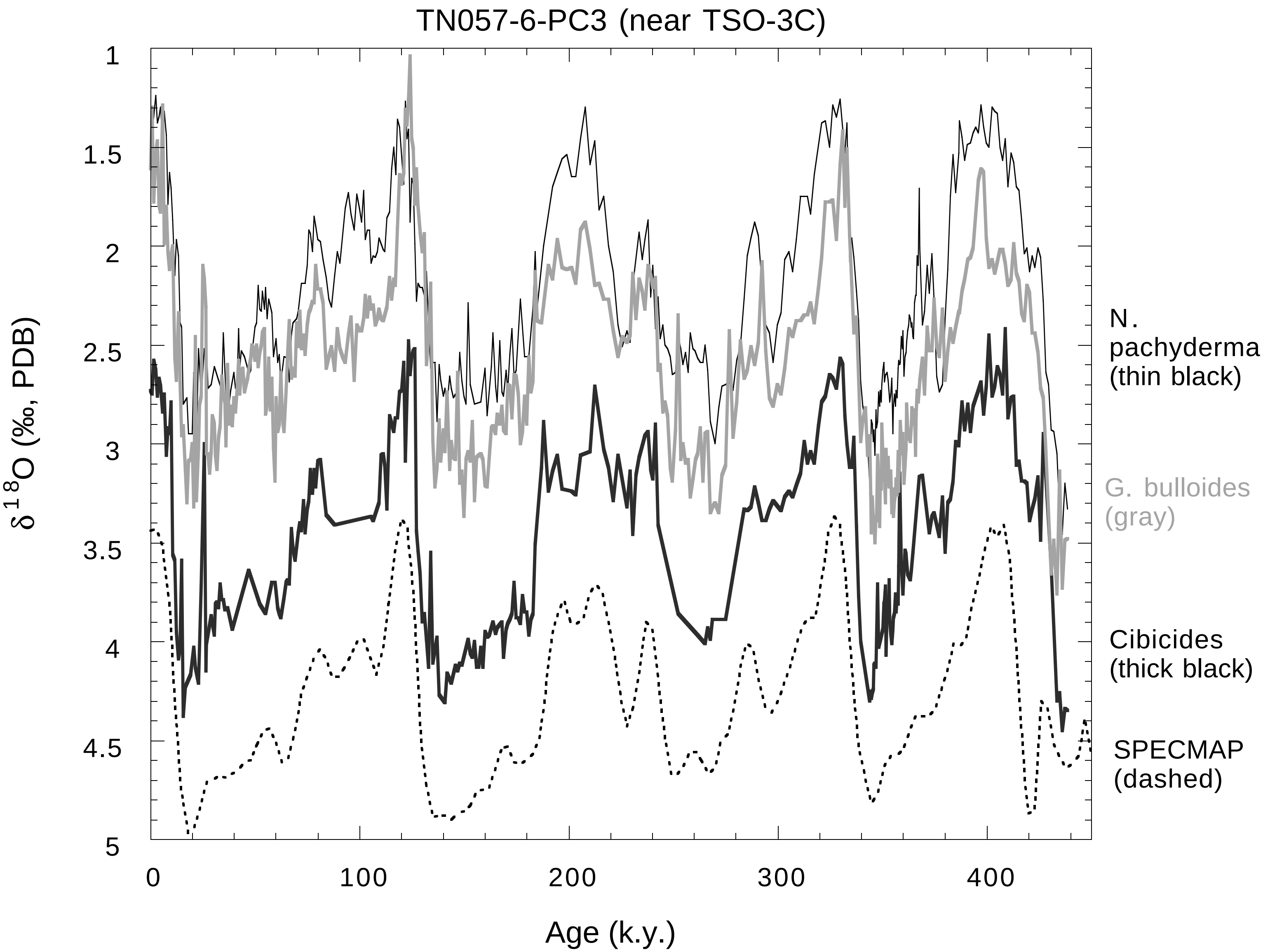
1‰ $\delta^{18}O$ = 110 m sea level or 4°C water temp.
(modified from Barrett, 1994)

Figure 6



VOSTOK
E. ANTARCTIC PLATEAU
δD
(‰ SMOW)
-420.0
-440.0
-480.0
-500.0
δ18O
(‰ PDB)
1.0
1.5
2.0
2.5
3.0
N.
pachy.
RC11-83
G. bulloides
0
10
20
30
40
50
60
70
80
Age (ky)

Figure 7



TN057-6-PC3 (near TSO-3C)
1
1.5
2
2.5
3
3.5
4
4.5
5
0
100
200
300
400
Age (k.y.)
δ18O (‰, PDB)
N. pachyderma (thin black)
G. bulloides (gray)
Cibicides (thick black)
SPECMAP (dashed)

Figure 8

Leg 177 Site Time Estimate Table

	Cape Town to Punta Arenas 10 December '97 to 9 February '98							
Site Name	Latitude Longitude	Water Depth (m)	Location	Operations	Transit 10.5 kt (days)	Coring Time (days)	Cond. & Log (days)	Total (days)
Leg 177 Port Call, Cape Town 10-14 Dec '97								
Transit Cape Town to TSO-2B = 444 nmi @ 10.5 kt					1.8			1.8
TSO-2B	41°08.20'S	2104	Cenozoic Agulhas Ridge	APC ref,HF,XCB 400 m		2.4		2.4
	13°33.65'E		PPSP 800 m	Drl 390 m,RCB 700 m,Log		3.5	1.3	4.8
Transit = 165 nmi					0.7			0.7
SubSAT-1B	40°56.18'S	4622	Neogene Agulhas Ridge	APC ref,HF,XCB 300 m		2.6		2.6
	09°53.65'E		PPSP 300 m	APC ref,XCB 300 m		2.0		2.0
				APC ref,XCB 300 m		2.5		2.5
Transit = 128 nmi					0.5			0.5
TSO-3C	42°54.82'S	3718	Cenozoic Agulhas Ridge	APC ref,HF,XCB 200 m		1.7		1.7
	08°53.99'E		PPSP 200 m	APC ref,XCB 200 m		1.3		1.3
				APC ref,XCB 200 m		1.5		1.5
Transit = 284 nmi					1.1			1.1
TSO-5C	47°05.673'S	4390	Neogene Meteor Rise	APC ref,HF,XCB 200 m		1.7		1.7
	05°55.106'E		PPSP 200 m	APC ref,XCB 200 m		1.3		1.3
				APC ref,XCB 200 m		1.8		1.8
Transit = 171 nmi					0.7			0.7
TSO-6A	49°58.58'S	3680	Cenozoic Shona Ridge	APC ref,HF 200 m		1.6		1.6
	05°51.92'E		PPSP 700 m	APC ref 200 m		1.2		1.2
				APC ref,XCB 400 m		3.1		3.1
				Drl 390 m,RCB 700 m,Log,Insp DP		4.7	1.5	6.2
Transit = 194 nmi					0.8			0.8
TSO-7C	53°10.84'S	2850	Neogene	APC ref 200 m		1.4		1.4
	05°07.84'E		PPSP 730 m	APC ref 200 m		1.1		1.1
				APC ref 200 m		1.4		1.4
Transit TSO-7C to Punta Arenas 9 Feb '98 = 2600 nmi @ 10.0 kt					10.8			10.8
				Estimated Time=	16.4	36.8	2.8	**56.0**
				Available Time =	16.0	40.0		**56.0**

Leg 177 Site Time Estimate Table

ALTERNATE SITES								
TSO-7C	53°10.84'S	2850	Neogene	Drl 190 m, RCB 730 m, Log		5.5	1.4	6.9
	05°07.84'E		PPSP 730 m					0.0
TSO-6B	50°00.98'S	3679	Cenozoic	APC ref, HF, XCB 200 m		1.6		1.6
alt to TS0-6A	05°50.13'E		PPSP 730 m	APC ref, XCB 200 m		1.3		1.3
				APC ref, XCB 200 m, Log		1.7		1.7
TSO-7B	53°12.95'S	2925	Neogene	APC ref, HF, XCB 400 m		1.4		1.4
alt to TSO-7C	05°08.07'E		PPSP 680 m	APC ref, XCB 200 m		1.1		1.1
				APC ref, XCB 200 m		1.4		1.4
				Drl 390 m, RCB 680 m, Log		4.8	1.3	6.1
TSO-4B	43°11.33'S	4630	Cenozoic	APC ref, HF, XCB 200 m		1.3		1.3
	11°43.62'E		PPSP 500 m					0.0
								0.0
SubSAT-3B	46°24.70'S	2008	Neogene	APC ref, HF, XCB 200 m		1.1		1.1
	07°04.79'E		PPSP 200 m	APC ref, XCB 200 m		0.9		0.9
				APC ref, XCB 200 m, Log		1.1		1.1
SubSAT-4B	52°03.01'S	3661	Cenozoic	APC ref, HF, XCB 200 m		1.6		1.6
	04°31.01'E		PPSP 800 m	APC ref, XCB 200 m		1.3		1.3
				APC ref, XCB 200 m, Log		1.7		1.7
SubSAT-4C	51°59.08'S	3701	Cenozoic	APC ref, HF, XCB 200 m		1.6		1.6
	04°31.00'E		PPSP 800 m	APC ref, XCB 200 m		1.3		1.3
				APC ref, XCB 200 m, Log		1.6		1.6
				Estimated Time=	0.0	17.7	1.3	19.0

SITE SUMMARIES

Site: TSO-2B

Priority: 1
Position: 41°8.20'S, 13°33.65'E
Water Depth: 2104 m
Sediment Thickness: 1300 m
Approved Maximum Penetration: 700 mbsf (PPSP: 800 mbsf)
Seismic Coverage: TN057/TSO-2, shot point TN1100

Objectives: Recover a Cenozoic sequence that will be used to reconstruct long-term changes in

1. surface-water parameters, and the evolution of the Subtropical Front (STF) and its response to southern-high latitude climate variability;

2. paleoproductivity north of the PFZ;

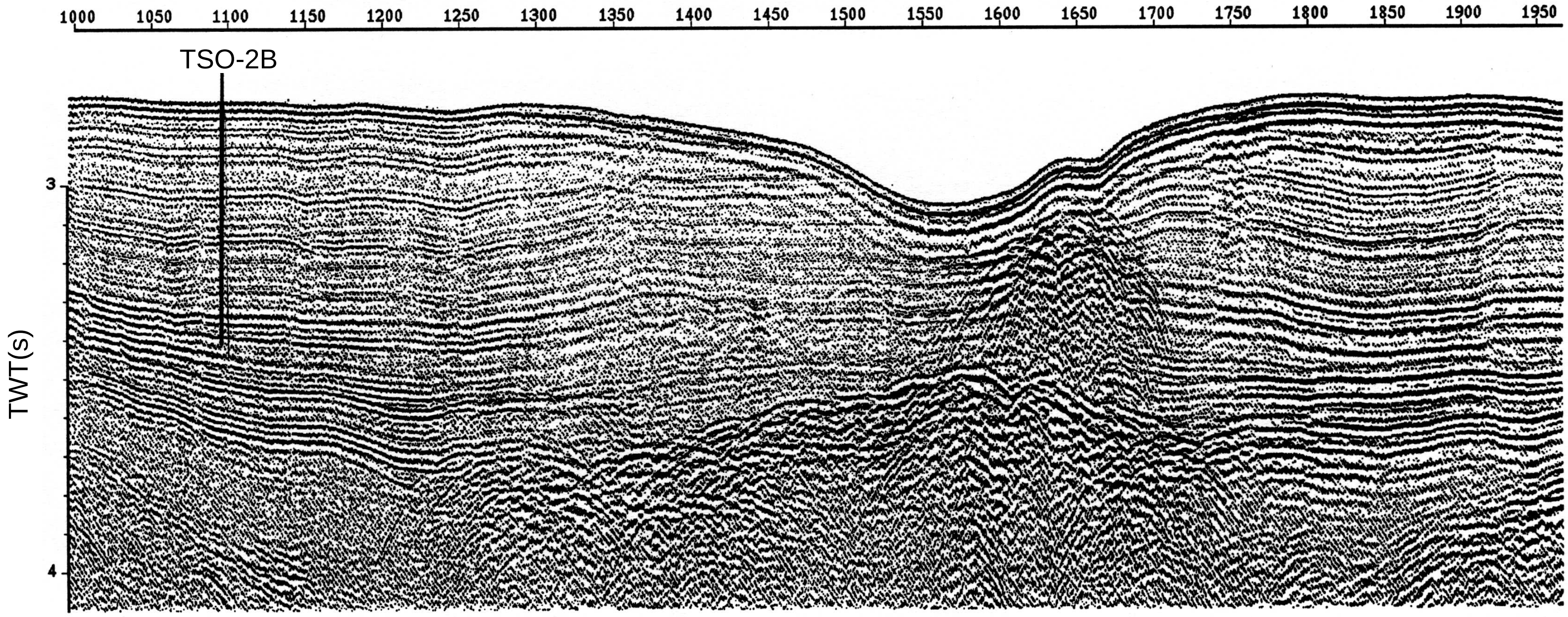
3. the mixing ratio between lower upper CPDW and upper NADW and the evolution of these water masses through time; and

4. the paleodepth history of the Agulhas Ridge.

Drilling Program: Single APC to 200 m, XCB to 400 m, RCB to 700 m

Logging and Downhole: Triple Combo, GHMT, and FMS logs

Nature of Rock Anticipated: Nannofossil-foraminiferal ooze, chalk, limestone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1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
TSO-2B
3
4
TWT(s)

Site: SubSAT-1B

Priority: 1
Position: 40°56.18´S, 9°53.65´E
Water Depth: 4622 m
Sediment Thickness: 1500 m
Approved Maximum Penetration: 300 m
Seismic Coverage: TN057/SubSAT-1, shot point TN3200

Objectives: Recover a Pleistocene section at ultra-high sedimentation rates to study:

1. rapid climate change on suborbital time scales in the Southern Ocean and its relation to climate signals recovered from ice cores in Greenland, Antarctica, and tropical glaciers;

2. glacial-to-interglacial variations in the properties of bottom-water masses in the South Atlantic Ocean and their relation to high-latitude climate change;

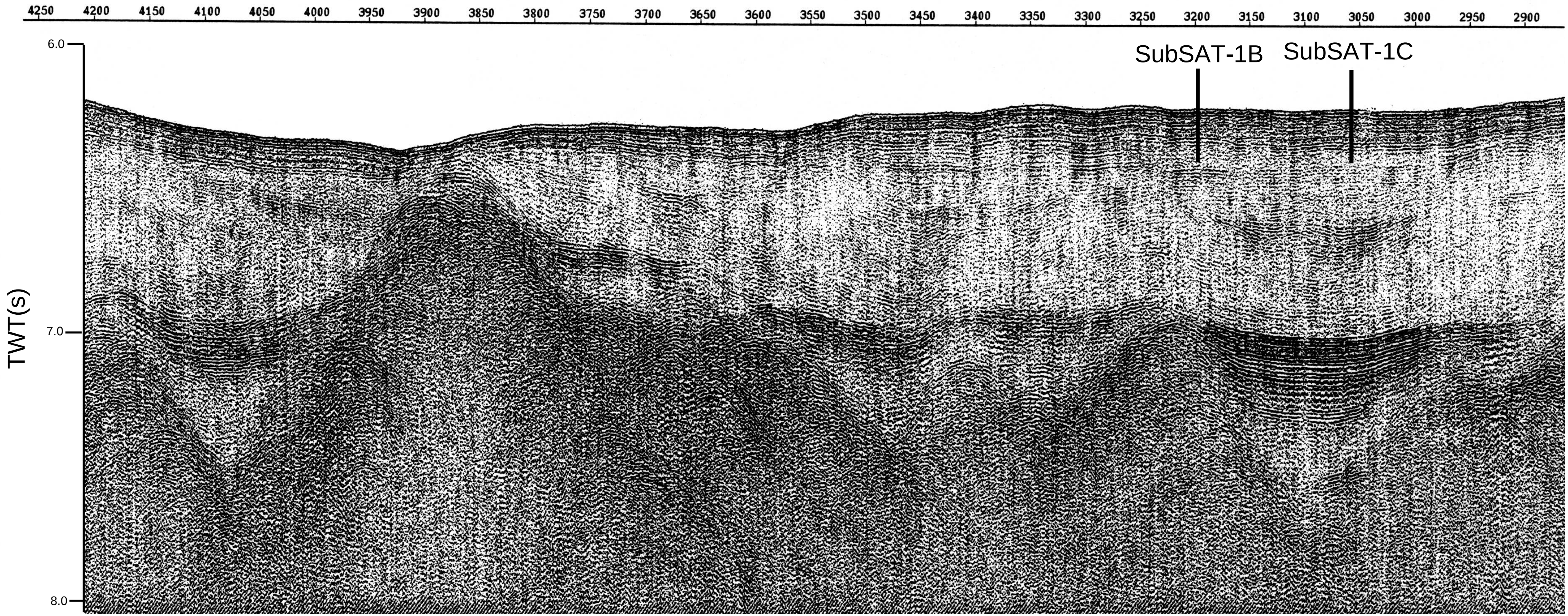
3. glacial-to-interglacial variations in Southern Ocean productivity, nutrient cycling, and pCO_2 and their role in global biogeochemical cycles.

4. the response to orbital forcing and the phase relationships of proxy records to climatic records in low and northern high latitudes.

Drilling Program: Triple APC/XCB to 300 m

Logging and Downhole: None

Nature of Rock Anticipated: Diatomaceous calcareous mud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4200
4150
4100
4050
4000
3950
3900
3850
3800
3750
3700
3650
3600
3550
3500
3450
3400
3350
3300
3250
3200
3150
3100
3050
3000
2950
2900
6.0
7.0
8.0
TWT(s)
SubSAT-1B
SubSAT-1C

Site: TSO-3C

Priority: 1
Position: 42°54.82´S, 8°53.99´E
Water Depth: 3718 m
Sediment Thickness: 800 m
Approved Maximum Penetration: 200 m
Seismic Coverage: TN057/TSO3, shot point TN1850

Objectives: Recover a continuous Pliocene-Pleistocene composite section at moderate sedimentation rates to study

1. past migrations in the position of the PFZ;

2. changes in the mixing ratios of lower NADW and CPDW in the Southern Ocean and its relation to high-latitude climate change;

3. the response of the Southern Ocean to orbital forcing and the phase relationships (leads and lags) to climatic changes in the high-latitude Northern Hemisphere;

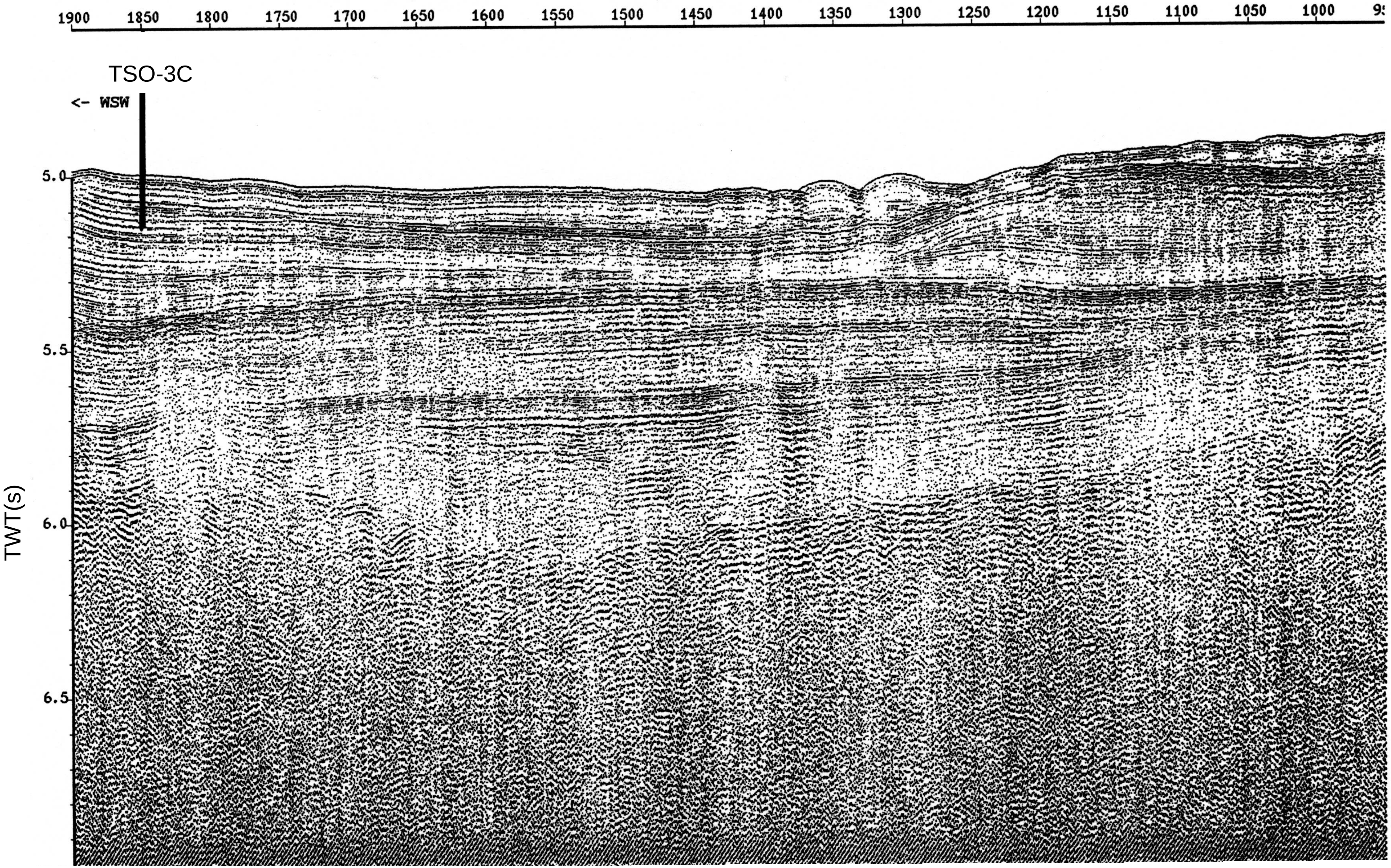
4. the stability of the Antarctic cryosphere during "warmer-than-present" climate during the Pliocene prior to the initiation of Northern Hemisphere glaciation.

5. the response to orbital forcing and the phase relationships of proxy records to climatic records in low and northern high latitudes.

Drilling Program: Triple APC/XCB to 200 m

Logging and Downhole: None

Nature of Rock Anticipated: Foram-nannofossil ooze


1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
TSO-3C
<- WSW
5.0
5.5
6.0
6.5
TWT(s)

Site: TSO-5C

Priority: 1
Position: 47°05.673´S, 5°55.106´E
Water Depth: 4390 m
Sediment Thickness: 1200 m
Approved Maximum Penetration: 200 m
Seismic Coverage: TN057/TSO5, shot point TN3750

Objectives: Recover a continuous late Pliocene-Pleistocene record at high sedimentation rates within the PFZ to reconstruct

1. surface-water parameters and the evolution of the PFZ;

2. paleoproductivity changes in the present PFZ region;

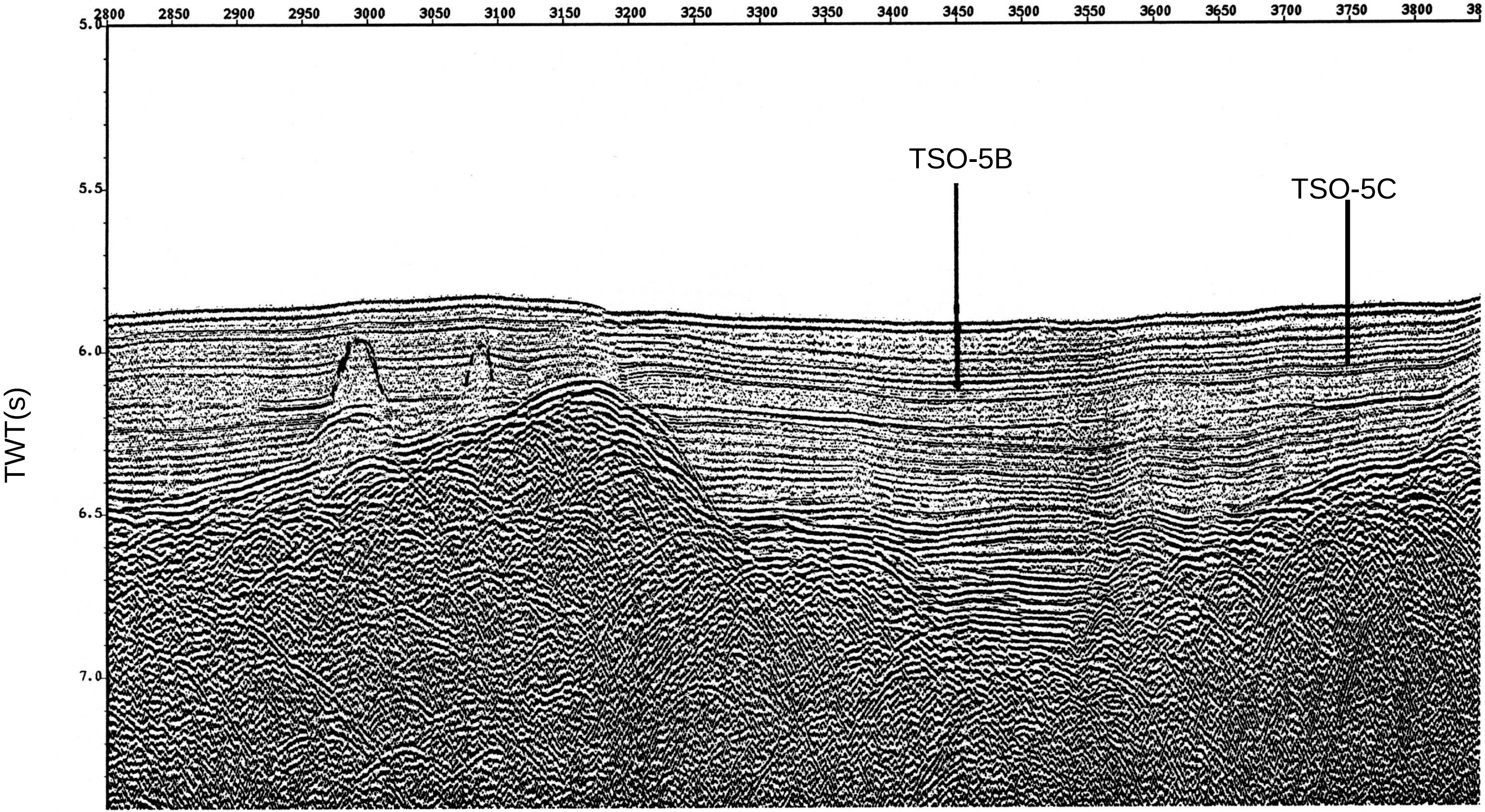
3. lower CPDW and AABW properties and their response to high-latitude climate and the changes in flux of NADW during glacial and interglacial cycles;

4. the response to orbital forcing and the phase relationships of proxy records to climatic records in low and northern high latitudes.

Drilling Program: Triple APC/XCB to 200 m

Logging and Downhole: None

Nature of Rock Anticipated: Calcareous-bearing diatom ooze


2800
2850
2900
2950
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
3500
3550
3600
3650
3700
3750
3800
38
5.0
5.5
6.0
6.5
7.0
TWT(s)
TSO-5B
TSO-5C

Site: TSO-6A

Priority: 1
Position: 49°58.58´S, 5°51.92´E
Water Depth: 3680 m
Sediment Thickness: 1100 m
Approved Maximum Penetration: 700 m
Seismic Coverage: AWI94090, shot point PS916

Objectives: Recover a 700-m sequence at moderate to high sedimentation rates to study

1. surface-water parameters, sea-ice distribution, and the evolution of the Polar Front (thermal isolation of Southern Ocean);

2. paleoproductivity changes (e.g., silica, carbon export rates) and the history of the circum-Antarctic biogenic silica belt in relation to surface-water-mass changes, deep-water circulation, and sea-ice distribution;

3. deep-water circulation including changes in the physical and chemical properties of CPDW;

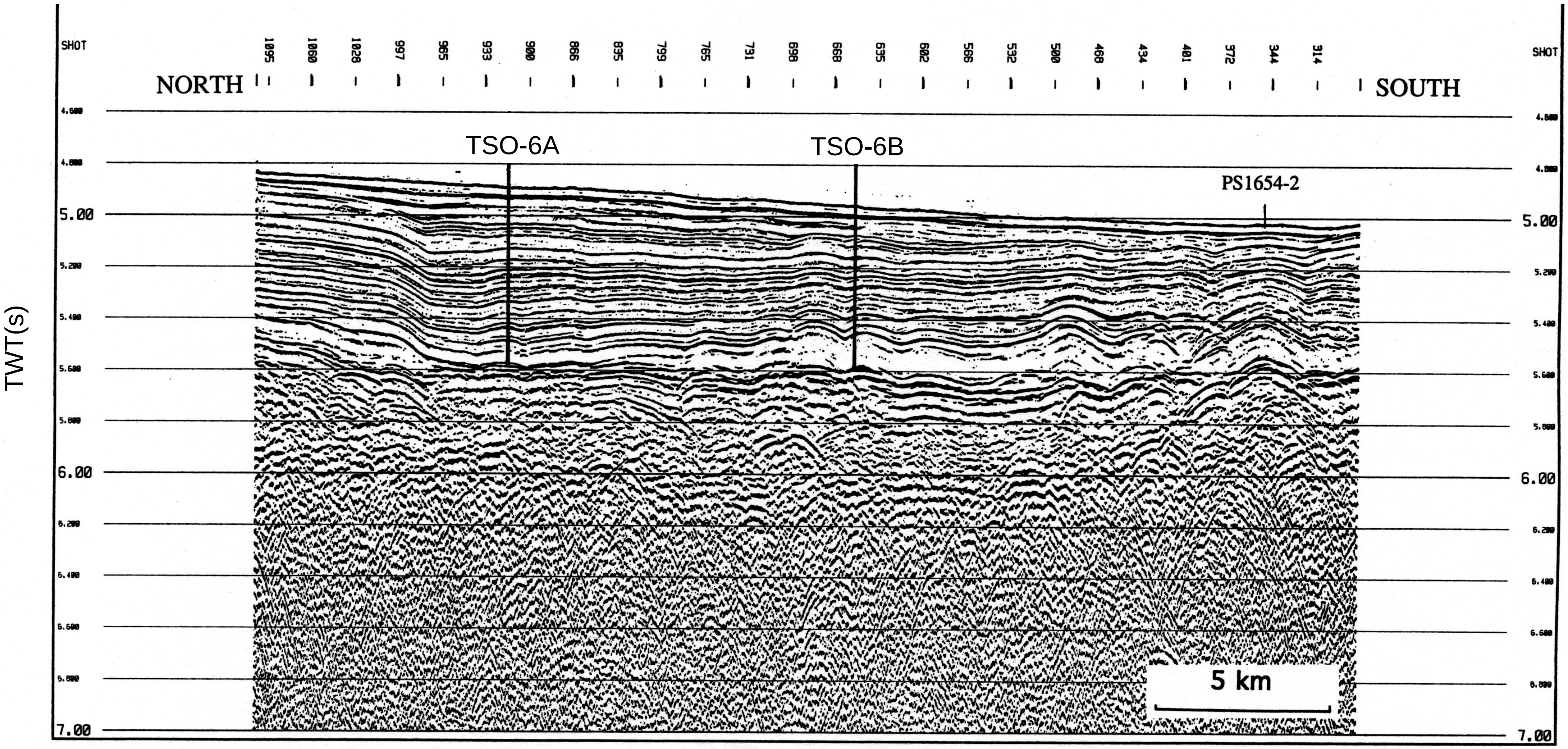
4. the response to orbital forcing and the phase relationships of proxy records to climatic records in low and northern high latitudes; and

5. silica diagenesis.

Drilling Program: Triple APC to 200 m, XCB to 400 m, RCB to 700 m

Logging and Downhole: Triple Combo, GHMT, and FMS logs

Nature of Rock Anticipated: Foram-bearing diatom ooze, calcareous diatom ooze, diatomaceous nannofossil chalk, limestone


SHOT
1095
1060
1028
997
965
933
900
866
835
799
765
731
698
668
635
602
566
532
500
468
434
401
372
344
314
NORTH
SOUTH
TSO-6A
TSO-6B
PS1654-2
TWT(s)
4.600
4.800
5.00
5.200
5.400
5.600
5.800
6.00
6.200
6.400
6.600
6.800
7.00
5 km

Site: TSO-6B

Priority: 2
Position: 50°0.98´S, 5°50.13´E
Water Depth: 3679 m
Sediment Thickness: 1100 m
Approved Maximum Penetration: 700 m
Seismic Coverage: TN057/TSO6, shot point TN650

Objectives: Same as TSO-6A.

Drilling Program: Triple APC to 200 m, XCB to 400 m, RCB to 700 m

Logging and Downhole: Triple Combo, GLT, GHMT, and FMS logs

Nature of Rock Anticipated: Foram-bearing diatom ooze, calcareous diatom ooze, diatomaceous nannofossil chalk, limestone

See seismic line for TSO-6A

Site: TSO-7C

Priority: 1
Position: 53°10.84´S, 5°7.84´E
Water Depth: 2850 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 730* m
Seismic Coverage: AWI94080, shot point 475

Objectives: Recover a Pliocene-Pleistocene sequence at ultra-high-resolution to reconstruct

1. rapid climate change on suborbital time scales in the Southern Ocean and its relation to climate signals recovered from ice cores in Greenland, Antarctica, and tropical glaciers;

2. surface-water parameters and sea-ice distribution south of the present PFZ;

3. paleoproductivity changes (e.g., silica, carbon export rates) in relation to surface-water-mass changes and sea-ice distribution;

4. deep-water circulation including changes in the physical and chemical properties of CPDW; and

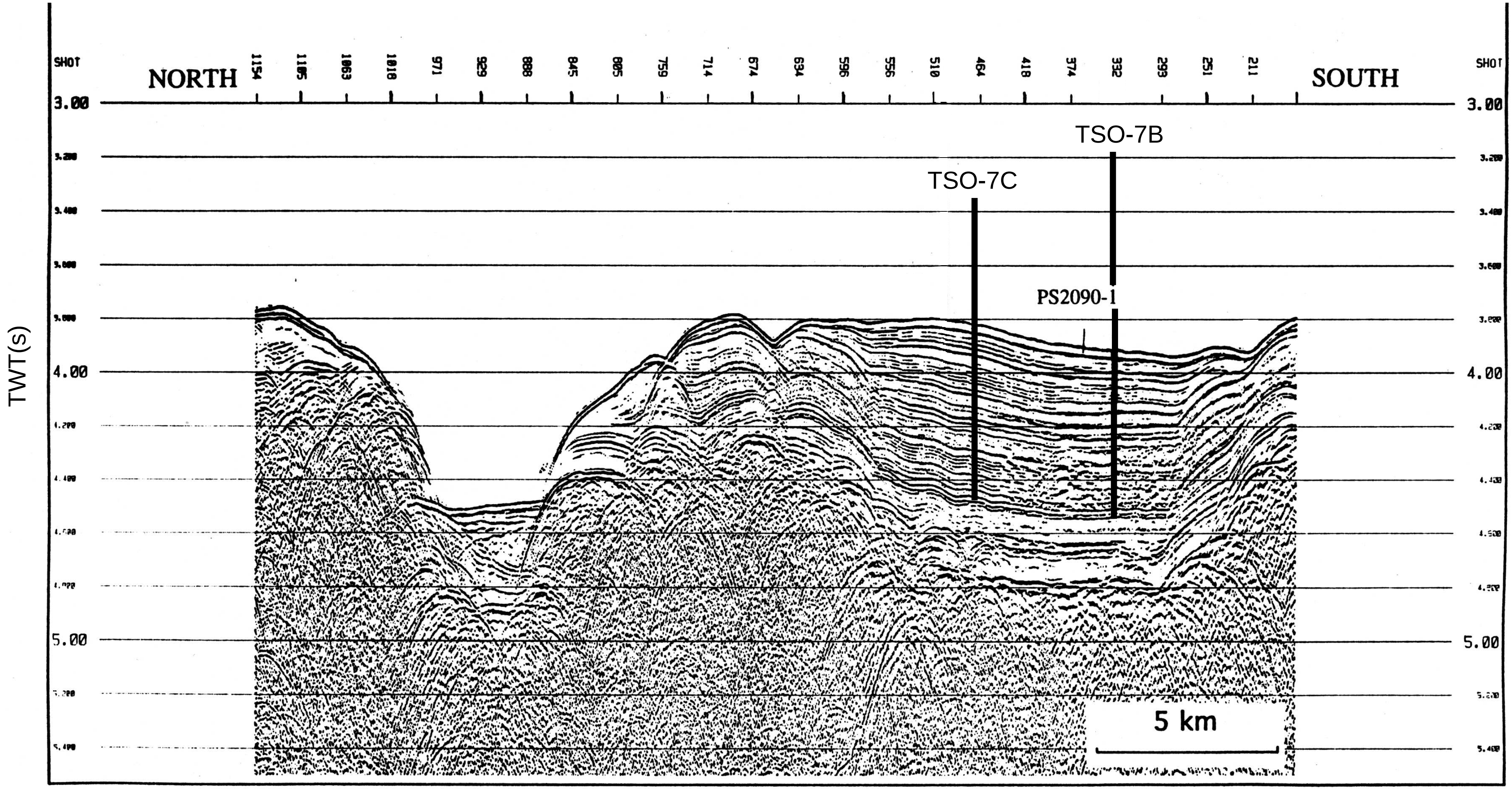
5. early low-temperature silica diagenesis.

Drilling Program: Triple APC/XCB to 200 m and, if time permits, XCB to 400 m, RCB to 730 m.

Logging and Downhole: None if <400 m

Nature of Rock Anticipated: Foram-bearing diatom ooze

*This site may be deepened to a maximum of 730 m, if time permits, at the end of Leg 177.



TWT(s)
SHOT
NORTH
SOUTH
1154
1105
1063
1018
971
929
888
845
805
759
714
674
634
596
556
510
464
418
374
332
293
251
211
3.00
4.00
5.00
TSO-7B
TSO-7C
PS2090-1
5 km

Site: TSO-7B

Priority: 2
Position: 53°12.95´S, 5°8.07´E
Water Depth: 2925 m
Sediment Thickness: 1000 m
Approved Maximum Penetration: 680* m
Seismic Coverage: AWI94080, shot point PS335

Objectives: Same as TSO-7A

Drilling Program: Triple APC to 200 m and, if time permits, XCB to 400 m, RCB to 730 m

Logging and Downhole: None if <400 m

Nature of Rock Anticipated: Foram-bearing diatom ooze

*This site may be deepened to a maximum of 730 m, if time permits, at the end of Leg 177.

See seismic line for TSO-7C

Site: TSO-4B

Priority: 2
Position: 43°11.33´S, 11°43.62´E
Water Depth: 4630 m
Sediment Thickness: 1600 m
Approved Maximum Penetration: 500 m
Seismic Coverage: AWI 94100, shot point PS3287

Objectives: To recover a Cenozoic sequence to

1. reconstruct surface-water parameters and paleoproductivity north of the Polar Front;

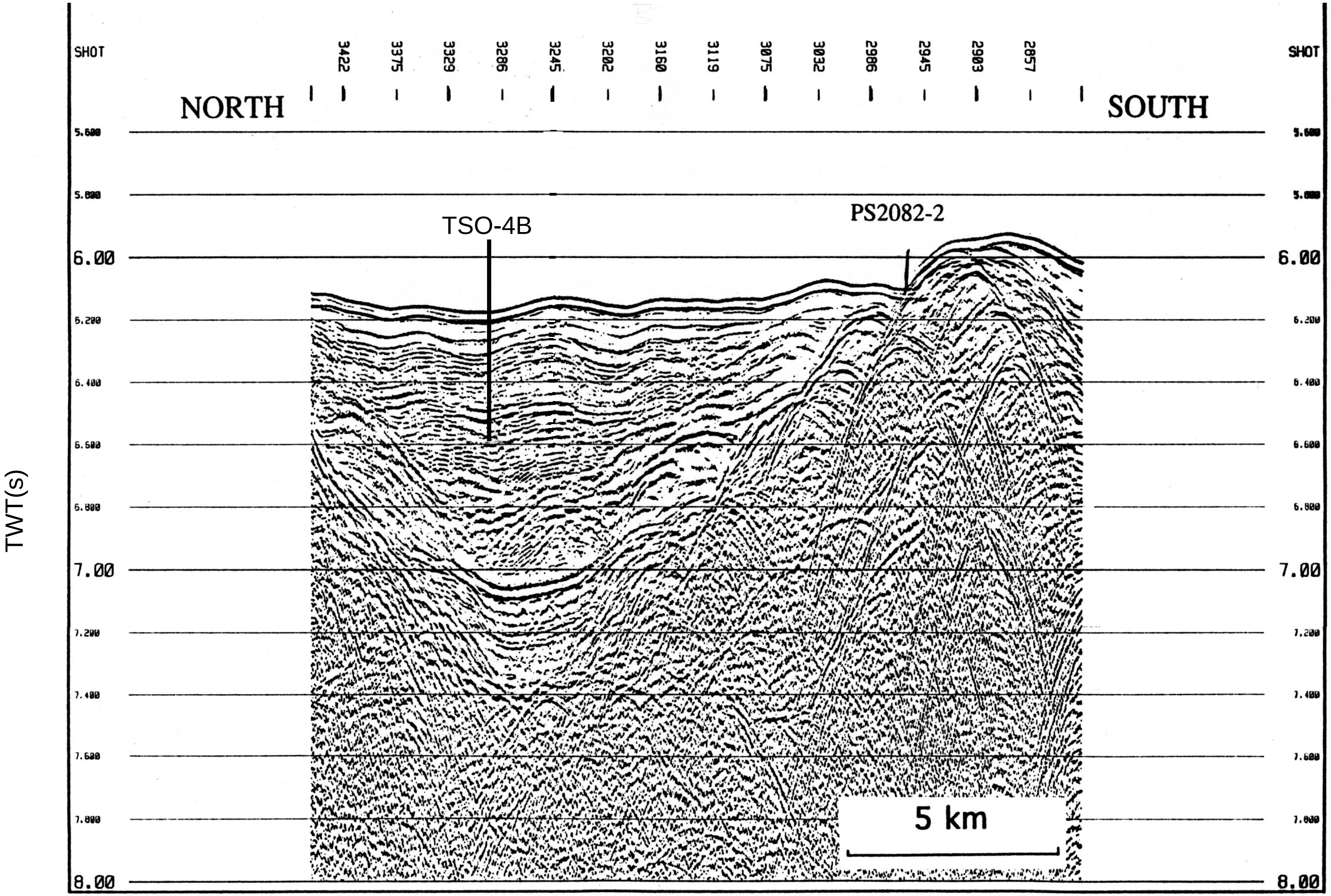
2. reconstruct the history of deep- and bottom-water masses related to the establishment of the southern hemisphere cryosphere; and

3. calibrate biostratigraphic markers to the geomagnetic polarity time scale.

Drilling Program: Single APC to 200 m, XCB to 400 m, RCB to 500 m

Logging and Downhole: Triple Combo, GHMT, and FMS logs

Nature of Rock Anticipated: Calcareous diatomaceous mud and mudstone



SHOT
3422
3375
3329
3286
3245
3202
3160
3119
3075
3032
2986
2945
2903
2857
SHOT
NORTH
SOUTH
TSO-4B
PS2082-2
TWT(s)
5.600
5.800
6.00
6.200
6.400
6.600
6.800
7.00
7.200
7.400
7.600
7.800
8.00
5 km

Site: SubSAT-3B

Priority: 2
Position: 46°24.7´S, 7°4.79´E
Water Depth: 2008 m
Sediment Thickness: 1600 m
Approved Maximum Penetration: 200 m
Seismic Coverage: TN057/SubSAT3, shotpoint TN1200

Objectives: Recover a Pliocene-Pleistocene section to study

1. past migrations in the position of the PFZ;

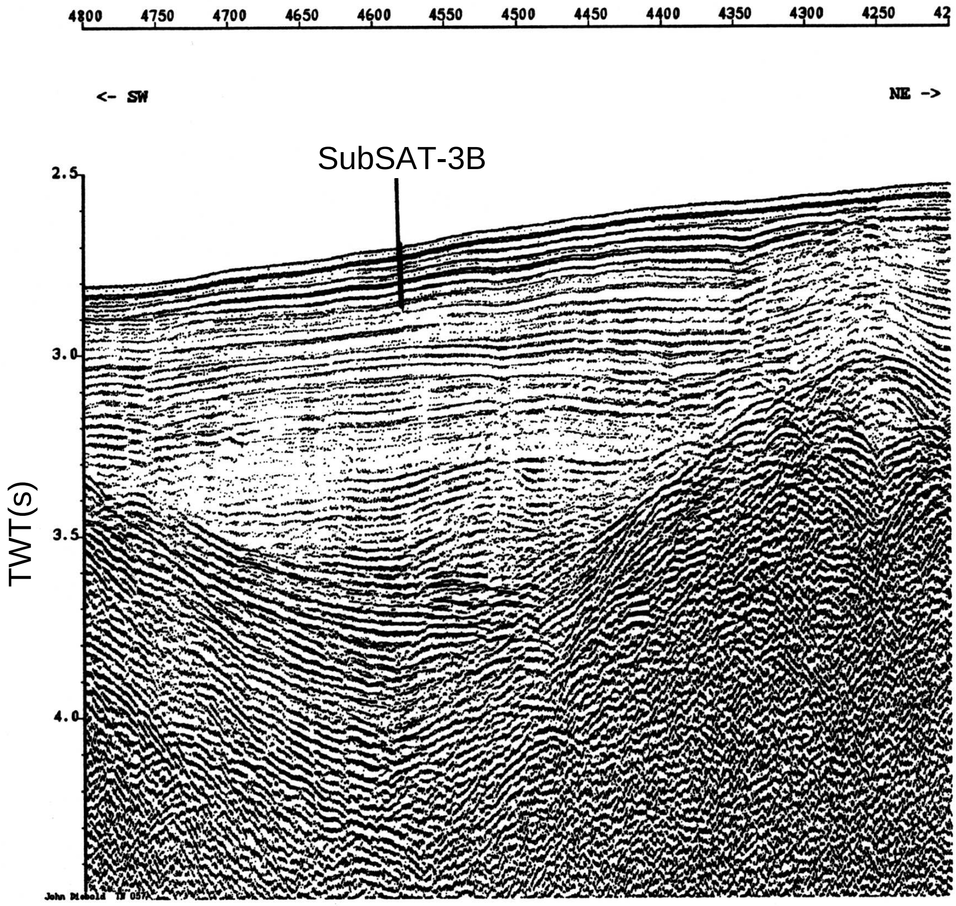
2. changes in mixing ratios of upper NADW and CPDW; and

3. stability of the Antarctic cryosphere during "warmer-than-present" climate during the Pliocene.

Drilling Program: Triple APC to 200 m

Logging and Downhole: None

Nature of Rock Anticipated: Alternating calcareous and siliceous ooze



4800
4750
4700
4650
4600
4550
4500
4450
4400
4350
4300
4250
42
<- SW
NE ->
SubSAT-3B
2.5
3.0
3.5
4.0
TWT(s)
John Diebold

Site: SubSAT-4B

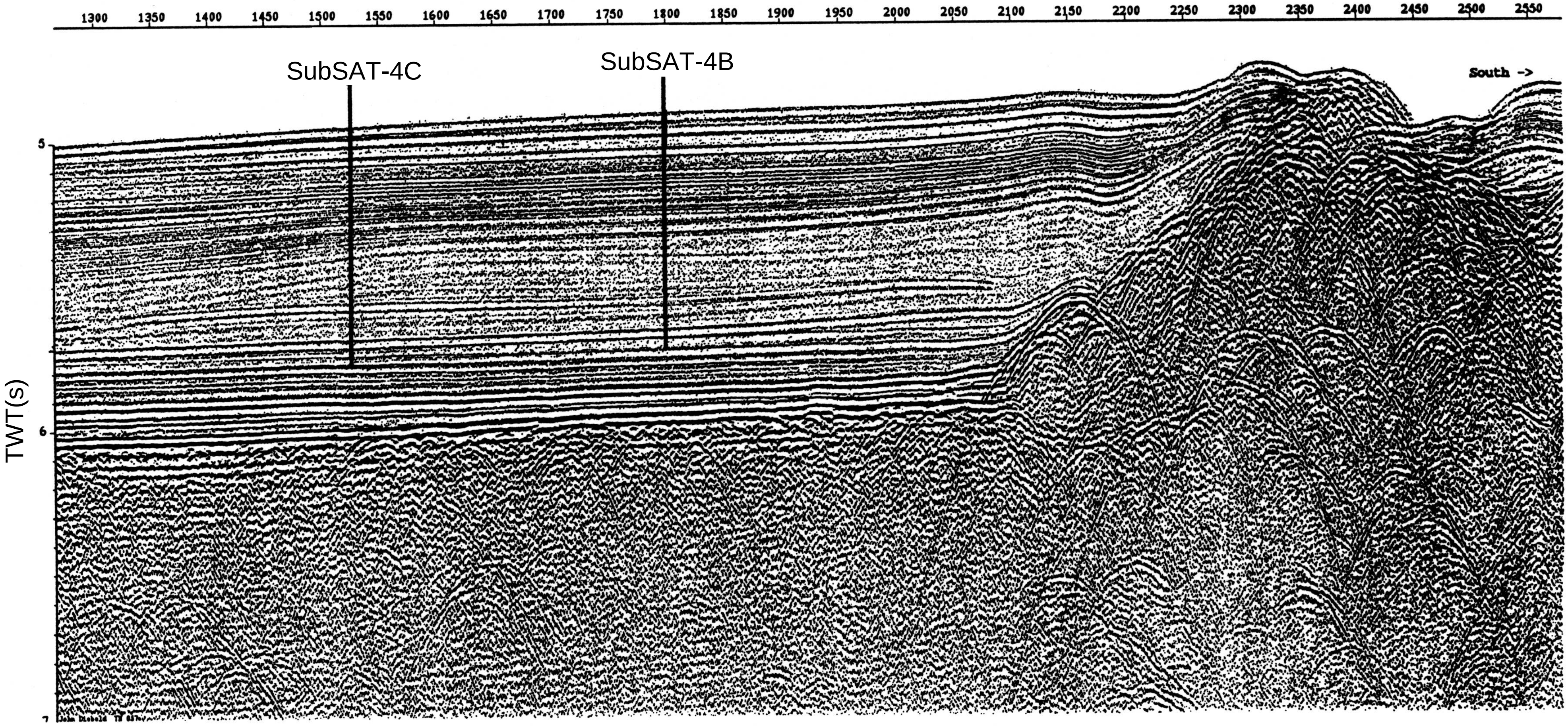
Priority: 2
Position: 52°3.01´S, 4°31.01´E
Water Depth: 3661 m
Sediment Thickness: 1100 m
Approved Maximum Penetration: 700 m
Seismic Coverage: TN057/SubSAT4, shotpoint TN1800

Objectives: The objectives of SubSAT-4B are to serve as a backup to either TSO-6A or TSO-7C. The objectives are essentially the same as those outlined for these sites.

Drilling Program: Triple APC to 200 m, XCB to 400 m, RCB to 700 m

Logging and Downhole: Triple Combo, GHMT, and FMS logs

Nature of Rock Anticipated: Foram-bearing diatom ooze, calcareous diatom ooze, diatomaceous nannofossil chalk, limestone



1300
1350
1400
1450
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
2350
2400
2450
2500
2550
SubSAT-4C
SubSAT-4B
South ->
5
6
7
TWT(s)

Site: SubSAT-4C

Priority: 2
Position: 51°59.08´S, 4°31.0´E
Water Depth: 3701 m
Sediment Thickness: 1100 m
Approved Maximum Penetration: 700 m
Seismic Coverage: TN057/SubSAT4, shotpoint TN4210

Objectives: The objectives of SubSAT-4C are the same as SubSAT-4B.

Drilling Program: Triple APC to 200 m, XCB to 400 m, RCB to 700 m

Logging and Downhole: Triple Combo, GHMT, and FMS logs

Nature of Rock Anticipated: Foram-bearing diatom ooze, calcareous diatom ooze, diatomaceous nannofossil chalk, limestone

See seismic line for SubSAT-4B

LEG 177 SCIENTIFIC PARTICIPANTS*

Co-Chief

Rainer E. Gersonde
Alfred-Wegener-Institut für Polar und Meeresforschung
Postfach 120161
Columbusstraße 2
Bremerhaven 27515
Federal Republic of Germany
Internet: rgersonde@awi-bremerhaven.de
Work: (49) 471-483-1203
Fax: (49) 471-483-1149

Co-Chief

David A. Hodell
Department of Geology
University of Florida
1112 Turlington Hall
Gainesville, FL 32611
U.S.A.
Internet: hodell@nervm.nerdc.ufl.edu
Work: (352) 392-6137
Fax: (352) 392-9294

Staff Scientist

Peter Blum
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
U.S.A.
Internet: peter_blum@odp.tamu.edu
Work: (409) 845-9299
Fax: (409) 845-0876

Inorganic Geochemist

Christopher D. Charles
Scripps Institution of Oceanography
University of California, San Diego
3119 Sverdup Hall
La Jolla, CA 92093-0784
U.S.A.
Internet: ccharles@ucsd.edu
Work: (619) 534-5911
Fax: (619) 534-0784

Inorganic Geochemist

Stagg L. King
School of Earth and Atmospheric Sciences
Georgia Institute of Technology
221 Bobby Dodd Way
Atlanta, GA 30332-0340
U.S.A.
Internet: king@eas.gatech.edu
Work: (404) 894-3976
Fax: (404) 894-5638

Organic Geochemist

Dr. Minoru Ikehara
Institute of Low Temperature Science
Hokkaido University
Kita-19, Nishi-8, Kita-ku
Sapporo, 060
Japan
Internet: ikehara@soya.lowtem.hokudai.ac.jp
Work: n/a
Fax: n/a

Paleomagnetist

James E.T. Channell
Department of Geology
University of Florida
1112 Turlington Hall
P. O. Box 117340
Gainesville, FL 32611-7340
U.S.A.
Internet: jetc@nervm.nerdc.ufl.edu
Work: (352) 392-3658
Fax: (352) 392-9294

Paleontologist (Diatom)

Ulrich Zielinski
Alfred-Wegener-Institut für Polar und Meeresforschung
Columbusstrasse
Bremerhaven 27568
Federal Republic of Germany
Internet: uzielinski@awi-bremerhaven.de
Work: (49) 471-483-1221
Fax: (49) 471-483-1149

Paleontologist (Foraminifer)	E. Carin Andersson Geologisk Instituit Universitetet i Bergen Allégaten 41 Bergen 5007 Norway Internet: carin.andersson@geol.uib.no Work: (47) 5558-3535 Fax: (47) 5558-9416
Paleontologist (Nannofossil)	Maria Marino Dipartimento di Geologia e Geofisica Università degli Studi di Bari via E. Orabona, 4 Bari 70125 Italy Internet: emonopoli@iol.it Work: (39) 80-544-2554 Fax: (39) 80-544-2625
Paleontologist (Nannofossil)	James J. Pospichal Department of Geology Hamilton College 198 College Hill Road Clinton, NY 13323 U.S.A. Internet: jpospich@hamilton.edu Work: (315) 859-7115 Fax: (315) 859-4807
Paleontologist (Radiolaria)	Kazuhiro Sugiyama Department of Earth and Planetary Sciences Nagoya University Chikusa Nagoya 464-01 Japan Internet: k46243a@nucc.cc.nagoya-u.ac.jp Work: (81) 52-789-3022 Fax: (81) 52-789-3033
Physical Properties Specialist	Gerhard Kuhn Alfred-Wegener-Institut für Polar und Meeresforschung Columbusstrasse Postfach 120161 Bremerhavn 27515 Federal Republic of Germany Internet: gkuhn@awi-bremerhaven.de Work: (49) 471-4831204

Fax: (49) 471-4831149

Physical Properties Specialist	Frank R. Rack Department of Geodesy and Geomatics Engineering University of New Brunswick P.O. Box 4400 Fredericton, NB E3B 5A3 Canada Internet: rack@omg.unb.ca Work: (506) 447-3138 Fax: (506) 453-4943
Physical Properties Specialist, Stratigraphic Correlator	Joseph S. Stoner Department of Geology University of Florida 1112 Turlington Hall PO Box 117340 Gainsville, FL 32611-7340 U.S.A. Internet: stoner@nervm.nerdc.ufl.edu Work: (352) 392-2231 Fax: (352) 392-9294
Sedimentologist	Gabriel M. Filippelli Department of Geology Indiana University/Purdue University, Indianapolis 723 W. Michigan St. Indianapolis, IN 46202-5132 U.S.A. Internet: gfilippe@iupui.edu Work: (317) 274-7484 Fax: (317) 274-7966
Sedimentologist	William R. Howard Antarctic CRC and Institute of Antarctic and Southern Ocean Studies University of Tasmania GPO Box 252-80 Hobart, Tasmania 7001 Australia Internet: will.howard@antcrc.utas.edu.au Work: (61) 3-6226-7859 Fax: (61) 3-6226-2973

Sedimentologist

Alan E.S. Kemp
Department of Oceanography
University of Southampton
Southampton Oceanography Centre
European Way
Southampton SO14 3ZH
United Kingdom
Internet: aesk@soc.soton.ac.uk
Work: (44) 1703-592788
Fax: (44) 1703-593059

Sedimentologist

Neil S. Summer
Department of Geology
University of Florida
112 Turlington Hall
P.O. Box 117340
Gainesville, FL 32611-7340
U.S.A.
Internet: summer@geology.ufl.edu
Work: (352) 392-2296
Fax: (352) 392-9294

Sedimentologist

Detlef A. Warnke
Department of Geological Sciences
California State University, Hayward
25800 Carlos Bee Boulevard
Hayward, CA 94542-3088
U.S.A.
Internet: dwarnke@csuhayward.edu
Work: (510) 885-3486
Fax: (510) 885-2526

Stratigraphic Correlator,
MST Operator

Thomas R. Janecek
Antarctic Research Facility
Florida State University
108 Carraway Building
Tallahassee, FL 32306-3026
U.S.A.
Internet: janecek@gly.fsu.edu
Work: (904) 644-2407
Fax: (904) 644-4214

Marine Computer Specialist	John Eastlund Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845 U.S.A. Internet: john_eastlund@odp.tamu.edu Work: (409) 845-3044 Fax: (409) 845-4857
Marine Computer Specialist	Chris Stephens Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547 U.S.A. Internet: chris_stephens@odp.tamu.edu Work: (409) 862-4846 Fax: (409) 845-4857
Marine Electronics Specialist	Eric Meissner Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547 U.S.A. Internet: eric_meissner@odp.tamu.edu Work: (409) 845-2473 Fax: (409) 845-2380
Marine Electronics Specialist	Larry St. John Ocean Drilling Program Texas A&M University 1000 Discovery Drive College Station, TX 77845-9547 U.S.A. Internet: larry_st.john@odp.tamu.edu Work: (409) 845-2473 Fax: (409) 845-2308

*Staffing list is subject to change.