LEG 181

Southwest Pacific Gateway

LEG 181

SOUTHWEST PACIFIC GATEWAY:

Paleohydrography of the Deep Pacific Source

Modified by R. Carter from Proposal 441-Rev Submitted By:

L. Carter, R.M. Carter, K.B. Lewis, I.N. McCave, C.S. Nelson, P.P.E. Weaver, and B. Alloway

Staff Scientist: Carl Richter **Co-Chief Scientists: Robert M. Carter***
I.N. McCave

ABSTRACT

The circulation of cold, deep Antarctic Bottom Water (AABW) is one of the controlling factors in Earth's climate. Today, 40% of this water enters the world ocean through the Southwest Pacific Gateway as a thermohaline driven Deep Western Boundary Current (DWBC). South of 46°S, the DWBC is coupled with the wind-driven Antarctic Circumpolar Current (ACC). Understanding the evolution of the Pacific DWBC is fundamental to understanding world oceanic and climatic histories. The ACC-DWBC system has evolved since the late Oligocene (32-20 Ma), when plate movements created the first deep-water oceanic gaps south of Australia and South America. An excellent stratigraphic record of these events, and of the development of the modern ACC-DWBC, occurs in sediment drifts east of the New Zealand microcontinental plateau. Seven Southwest Pacific drill sites are proposed to reconstruct the stratigraphy, paleohydrography, and dynamics of the DWBC and related water masses. The proposed sites comprise a transect of water depths from 320 m to 4460 m, and span a latitudinal range from 39°S to 51°S. Only one previous hydraulic piston core site is located in this large region (Deep Sea Drilling Project [DSDP] Site 594), and earlier DSDP drilling (Sites 275-276) occurred at sites where Neogene sediment is largely missing due to DWBC erosion. Consequently, our knowledge of Southwest Pacific ocean history, and of the development of the ACC-DWBC system, is extremely poor. Coring during Leg 181 will provide the sedimentary sequences needed to study a range of high-priority problems in Southern Ocean Neogene paleohydrography, sedimentology, paleoclimatology, and micropaleontology.

INTRODUCTION

Leg 181 will drill sites (Tables 1, 2) located around the Southwest Pacific Gateway because:

1. The Pacific Deep Western Boundary Current (DWBC) is the largest single contributor today to the deep waters of the world's oceans (20 Sverdrups [1 Sv = 10^6 $m^3 s^{-1}$]; Fig. 1), and deciphering its history is, therefore, of fundamental importance to global ocean hydrography.

2. The stratigraphic record of the eastern New Zealand Plateau and its abyssal margins is the best one available for deciphering the development history of Pacific Southern Ocean water masses and the sediment drifts they deposited. Recent publications (Carter and Carter, 1993; Lewis, 1994; Carter and McCave, 1994; L. Carter et al., 1996) delineate the region between the Solander Trough and the Kermadec Trench, east of the modern Australian-Pacific plate boundary, as an integrated sediment source-transport-sink area, termed the Eastern New Zealand Oceanic Sedimentary System (ENZOSS). Since ~10 Ma, sediment from mountains along the New Zealand plate boundary has been transported through deep-sea channel/fan systems, delivered into the path of the DWBC, entrained northwards within this current system, and finally consumed by subduction at the same plate boundary after a transport path of some 3500 km. The stratigraphic record from the ENZOSS and, in particular, any new high-resolution Neogene Ocean Drilling Program (ODP) sections from its deep-sea parts, are directly relevant to one of the most important unresolved problems of Cenozoic climatology—namely, the timing and precise nature of the development of widespread glaciation on the Antarctic continent (e.g., Barrett, in press). In turn, the same glacial events that contribute source water to the DWBC and its companion flow, the Antarctic Circumpolar Current (AAC), force the boundary current south of 49°S.

3. The gateway region includes two major oceanic fronts, the Subtropical Convergence and the Subantarctic Front, and is proximal to a third, the Antarctic Convergence (Figs. 2, 3). Thus, the region is in a prime position to allow determination of the migration of these boundaries, the forcing processes which cause them to move, and the environmental response to their

movement.

BACKGROUND

Tectonic Creation of the Southern Ocean

The origin of the modern thermohaline ocean circulation system must postdate the tectonic creation of a continuous Southern Ocean. Particularly important for the origin of the ACC-DWBC was the opening of the Australian-Antarctic (South Tasman) and South American-Antarctic (Drake Passage) deep-water flow gateways (Lawyer et al., 1992). The South Tasman Gateway, including the Balleny Fracture Zone (Lonsdale, 1988), opened to deep water in the early Oligocene (~32 Ma), thereby allowing connection between the Indian and Pacific Oceans for the first time (Kennett, et al., 1972). Later, at ~20 Ma (earliest Miocene), the opening of Drake Passage (Boltovskoy, 1980) allowed the establishment of the full circum-Antarctic ocean circulation. During the critical period from the late Eocene to the Miocene, the New Zealand Plateau was located downcurrent from the evolving South Tasman gateway (Watkins and Kennett, 1971) and directly in the path of the evolving AAC-DWBC system.

Modern Oceanography

The supply of deep water to the Pacific Ocean is dominated by a single source—the DWBC, which flows north out of the Southern Ocean along the east side of the Campbell Plateau-Chatham Rise-Hikurangi Plateau located east of New Zealand (Figs. 1-6). The volume transport of the DWBC is about 20 Sv, which comprises ~40% of the total input of deep water to the world’s oceans (Warren, 1973; 1981). (A secondary, but, minor, flow of ~3 Sv of deep-water flows north into the Peru-Chile basin; Lonsdale, 1976). The magnitude of DWBC flow, and the low temperature of the water involved, are major determinants of the oceanography of the Pacific Ocean and of the global heat balance. Monitoring the DWBC flow at its entry into the Pacific is a key area where the "global salt conveyor" hypothesis (Gordon, 1988; Broecker et al., 1990; Schmitz, 1995) can be tested, as the flow, thereafter, is believed to spread out to fill the Pacific. Some water upwells and returns at shallower depths to the Atlantic, whereas other waters return south as North Pacific Deep Water (NPDW).

The supply of cold water to the deep Pacific from the main generating regions in the Weddell and Ross Seas is modulated by the ACC, which mixes these waters with North Atlantic Deep Water (NADW) in the South Atlantic to form Circumpolar Deep Water (CDW). Deep-water output to the Pacific, therefore, carries the combined signatures of Southern Ocean processes in the region of deep-water formation, chemical composition related to Southern Ocean gas exchange, and NADW. Despite its turbulent passage around Antarctica, CDW is not completely mixed, and a distinct NADW salinity-maximum can be recognized at depths of 2800 m (at 55°S) deepening northwards to 3400 m (at 28°S). In the southwest Pacific, the DWBC comprises three main divisions (1) lower CDW, a mixture of bottom waters generated around Antarctica, in particular cold Weddell Sea deep water and NADW; (2) salinity-maximum middle CDW, representing the NADW core; and (3) strongly nutrient-enriched and oxygen-depleted upper CDW, mainly derived from Indian Ocean outflow added to Pacific outflow returning through the Drake Passage. The DWBC has its upper boundary at depths around 2000-2500 m. On the eastern side, the DWBC is overlain between 2550 and 1450 m depth by south-flowing NPDW, and is marked by high silica and an oxygen minimum. Regionally, both DWBC and NPDW are overlain by low-salinity Antarctic Intermediate Water (AAIW) (Figs. 4, 6).

The ACC-DWBC enters the Southwest Pacific through gaps in the Macquarie Ridge complex before passing along the 3500-m-high margin of the Campbell Plateau. Near the mouth of the Bounty Trough, the ACC uncouples and continues its eastward path, whereas the DWBC flows north around the eastern end of Chatham Rise and through Valerie Passage, where a small part of the flow diverges through gaps in the Louisville Ridge. Valerie Passage, the 250-km-wide gap between the Chatham Rise and the Louisville seamount chain, therefore marks the gateway to the Pacific for the DWBC.

Sedimentary Record of the ACC-DWBC

Sediments on the eastern New Zealand margin at shelf to upper bathyal depths (100-1000 m) are known to have been strongly affected by currents since at least the late Oligocene (Ward and Lewis, 1975; Carter, 1985; Fulthorpe et al., 1996). This evidence for strong paleoflows, together with the confirmation that substantial Antarctic glaciation commenced at least as early as the early Oligocene (Shackelton and Kennett, 1975; Barrett, in press; Prydz Bay drilling, Barren and Larsen, 1989), implies that Pacific hydrography has been fundamentally affected by an evolving circumpolar current and western boundary current system since the mid-Cenozoic.

To reconstruct the paleoflow of the DWBC and overlying current system requires drill sites through thick undisturbed fine-grained sediment masses constructed under the influence of the current. Seismic records indicate the presence of suitable sedimentary drifts at many points along the eastern edge of the New Zealand Plateau in water and paleowater depths between 300 m and 5500 m (Carter and McCave, 1994; L. Carter et al., 1996). Three sediment sources are involved in building these drifts: (1) transport into the area via the DWBC itself (e.g., subantarctic diatoms present in the drifts at 40°S; Carter and Mitchell, 1987); (2) pelagic and hemipelagic rain and airfall rhyolitic ash which, over the last 20 k.y., has been input at a rate of up to one third that of fluvial terrigenous sediment (Carter et al., 1995); and (3) terrigenous sediment from New Zealand, deposited at the shelf-edge by mid-accretion (Fulthorpe and Carter, 1991) or delivered into the path of the DWBC from turbidity currents traveling down the Solander, Bounty, and Hikurangi channel systems. Each of these sediment sources can be constrained, and the sedimentary dynamics and transport paths of the modern system are moderately well delineated (e.g., Carter and Carter, 1993; Carter and McCave, 1994; Lewis, 1994). In contrast, little is known regarding the earlier Cenozoic record of the DWBC.

The available seismic records show that the DWBC has been active along the eastern New Zealand margin since at least the Miocene, and probably since the mid-Oligocene (32 Ma) (Carter and McCave, 1994). After ~10 Ma, abundant terrigenous material was shed from rising mountains along the Alpine Fault plate boundary (Kennett, von der Borch, et al., 1986) and fed into the Solander, Bounty, and Hikurangi channel systems, especially at times of late Neogene glacial sea-level lowstand. Much of this sediment was then entrained into the DWBC drift system, which carried it northward to be eventually subducted into the Kermadec Trench.

Sediment is delivered into the DWBC through two newly described transport conduits, the Bounty

(Carter and Carter, 1993) and Hikurangi (Lewis, 1994) channel-fan systems. A third feeder channel, Solander, is poorly known, but extends for >450 km before discharging into the DWBC at Emerald Basin between Macquarie Ridge and the Western side of Campbell Plateau (R. Carter et al., 1996). The Hikurangi Fan has been termed a "fan-drift" by Carter and McCave (1994) because it apparently represents the extreme case of a fan whose thickness and facies pattern are directly remolded by a deep current into the form of a sediment drift. In contrast, the Bounty Fan, located in a bathymetric embayment, has retained its fan morphology and has developed directly across the path of the DWBC (Carter and Carter, 1993), the only evidence of drift formation being scour of the northern fan and redeposition of material as a series of small discrete ridges. Compared to Hikurangi Fan Drift, the Bounty Fan has formed in a region where the DWBC is slowed because of a gently sloping western boundary and the shelter provided by Bollons Seamount.

The two described abyssal fans are supplied with sediment by turbidites passing through the Bounty and Hikurangi channels, each of which is over 1000 km long. The Hikurangi channel heads in the Kaikoura Canyon, only a few hundred meters from shore, and less than ten kilometers from the rapidly rising 2.5-km-high Seaward Kaikoura Mountains. The Hikurangi system is therefore active today during interglacial times. In contrast, the Solander and Bounty Channels head in a number of canyons that indent the edge of the continental shelf. The Bounty and Solander systems are, therefore, strongly sea-level (i.e., climatically) controlled with most sediment being fed into them during glacial lowstands. In contrast, during interglacial periods the same sediment stream is diverted along the inner shelf, some of it even reaching the Hikurangi System via the Kaikoura Canyon (Carter and Herzer, 1979).

SCIENTIFIC OBJECTIVES

The Leg 181 drill sites are mostly located in sediment drifts across a depth range of 320-4460 m, and will provide a moderate resolution record (2-5 cm/k.y.) of climatic and paleohydrographic changes since the early Miocene. We aim to recover material that will allow the following scientific problems to be studied.

1. Delineate the Cenozoic development of zonal water masses and the ACC system. Current understanding of paleoclimate suggests that the earliest major meltwater events from Antarctic glaciation occurred at ~38 Ma (Eocene/Oligocene boundary; Shackleton and Kennett, 1975; Miller et al., 1990). At 32 Ma (mid-Oligocene), the South Tasman Gateway opened, including the Balleny Fracture zone (Lonsdale, 1988), thereby connecting the Indian and Pacific Oceans for the first time (Kennett, et al., 1972). Finally, it was not until ~20 Ma (earliest Miocene) that the opening of Drake Passage (Boltovskoy, 1980) allowed the establishment of the full pattern of circum-Antarctic ocean circulation. The evolution of this system, including periods when the boundary current component may have extended into shallow depths or reversed (Mikolajewicz et al., 1993), is the target of Sites SWPAC-5A and 6B. These sites may also penetrate to the regionally widespread 29 Ma mid-Oligocene unconformity (Marshall Paraconformity; Carter, 1985), the genesis of which may relate to the inception of ACC-DWBC activity as much as to global sea-level change (cf. the postulated large 29 Ma lowstand of Haq et al., 1987). Site SWPAC-1A is targeted on large Miocene-Pliocene platform drifts that grew from a paleowater depth of 1000 m in the head of the Bounty Trough (Fulthorpe and Carter, 1991).

2. Infer the changing paleohydrography of the CDW supply to the Pacific Ocean; in particular, to trace the history of mixing of Weddell Sea Deep Water (WSDW) and NADW components.

Measurement of δ^{18}O, δ^{13}C and Cd/Ca from microfossil tests will be used to distinguish the relative contribution of nutrient-enriched NADW and δ^{13}C depleted components (Boyle and Keigwin, 1987; Oppo and Fairbanks, 1987; Charles and Fairbanks, 1992; Bertram et al., 1995). Sites SWPAC-2A and 5A were selected to maximize the chance of obtaining the high-quality carbonate-rich records required for such measurements. For the deeper water sites, should carbonate percentages be low, the bulk carbonate technique of Shackleton et al. (1993) may yield a satisfactory isotope stratigraphy. However, we have obtained monospecific benthic and planktonic oxygen isotope records for the mid-Holocene to Stage 3 from a core at 4802 m water depth, and McCave and Carter (in press) estimate the carbonate compensation depth (CCD) to lie at ~4750 m. The late Neogene stratigraphy may be strongly supported by a tephrochronology derived from the numerous widespread Cenozoic ash beds deposited east of New Zealand. Global understanding of the history of these water masses will require the comparison of gradients of water composition between sites in the North Atlantic, South Atlantic, North Pacific, and Southern Oceans.

3. Determine the relative paleoflow speeds of deep and intermediate waters, and thereby estimate the changing flux of CDW into the Pacific through time.

The noncohesive sortable silt (10-63 micron) fraction has been shown at widely separated locations to yield coherent indications of flow speed and, hence, water mass movement (McCave et al., 1995a, b; Manighetti and McCave, 1995; Robinson and McCave, 1994; Haskell et al., 1991). Evaluation of such grain-size signals in the North Chatham Drift (Site SWPAC-5A) and Campbell Drift (Site SWPAC-7A) will permit estimation of the velocity behavior of the DWBC. Sites 1C, 2A, and 6B will yield indications of the behavior of low salinity AAIW. Site SWPAC-7A, located a little to the south of the Bounty Trough, will be important for assessing the extent to which the ACC acts as a driving force for CDW inflow, because it is at the latitude of the mouth of the trough that the modern ACC veers east into the Pacific where it decouples from the deep boundary flow (cf. Semtner and Chervin, 1992).

4. Establish the history and depth ranges of AAIW across the New Zealand Plateau.

In the North Atlantic, an intermediate water (possibly paleo-Labrador sea water) has been shown to increase both in depth range and speed during glaciation, concomitant with a decrease in NADW production (Boyle and Keigwin, 1987; Manighetti and McCave, 1995). Since this change is associated with suppression of the NADW, there is little reason to expect the same glacial/interglacial changes to AAIW in the southern ocean. However, Pudsey et al. (1988) have argued that AABW production also diminished during glacial periods as a result of the grounding of ice sheets, in which case the thickness of AAIW may well have increased concomitantly. If the vigor of global deep circulation was decreased by these North Atlantic and Antarctic events, then, during glacial times, the Indian/Pacific upper CDW should have become even more nutrient enriched and oxygen depleted than it is today. Material from Site SWPAC-5A (water depth 3308 m) will be used for $\delta^{13}C$ and trace element analysis (e.g., Cd/Ca in calcite and opal) to allow ocean paleochemistry to be used to determine whether during glaciation periods the site lay under severely depleted AAIW or enriched CDW.

5. Determine the history of productivity and surface water mass fluctuations in the vicinity of the Subtropical Convergence.

Near zones of upwelling, such as the subtropical convergence (STC), it is usually difficult to distinguish between climatically controlled temporal and spatial changes in productivity because the convergence moves. However, for at least the last full glacial/interglacial cycle the STC has apparently been topographically trapped over the Chatham Rise (Fenner et al., 1992; Nelson et al., 1993). This raises the prospect of being able to obtain temporal records of productivity change from faunal, isotopic, and chemical data without the aliassing usually produced by shifts in the position of such convergences. ODP Site 594, in 1200 m of water just south of the present STC is a valuable control because it shows that cold water reached there during the last glaciation (Nelson et al., 1993), probably representing waters wind-drifted from the Subantarctic Front (SAF), which itself remained bounded by the Campbell Plateau. Site 594 provides a high-quality record extending to the middle Miocene, and we aim to match it by similar records from beneath the STC and farther north (Site SWPAC-5A) and south (Sites SWPAC-6A, 7A).

6. Examine the shifting positions of the Subantarctic Convergence.

The zone of cold water between the STC and the Antarctic Convergence (AAC) at 60°S is divided by the SAF at about 51°S (Health, 1995). Nelson et al. (1993) found a sharp cooling of waters at glacial levels in Site 594, suggesting that the SAF lay nearby. Our most southerly drift sites (Sites SWPAC-6B, 7A) and Site SWPAC-8A on the levee of the Bounty Channel will allow us to assess the shift in position of these climatically important fronts, using faunal and coarse-fraction analysis, and stable isotopic and magnetic susceptibility measurements to trace ice-rafted detritus.

7. Test the record of circum-Antarctic flow against the Milankovitch orbital model, including estimates of simultaneity with Northern Hemisphere records.

Achieving this objective requires the retrieval of high-quality, long-term faunal and isotopic records from Southern Ocean sites to assess changes in temperature, salinity, and CO_2 as components of the climate system. The relative timing of events between the Northern and Southern Hemispheres will be evaluated (cf. Nelson et al., 1985). We anticipate the best long-term records will come from Sites SWPAC-2A and 5A on the north flank of Chatham Rise, where the North Chatham Drift is up to 1000 m thick and probably extends back to the late Oligocene. The deeper levels of the drift will be principally examined farther north (Site SWPAC-9A), where the thickness is reduced, although obviously with less stratigraphic resolution.

8. Study the effect of an oscillating sediment source controlled by Pleistocene sea-level cyclicity on fan overbank turbidite deposition and sediment supply to the DWBC.

The Bounty Channel and Fan are fed with terrigenous sediment through a number of submarine canyons, which cut the eastern South Island shelf edge. Located about 30-60 km offshore, these canyons were alternately supplied directly with sediment during the Pliocene-Pleistocene glacial lowstands, and cut off during interglacial highstands when sediment was moved directly along the inner shelf (Carter and Carter, 1993). Consequently, the Bounty Fan was supplied with terrigenous sediment mostly during glacial periods, and the levees of the Bounty Channel comprise a regular sequence of 5 to 8-m-thick packets of glacial silt-mud turbidites alternating with interglacial biopelagic calcareous ooze (Carter et al., 1990). The regularity of these cycles is such that they can be matched *prima facie* with the oxygen isotopic record back to Stage 100, and viewed as the deep-sea record of continental shelf stratigraphic sequences (Carter and Carter, 1992). Site SWPAC-8A will penetrate about 50 of the cycles identified on seismic records, providing (1) a high-quality record of turbidity current activity through the Bounty Channel since the early Pleistocene; (2) a test of the correlation between the observed seismic cyclothems and the oxygen isotopic stages; and (3) a quantitative model of rates of sediment supply to the DWBC and deep sea during a time of glacio-eustatic oscillation of sea-level.

9. Estimate the quantities of sediment fed into the DWBC from all sources, including terrigenous sediment delivered through the Solander, Bounty, and Hikurangi channels to understand the relative importance of tectonic, climatic, sea-level and water-mass controls and to derive a sedimentary budget for the ENZOSS.

Since the Pliocene the three largest sources of sediment for the DWBC drifts have been turbidity currents traveling the length of the Solander, Bounty, and Hikurangi channel systems (Carter et al., 1990; 1994; and 1996; Lewis, 1994). Other major sediment sources are direct transport into the region by the DWBC and pelagic, hemipelagic, and volcanic fallout. In addition to the differing primary targets at each site, all SWPAC sites will contribute data toward the development of a quantitative sedimentary model and budget for the ENZOSS.

Some of the drift sequences targeted for drilling, particularly those nearer North Island, will contain Pliocene-Pleistocene volcanic ash layers of potential value for correlation. Several very large explosive eruptions have occurred in the Central Volcanic Region of New Zealand in the last few million years (Shane et al., 1996). The largest eruptions in the last 50 k.y. have exceeded 100 km^2 in volume. These ashes are generally distributed to the east of New Zealand (Stewart and Neall, 1984), and occur widely in marine cores (Ninkovitch, 1968; Lewis and Kohn, 1973; Watkins and Huang, 1977; Kyle and Seward, 1984; Nelson, 1988; Carter et al., 1995). Volcanic ash horizons may also provide useful stratigraphic markers at horizons as old as late Miocene (van der Lingen, 1968) and perhaps earlier.

The application of combined isothermal plateau fission-track (ITPFT) for dating and laser ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) for fingerprinting has revolutionized the ash chronostratigraphy of the Pliocene-Pleistocene Wanganui Basin (e.g., Naish et al., 1996), and holds great promise for application to any ash layers that are recovered from Leg 181 sites.

DRILLING STRATEGY AND PROPOSED SITES

Sites (Table 2) were selected along two depth transects (A and B on Fig. 1) and one latitudinal transect (C on Fig. 1, ~12° long) that links the two depth transects. The latitudinal transect extends from near the estimated glacial position of the SAF (51°S) to north of the modern position of the STC (39°S). With the time constraints of a single leg, a tradeoff is required between providing either (1) fewer and shallower extremely high-quality (triple advanced hydraulic piston corer [APC]) records through mainly younger Neogene sediments; or (2) a greater number of high-quality (double APC) records which cover a wider geographic range, some of which penetrate back to the critical 35-20 Ma interval over which the South Tasman and Drake Passage Gateways opened. We have approached this tradeoff by scheduling triple-APC coring on the primary Chatham Rise transect and double-APC coring at most other sites.

1. Chatham Rise Transect (A)

This transect comprises three holes in water depths between 300 and 3308 m located in a northeast band across major sediment drifts of the Chatham Rise. All sites are above the modern CCD, recently determined to be at ~4750 m in this area (McCave and Carter, in press). Sections span an inferred age of early Miocene to Holocene within a thickness of 400-750 m. Two sites (Sites SWPAC-2A and 4A) terminate in presumed Oligocene sediment, which marks the regional inception of strong bottom-water flow into the Pacific.

2. Campbell Plateau Transect (B)

This transect commences with Site SWPAC-1A in 300 m of water on the eastern South Island shelf (Canterbury Drifts; to sample upper AAIW and basal thermocline water), then passes southeast of DSDP Site 594 to link to two sites near the eastern edge of the Campbell Plateau, Sites SWPAC-6B and 7A. Site SWPAC-6A (960 m water depth) is targeted to sample AAIW. Biopelagite is present at the surface and is expected to extend downhole to the target depth. Sedimentation rate in a nearby core (F-121) is <1 cm/yr, but, from the thickening of seismic intervals toward Site SWPAC-6A, significantly higher rates are expected there. Site SWPAC-7A is situated on the crest of the large Campbell Drift, and at 4390 m lies close to the regional CCD. However, a benthic and planktonic isotope record from a site to the north at 4802 m, and pilot studies of bulk carbonates (Shackleton et al., 1993) indicate that an isotope record may be determinable with paleomagnetics and perhaps tephrochonology as additional means of age control.

The Campbell Plateau transect will yield a terrigenous silt record of late Miocene to Holocene fluctuations in current strength near the AAIW/thermocline transition (Site SWPAC-1A), a mainly carbonate record of the Neogene AAIW paleohydrography of the Campbell Plateau (Site SWPAC-6B), and a mixed carbonate abyssal mud record of Neogene paleohydrography of the DWBC (Site SWPAC-7A).

3. Linking Latitudinal Transect (C)

This transect spans a latitudinal range from 51°S to 39°S, commencing on the Campbell Drift (Site SWPAC-7A, Campbell Plateau transect) and passing through the North Chatham Drift (Site SWPAC-2A, Chatham Rise transect). The addition of two other sites completes the transect: Site SWPAC-8A near 47°S on the north levee of the Bounty Fan and Site SWPAC-9A at 39°S on the Rekohu Drift.

The latitudinal transect has been inserted to better track movements of fronts (STC, SAF, and possibly the AAC) during glacial and interglacial cycles. Penetration is therefore limited to the Plio-Pleistocene (last 3 m.y.) at Site SWPAC-8A. This site is also deliberately located on a fan levee to retrieve information on sedimentary processes, particularly on the frequency of turbidity currents and their potential as a proxy for paleoseismic events, and the glacial/interglacial switching of sediment supply into the DWBC system.

LOGGING PLAN

Sediments encountered at the seven primary 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 sediment accumulation rates so there is great potential for generating very high-resolution records of the regional paleoclimatic and paleoceanographic variability. All proposed sites have penetration depths exceeding 300 m and will be logged with the Triple-combo, FMS, and Geological High-resolution Magnetometer (GHMT) tool strings.

REFERENCES

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

Barrett, P.J., in press. Antarctica and global climate change—a geological perspective.*In* Harris, C.M., and Stonehouse, B. (Eds.), *Antarctica and Global Climatic Change*: Cambridge (Scott Polar Res. Inst. and Belhaven Press).

Bertram, C.J., Elderfield, H., Shackelton, N.J., and MacDonald, J.A., 1995. Cadmium/calcium and carbon isotope reconstructions of the glacial northeast Atlantic Ocean. *Paleoceanography*, 10:563-578.

Boltovskoy, E., 1980. The age of the Drake Passage. *Alcheringa*, 4:289-297.

Boyle, E.A., and Keigwin, L., 1987. North Atlantic thermo-haline circulation during the past 20,000 years linked to high latitude surface temperature. *Nature*, 330:3540.

Broecker, W.S., 1991. The great ocean conveyor. *Oceanography*, 4:79-89.

Broecker, W.S., Bond, G., and Klas, M., 1990. A salt oscillator in the glacial Atlantic? 1. The concept. *Paleoceanography*, 5:469-477.

Carter, L., and Carter, R.M., 1993. Sedimentary evolution of the Bounty Trough: a Cretaceous rift basin, southwestern Pacific Ocean. *In* Ballance, P. (Ed.), *Sedimentary Basins of the World-South Pacific*: Amsterdam (Elsevier).

Carter, L., Carter, R.M., McCave, I.N., and Gamble, J., 1996. Regional sediment recycling in the abyssal SW Pacific Ocean. *Geology*, 24:735-738.

Carter, L., Carter, R.M., Nelson, C.S., Fulthrope, C.S., and Neil, H.L., 1990. Evolution of Pliocene to Recent Abyssal Sediment Waves on Bounty Channel levees, New Zealand. *Marine Geology*, 95:97-109.

Carter, L., and Herzer, R.H., 1979. The hydraulic regime and its potential to transport sediment on the Canterbury continental shelf. *New Zealand Oceanographic Institute, Memoir*, 83:1-33.

Carter, L., and McCave, I.N., 1994. Development of sediment drifts approaching an active plate margin under the SW Pacific Deep Western Boundary Current. *Paleoceanography*, 9:1061-1085.

Carter, L., and Mitchell, J.S., 1987. Late Quaternary sediment pathways through the deep ocean, east of New Zealand. *Paleoceanography*, 2:409-422.

Carter, L., Nelson, C.S., Neil, H.L., and Froggett, P.C., 1995. Correlation, dispersal, and perservation of the Kawakawa Tephra and other late Quatermary tephra layers in the Southwest Pacific Ocean. *New Zealand Jour. Geology and Geophysics*, 38:29-46.

Carter, R.M., 1985. The mid-Oligocene Marshall Paraconformity, New Zealand: coincidence with global eustatic sea-level fall or rise? *Jour. Geology*, 93:359-371.

Carter, R.M., and Carter, L., 1992. Seismic Imaging of Pleistocene deep-sea cyclothems: implications for sequence stratigraphy. *Terra Nova*, 4:682-692.

Carter, R.M., Carter, L., and Davy, B., 1994. Geologic and stratigraphic history of the Bounty Trough, southwestern Pacific Ocean. *Marine and Petroleum Geology*, 11:79-93.

Carter, R.M., Carter, L., and McCave I.N., 1996. Current controlled sediment deposition from shelf to deep sea: the history of the Pacific DWBC system. *Geologisches Rundschau*, 85:438-451.

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

Fenner, J., Carter, L., and Stewart, R., 1992. Late Quatemary paleoclimatic and paleoceanographic change over northern Chatham Rise, New Zealand. *Marine Geology*, 108:383-404.

Fulthorpe, C.S., and Carter, R.M., 1991. Continental shelf progradation by sediment drift accretion. *Geol. Soc. Amer. Bull.* 103:300-309.

Fulthorpe, C.S., Carter, R.M., Miller, K.G., and Wilson, J. 1996. The Marshall Paraconformity: a Southern Hemisphere record of a mid-Oligocene glacioeustatic lowstand? *Mar. Petrol. Geol.*, 13, 61-77.

Gordon, A.L., 1988. The Southern Ocean and Global Climate. *Oceanus*, p.39-46.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235:1156-1167.

Haskell, B.U., Johnson, T.C. and Showers, W.J., 1991. Fluctuations in deep western North Atlantic circulation on the Blake Outer Ridge during the last deglaciation. *Paleoceanography*, 6:21-31.

Kennett, J.P., Burns, R.E., et al., 1972. Australian-Antarctic continental drift, paleocirculation changes and Oligocene deep sea erosion. *Nature*, 239:51-55.

Kennett, J.P., von der Borch, C.C., et al., 1986. *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office).

Kyle, P.R., and Seward, D., 1984. Dispersed rhyolitic tephra from New Zealand in deep-sea sediments of the Southern Ocean. *Geology*, 12:487-490.

Lawyer, L.A., Gahagan, L.M., and Coffin, M.F., 1992. The development of paleoseaways around Antarctic.

In Kennett, J.P., and Warnke, D.A. (Eds.), *The Antarctic Paleoenvironment: A Perspective on Global Change*, Part 1, American Geophysical Union, Antarctic Research Series, 56:7-30.

Lewis, K.B., 1994. The 1500 km long Hikurangi Channel: a trench-axis channel that leaves the trench, crosses a plateau and feeds a fan-drift. *Geomarine Letters*, 14:19-28.

Lewis, K.B., and Kohn, B.P., 1973. Ashes, turbidites and rates of sedimentation on the continental slope off Hawkes Bay. *New Zealand Jour. Geology and Geophysics*, 16:439-454.

Lonsdale, P., 1976. Abyssal circulation in the southeast Pacific and some geological implications. *Geophys. Res.*, 93:3078-3104.

Lonsdale, P., 1988. Geography and history of the Louisville hotspot chain in the southwest Pacific. *Geophys. Res.*, 93:3078-3104.

Manighetti, B. and McCave, I.N., 1995. Late glacial and Holocene paleocurrents around Rockall Bank, NE Atlantic Ocean. *Paleoceanography*, 10:611-626.

McCave, I.N. and Carter, L., in press. Recent sedimentation beneath the Deep Western Boundary Current off northern New Zealand. *Deep Sea Research*.

McCave, I.N., Manighetti, B. and Robinson, S.G. 1995a. Sortable silt and fine sediment size/composition slicing: parameters for paleocurrent speed and paleoceanography. *Paleoceanography*, 10:593-610.

McCave, I.N., Manighetti, B. and Beveridge, N.A.S. 1995b. Circulation in the glacial North Atlantic inferred from grain-size measurements. *Nature*, 374:149-152.

Mikolajewicz, U., Maier-Reimer, E., Crowley, T.J., and Kim, K.-Y., 1993. Effect of Drake and Panamanian gateways on the circulation of an ocean model. *Paleoceanography*, 8:409-426.

Miller, K.G., Wright, J.D., and Fairbanks, R.G., 1990. Unlocking the ice house: Oligocene-Miocene oxygen isotopes, eustasy and margin erosion. *Geophys. Res.*, 96:6829-6848.

Naish, T.R., Kamp, P.J.J., Alloway, B.V., Pillans, B.J., Wilson, G.S., and Westgate, J.A., 1996. Integrated tephrochronology and magnetostratigraphy for cyclothemic marine strata, Wanganui Basin: implications for the Pliocene-Pleistocene boundary in New Zealand. *Quatemary International*, 34-36:28-48.

Nelson, C.S., 1988. Revised age of late Quatemary tephra at DSDP Site 594 off eastern South Island and some implications for correlation. *Geol. Soc. New Zealand Newsletter*, 82:35-40.

Nelson, C.S., Cooke, P.J., Hendy, C.H., and Cuthbertson, A.M., 1993. Oceanographic and climatic changes over the past 150,000 years at Deep Sea Drilling Project Site 594 off southeastern New Zealand, southwest Pacific Ocean. *Paleoceanography*, 8:435-458.

Nelson, C.S., Hendy, C.H., Jarrett, G.R., and Cuthbertson, A.M., 1985. Near-synchroneity of New Zealand alpine glaciations and Northern Hemisphere continental glaciations during the past 750 kyr. *Nature*, 318:361-363.

Ninkovitch, D., 1968. Pleistocene volcanic eruptions in New Zealand recorded in deep sea sediments. *Earth Planet. Sci. Lett.*, 4:89-102.

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

Pudsey, C.J., Barker, P.F., and Hamilton, N., 1988. Weddell Sea abyssal sediments: a record of Antarctic bottom water flow. *Marine Geology*, 81:289-314.

Robinson, S.G., and McCave, I.N., 1994. Orbital Forcing of bottom-current enhanced pelagic sedimentation on Feni Drift, N.E. Atlantic, during the mid-Pleistocene. *Paleoceanography*, 9:943-972.

Schmitz, W.J., 1995. On the interbasin-scale thermohaline circulation. *Reviews of Geophysics*, 33:151-173.

Semtner, A.J., and Chervin, R.M., 1992. Ocean general circulation from a global eddy-resolving model. *Geophys. Res.*, 97:5493-5550.

Shackleton, N.J., Hall, M.A., Pate, D., Meynadier, L., and Valet, L., 1993. High-resolution stable isotope stratigraphy from bulk sediment. *Paleoceanography*, 8:141-148.

Shackleton, N.J., and Kennett, J.P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses. *In* Kennett, J.P., Houtz, R.E., et al., *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office), 743-755.

Shane, P.A.R., Black, T.M., Alloway, B.V., and Westgate, J.A., 1996. Early to middle Pleistocene tephrochronology of North Island, New Zealand: implications for volcanism, tectonism, and paleoenvironments. *Geol. Soc. Amer. Bull.*, 108:915-925.

Stewart, R.B. and Neall, V.E., 1984. Chronology of paleoclimatic change at the end of the last glaciation. *Nature*, 311:47-48.

Van der Lingen, G.J., 1968. Volcanic ash in the Makara Basin (Upper Miocene), Hawkes Bay, New Zealand. *New Zealand Jour. Geology and Geophysics*, 11:693-705.

Ward, D.M., and Lewis, D.W., 1975. Paleoenvironmental implications of storm-scoured ichnofossiliferous mid-

Tertiary limestones, Walhao district, South Canterbury, New Zealand. *New Zealand Jour. of Geology and Geophysics*, 18:881-908.

Warren, B.A., 1973. Transpacific hydrographic sections at latitudes 43°S and 28°S; the SCORPIO Expedition II - deep water. *Deep-Sea Research*, 20:9-38.

Warren, B.A., 1981. Deep circulation of the world ocean. *In* Warren, B.A., and Wunsch, C. (Eds.), *Evolution of Physical Oceanography*, 6-41: Massachusetts (MIT Press).

Watkins, N.D., and Huang, T.C., 1977. Tephras in abyssal sediments east of the North Island, New Zealand; Chronology, paleowind velocity, and paleoexplosivity. *New Zealand Jour. Geology and Geophysics*, 20:179-199.

Watkins, N.D., and Kennett, J.P. 1971. A major sedimentary disconformity as evidence of an upper Cenozoic change in bottom water velocity between Australia, New Zealand and Antarctica. *Geol. Soc. Amer., Abstr.* 746.

LEG 181 FIGURE CAPTIONS

Figure 1. Regional bathymetry, sediment bodies, sediment pathways, and SWPAC transects and sites within the ENZOSS system, Southwest Pacific Ocean. STST = Solander trough submarine channel.

Figure 2. Location of SWPAC sites (numbered black dots) projected onto a meridional section through the major water masses of the Pacific Ocean basin. Lines show salinity values.

Figure 3. Major water masses, fronts, and current systems of the Southwest Pacific. The ACC reenters the region from the west with DWBC flow commencing east of the Macquarie Ridge complex. Near latitude 50°S, the ACC resumes its eastward path with 20 Sv of DWBC flow continuing northwards around the east end of Chatham Rise. SSW = subtropical surface water, STC = subtropical convergence, ASW = Australasian subantarctic water, SAF = subantarctic front, CSW = circumpolar subantarctic water, and AAC = Antarctic convergence.

Figure 4. Southwest-northeast section across the DWBC system and related water masses, from north Chatham Rise to the Louisville seamount chain and beyond.

Figure 5. West-east section through the eastern New Zealand continental margin, showing location of proposed SWPAC drilling sites in relation to bathymetry and major water masses (abbreviations are expanded in Table 1). Site SWPAC-3A is an alternate site.

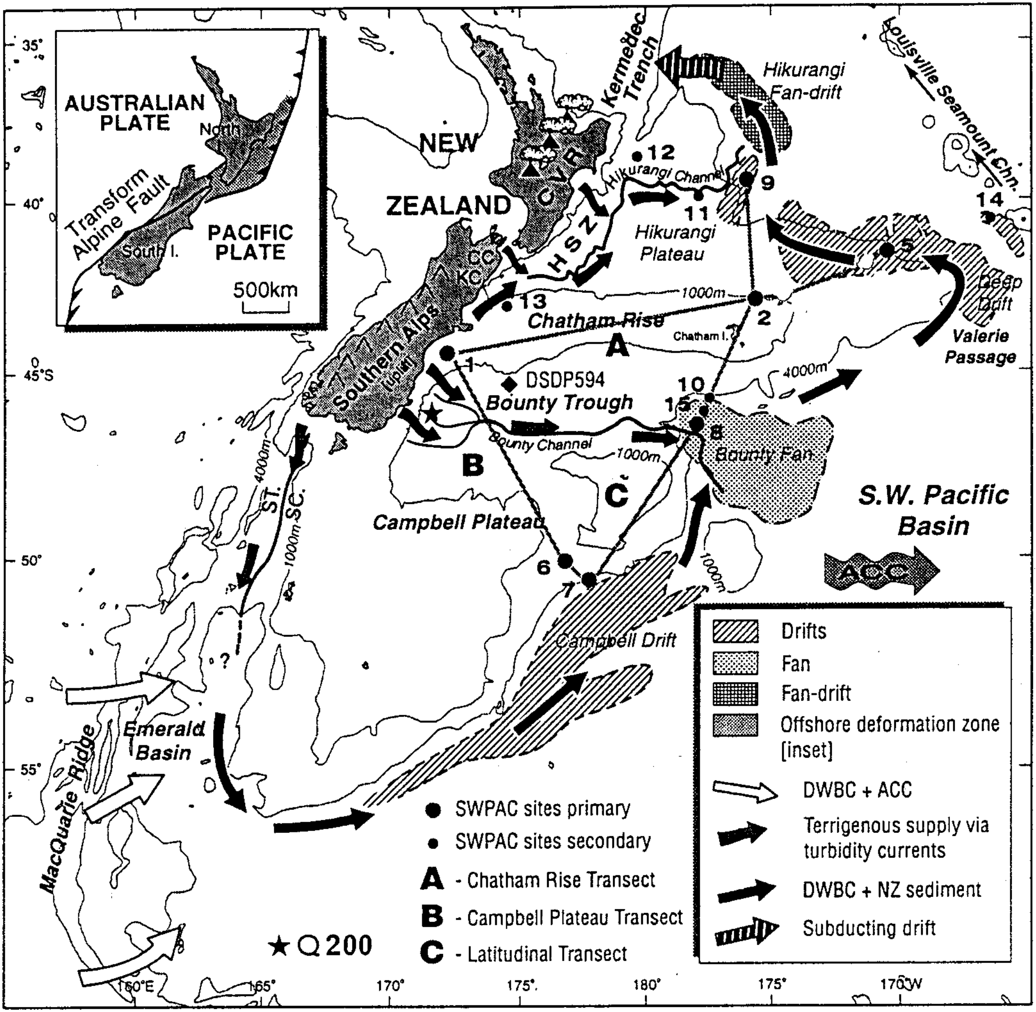

AUSTRALIAN PLATE
North I.
Transform Alpine Fault
South I.
PACIFIC PLATE
500km
NEW ZEALAND
Kermadec Trench
Hikurangi Fan-drift
Louisville Seamount Chn.
12
Hikurangi Channel
9
11
Hikurangi Plateau
HSZ
CVR
CC
KC
14
5
Deep Drift
13
1000m
2
Chatham Rise
Chatham I.
A
Valerie Passage
1
Southern Alps (uplift)
DSDP594
Bounty Trough
10
15
8
4000m
Bounty Channel
1000m
Bounty Fan
B
C
S.W. Pacific Basin
4000m
ST.
SC.
1000m
Campbell Plateau
6
7
1000m
ACC
Campbell Drift
?
Emerald Basin
MacQuarie Ridge
★ Q 200
35°
40°
45°S
50°
55°
160°E
165°
170°
175°
180°
175°
170°W
Drifts
Fan
Fan-drift
Offshore deformation zone [inset]
DWBC + ACC
Terrigenous supply via turbidity currents
DWBC + NZ sediment
Subducting drift
● SWPAC sites primary
• SWPAC sites secondary
A - Chatham Rise Transect
B - Campbell Plateau Transect
C - Latitudinal Transect

Figure 1

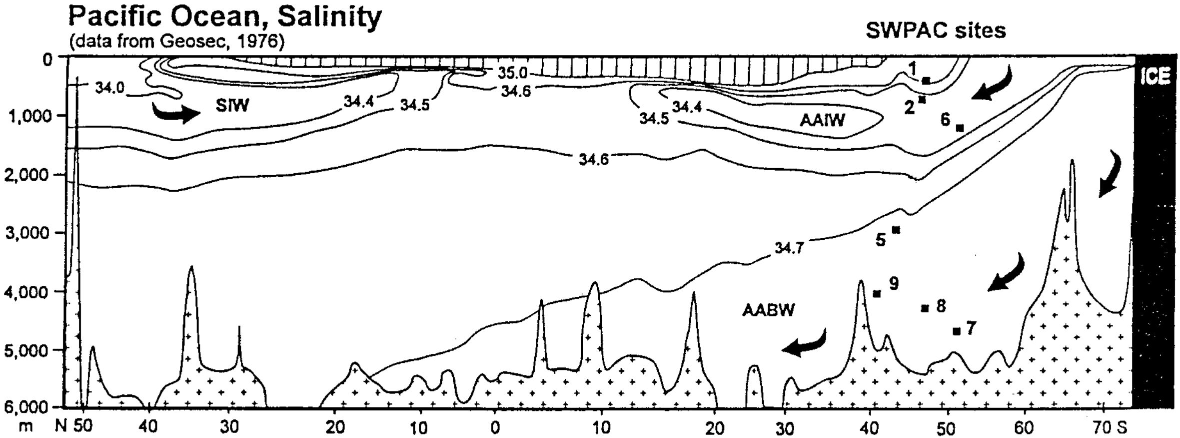
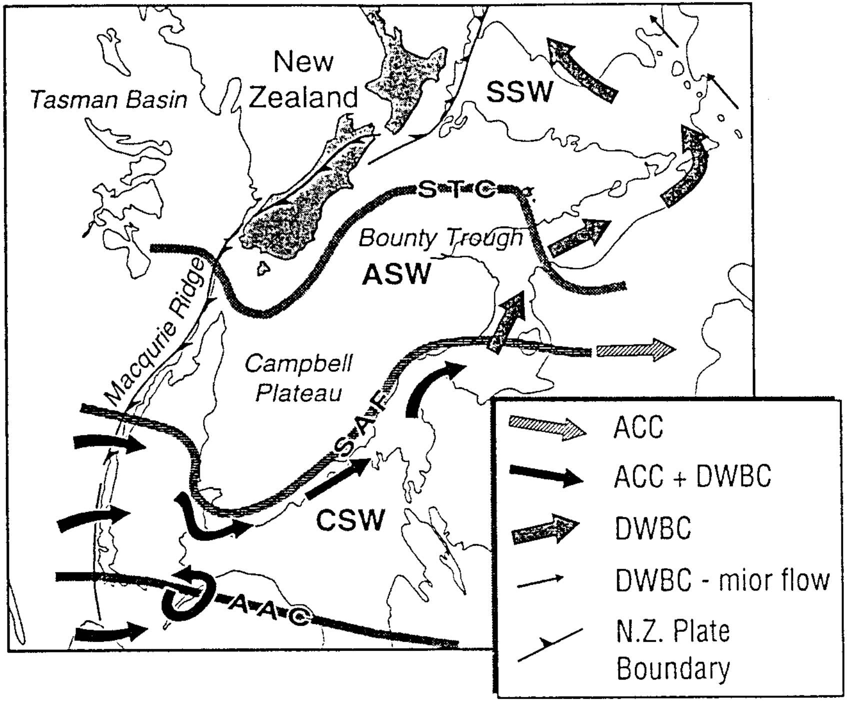

Pacific Ocean, Salinity
(data from Geosec, 1976)
SWPAC sites
0
1,000
2,000
3,000
4,000
5,000
6,000
m
34.0
SIW
34.4
34.5
35.0
34.6
34.4
34.5
AAIW
34.6
34.7
AABW
ICE
1
2
6
5
9
8
7
N 50
40
30
20
10
0
10
20
30
40
50
60
70 S

Figure 2



Tasman Basin
New Zealand
SSW
S T C
Bounty Trough
ASW
Macquarie Ridge
Campbell Plateau
S A F
CSW
A A C
ACC
ACC + DWBC
DWBC
DWBC - mior flow
N.Z. Plate Boundary

Figure 3

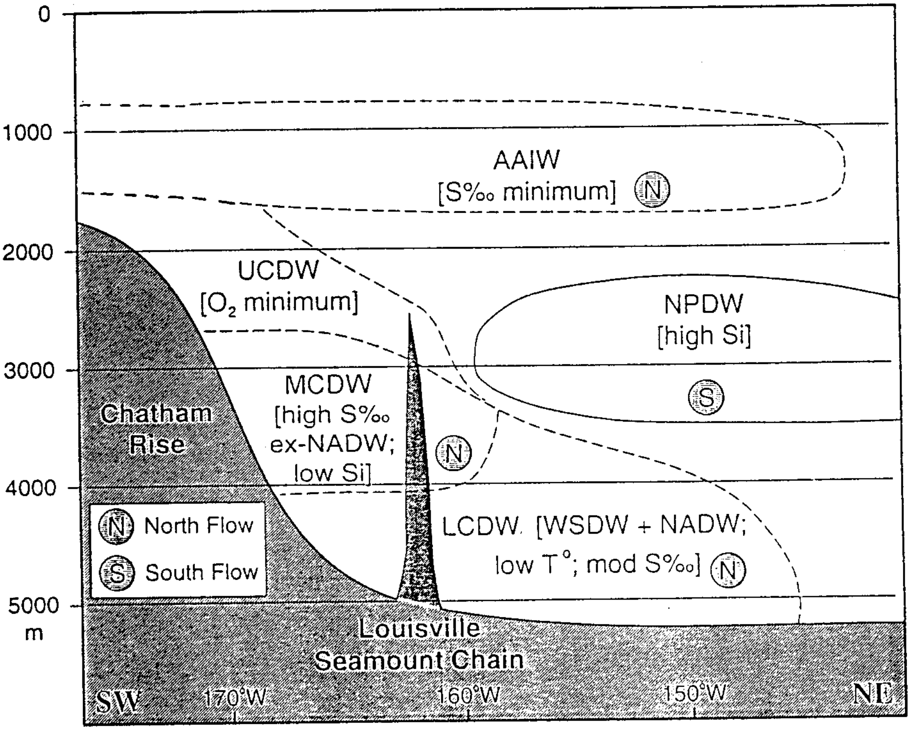
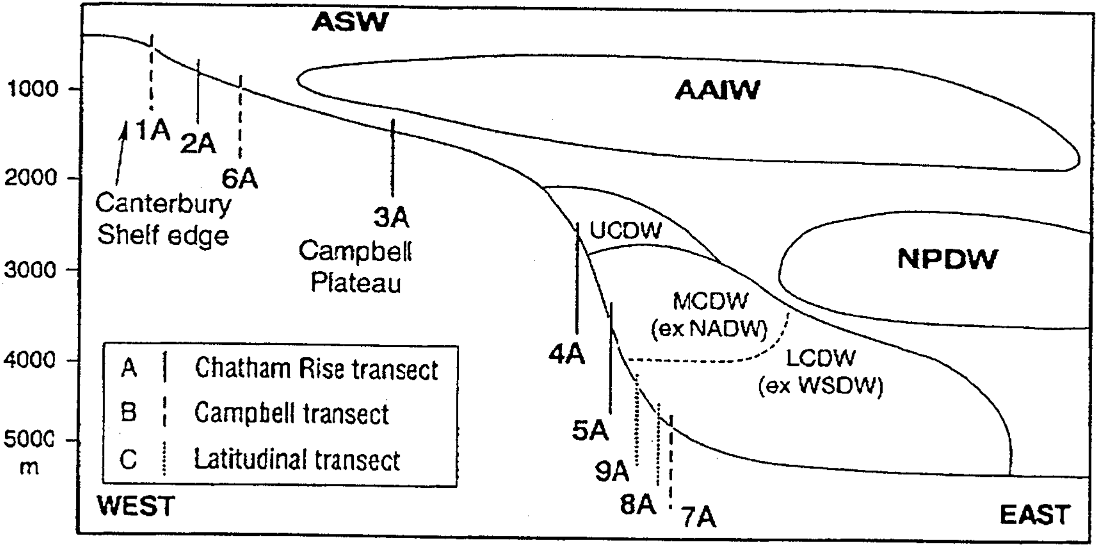

0
1000
2000
3000
4000
5000
m
AAIW
[S‰ minimum]
N
UCDW
[O₂ minimum]
NPDW
[high Si]
S
MCDW
[high S‰
ex-NADW;
low Si]
N
Chatham
Rise
N North Flow
S South Flow
LCDW [WSDW + NADW;
low T°; mod S‰]
N
Louisville
Seamount Chain
SW
170°W
160°W
150°W
NE

Figure 4



ASW
AAIW
NPDW
UCDW
MCDW
(ex NADW)
LCDW
(ex WSDW)
1000
2000
3000
4000
5000
m
1A
2A
6A
3A
4A
5A
9A
8A
7A
Canterbury
Shelf edge
Campbell
Plateau
A Chatham Rise transect
B Campbell transect
C Latitudinal transect
WEST
EAST

Figure 5

MAJOR WATER MASSES AND FRONTS OF THE SOUTHWEST PACIFIC

Water Mass	Abbr.	Depth (m)	Density	Salinity	Temp. (°C)	Oxygen	Silica
Subtropical Surface Water	SSW	Surface	>15				
Subtropical Convergence	STC		*Separates CSTW from ASW at 15 degree summer surface isotherm*				
Australasian Subantarctic Water	ASW	Surface	8-15				
Subantarctic Front	SAF		*Separates ASW from CSW at 8 degree summer surface isotherm*				
Circum-polar Surface Water	CSW	Surface	5-8				
Antarctic Convergence (Polar Front)	AAC		*Separates CSW from Antarctic Water (AAW), with icebergs (<5 °C)*				
Thermocline water		0-400		34.42-34.90	7.00-11.00	4.40-5.00	
Subantarctic Mode Water	SAMW	400-600	(26.80-27.20)	(34.0-34.2)	(6-10)	(very high)	(very low)
Antarctic Intermediate Water (S min)	AAIW	600-1450	27.20-27.35	34.50-34.36	3.20-7.00	3.20-4.70	
	NPDW	1450-2550		34.67-34.50	1.80-3.20	2.80-3.20	
North Pacific Deep Water (O min)	UCDW	2550-2900	36.50-37.00	34.67-34.71	1.60-1.80	3.03-3.45	
Circum-polar Deep Water (upper)	MCDW	2900-3800	37.00-45.93	34.71-34.73	0.90-1.60	3.45-3.63	high
Circum-polar Deep Water (middle) (S max)	LCDW	>3800	45.93-46.00	<34.71	0.55-0.90	4.70-4.80	high
Antarctic Circum-polar Current	ACC	0-seafloor	Various	---------------------	----------------	-----------------	----------------
Weddell Sea Deep Water	WSDW				-0.30-0.00		
North Atlantic Deep Water	NADW		As for MCDW	---------------------	----------------	-----------------	---------------
Antarctic Bottom Water*	AABW						

*General term for cold water of Antarctic origin which spreads north into the major ocean basins

Table 1. Tabulated data for the major water masses and fronts of the Southwest Pacific

TABLE 2

PROPOSED SITE INFORMATION AND DRILLING STRATEGY

SITE: SWPAC-1C **PRIORITY**: 1 **POSITION**: 44°45.33'S, 172°23.5'E
WATER DEPTH: 420 m **SEDIMENT THICKNESS**: >2000 m **TOTAL PENETRATION**: 500 m
SEISMIC COVERAGE: Line CB-82-22

Objectives: Determine the Cenozoic history of shallow WBC and associated drift formation, evaluate late Miocene changes in sea level.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Terrigenous silts and muds.

SITE: SWPAC-2A **PRIORITY**: 1 **POSITION**: 42°56.664'S, 177°33.40'W
WATER DEPTH: 595 m **SEDIMENT THICKNESS**: ~1200 m **TOTAL PENETRATION**: 520 m
SEISMIC COVERAGE: SCS high resolution seismic Mobile 72-211; SCS deep penetration; 3.5 and 12 kHz lines

Objectives: Test the record of circum-Antarctic flow against the Milankovitch orbital model, including estimates of simultaneity with Northern Hemisphere records. Obtain high-resolution oxygen isotope record of Eocene/Oligocene. Determine paleoproductivity and location of STC and paleohydrography of AAIW.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Hemipelagites, carbonate pelagites

SITE: SWPAC-5A	**PRIORITY**: 1	**POSITION**: 41°47.178'S, 171°29.95'W
WATER DEPTH: 3308 m	**SEDIMENT THICKNESS**: 860 m	**TOTAL PENETRATION**: 700 m
SEISMIC COVERAGE: SCS high resolution seismic, NZOI CR2050, 3.5 and 12 kHz data from CR2050		

Objectives: Test coherence of paleoclimatic record with Milankovich cycles. Determine the evolution of circum-Antarctic ocean circulation, including periods when the boundary current component may have extended into shallow depths or reversed. Evaluate grain-size signals (flow speed) to determine water mass movement to estimate the velocity behavior of the DWBC. Determine paleoproductivity and location of STC and paleohydrography of CDW (including NADW component).

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT

Nature of Rock Anticipated: Hemipelagites, carbonate pelagites

SITE: SWPAC-6B	**PRIORITY**: 1	**POSITION**: 50°03.80'S, 173°22.296'E
WATER DEPTH: 750 m	**SEDIMENT THICKNESS**: ~700 m	**TOTAL PENETRATION**: 500 m
SEISMIC COVERAGE: SCS high resolution seismic, 3.5 and 12 kHz data		

Objectives: Determine the evolution of circum-Antarctic ocean circulation, including periods when the boundary current component may have extended into shallow depths or reversed. Determine the behavior of low salinity AAIW. Stable isotope analyses to outline water mass and productivity variability through mid-Oligocene.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Calcareous biopelagites

SITE: SWPAC-7A	**PRIORITY**: 1	**POSITION**: 50°54.252'S, 177°00.30'E
WATER DEPTH: 4490 m	**SEDIMENT THICKNESS**: 840 m	**TOTAL PENETRATION**: 450 m
SEISMIC COVERAGE: SCS high resolution seismic		

Objectives: Determine history of CDW incursions into SW Pacific. Evaluate grain-size signals (flow speed) to determine water mass movement at this site to estimate the velocity behavior of the DWBC. This site will be important for assessing the extent to which the ACC acts as a driving force for CDW inflow.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Sand and Mn nodules on surface. Siliceous ooze and red clay.

SITE: SWPAC-8A	**PRIORITY**: 1	**POSITION**: 46°34.36'S, 177°24.05'W
WATER DEPTH: 4460 m	**SEDIMENT THICKNESS**: --	**TOTAL PENETRATION**: 650 m

SEISMIC COVERAGE: SCS high resolution seimic NZOI Lines CR2023, CR2040, and CR1151; 3.5 and 12 kHz data

Objectives: Determine climate, sea level, and tectonic controls on abyssal sediment supply. Test deep-sea cyclotherm model. Evaulate late Miocene to Holocene sediment injection into DWBC. This site in combination with the most southerly drift sites (Sites SWPAC-6B, 7A) will allow us to assess the shift in position of the climatically important AAC and SAF fronts using faunal and coarse-fraction analysis and stable isotopic and magnetic susceptibility measurements to trace ice-rafted detritus.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Terrigenous silt/mud turbidites, hemipelagites

SITE: SWPAC-9A **PRIORITY**: 1 **POSITION**: 39°29.898'S, 176°33.87'W
WATER DEPTH: 3940 m **SEDIMENT THICKNESS**: -- **TOTAL PENETRATION**: 450 m
SEISMIC COVERAGE: SCS high resolution seimic, 3.5 and 12 kHz data

Objectives: Determine (1) Miocene evolution of DWBC and associated water masses, (2) abyssal sediment budget, and (3) paleovolcanic history of the Neogene.

Drilling Program: APC, XCB

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Terrigenous and siliceous mud, tephra

SITE: SWPAC-3A **PRIORITY**: 2 **POSITION**: 42°33'S, 178°10'W
WATER DEPTH: 1320 m **SEDIMENT THICKNESS**: -- **TOTAL PENETRATION**: 625 m
SEISMIC COVERAGE:

Objectives: Alternate for SWPAC-2A.

Drilling Program: APC

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Biosiliceous and carbonate sediments with variable amounts of clay and ice-rafted debris.

SITE: SWPAC-10B **PRIORITY**: 2 **POSITION**: 45°40.0'S, 176°17.7'W
WATER DEPTH: 3940 m **SEDIMENT THICKNESS**: -- **TOTAL PENETRATION**: 450 m
SEISMIC COVERAGE:

Objectives: Alternate for SWPAC-8A.

Drilling Program: APC

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Biosiliceous and carbonate sediments with variable amounts of clay and ice-rafted debris.

SITE: SWPAC-16A	**PRIORITY**: 2	**POSITION**: 42°25.0'S, 167°20.0'W
WATER DEPTH: 4870 m	**SEDIMENT THICKNESS**: --	**TOTAL PENETRATION**: 480 m
SEISMIC COVERAGE:		

Objectives: Alternate for SWPAC-9A and -5A.

Drilling Program: APC

Logging and Downhole Operations: Triple-combo, FMS/Sonic, GHMT.

Nature of Rock Anticipated: Biosiliceous and carbonate sediments with variable amounts of clay and ice-rafted debris.