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Extended Abstracts for the International ANTOSTRAT Symposium on

THE GEOLOGIC RECORD OF THE ANTARCTIC ICE SHEET FROM DRILLING, CORING AND SEISMIC STUDIES

"Ettore Majorana" Foundation and Centre for Scientific Culture, Erice, Italy, September 8-14, 2001

Edited by
Fabio Florindo and Alan K. Cooper

Istituto Nazionale di Geofisica e Vulcanologia

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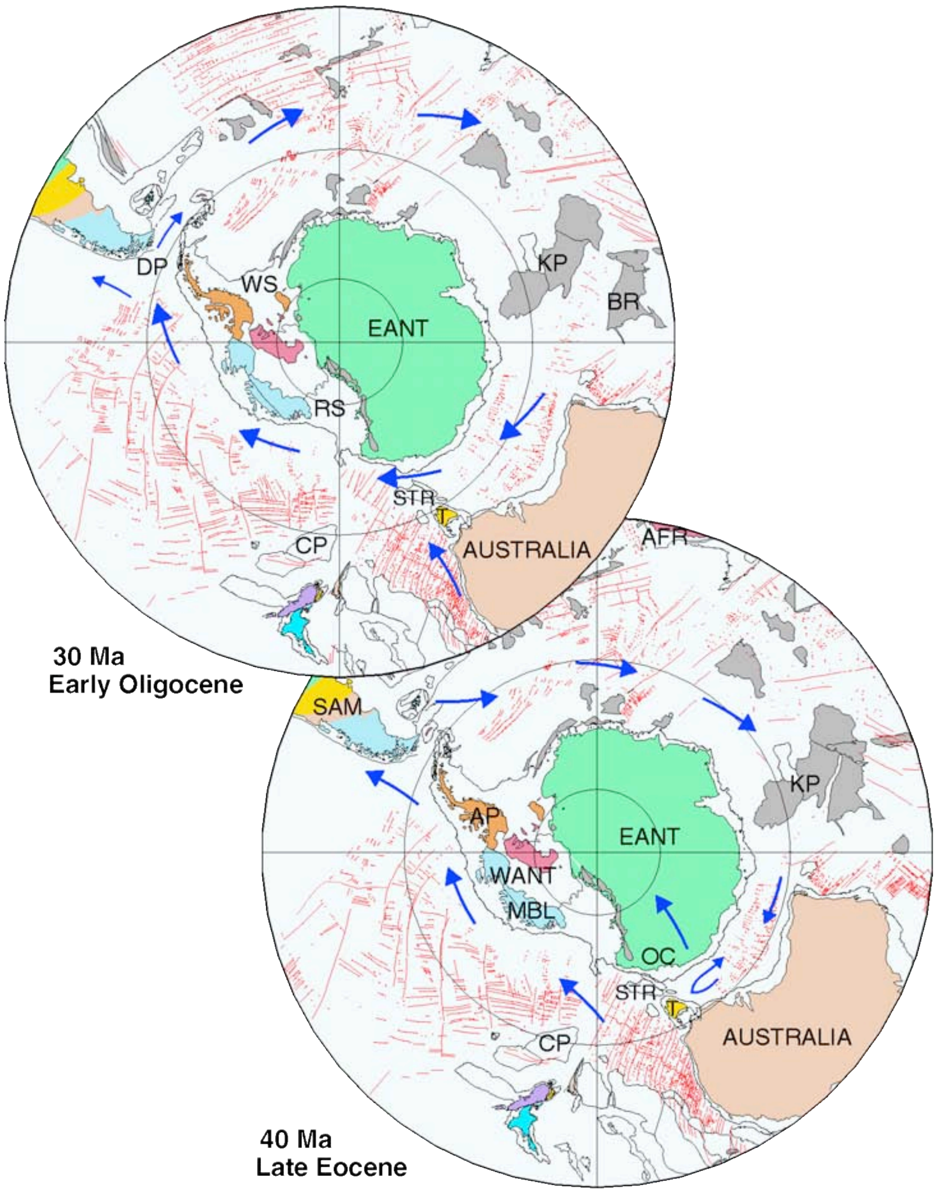

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Foreword

The Antarctic Offshore Stratigraphy Project (ANTOSTRAT) was conceived in 1989 under the auspices of the Scientific Committee on Antarctic Research (SCAR) to promote collaborative studies on Cenozoic Antarctic glacial history derived from offshore geologic and geophysical information. The initial thrust was the compilation of existing seismic and coring data in five principal working areas around Antarctica, with each considered to record the history of different parts of the Antarctic ice sheet, e.g. Antarctic Peninsula, Prydz Bay, Ross Sea, Weddell Sea, Wilkes Land. Studies based on these compilations were reported at Symposia in Monterey, California, USA (Asilomar) in 1990 and in Siena, Italy (Certosa di Pontignano) in 1994. Thereafter, the project objectives changed to emphasise acquisition of geologic samples by drilling and coring, and to provide basic information for building palaeoenvironmental and palaeoclimate models for key periods in Antarctic glacial history.

The extended abstracts herein for this symposium in Erice, Sicily (Ettore Majorana Foundation and Centre for Scientific Culture) in 2001, present contributions that deal with many recent drilling and coring operations (e.g. ODP Legs 177, 178, 188, and 189; CIROS and Cape Roberts Project) and seismic investigations, conducted principally over the Antarctic continental margin and adjacent ocean basins. The symposium is also a forum for reevaluating general science priorities and for planning future collaborative projects, to ensure continued progress in understanding Cenozoic Antarctic palaeoenvironmental history.

This compilation was prepared before the symposium, and the extended abstracts are given without additional peer review. One or more volumes of papers will be published based on these studies.

The Erice ANTOSTRAT Symposium is made possible by the financial support of the Scientific Committee on Antarctic Research (SCAR), the Istituto Nazionale di Geofisica e Vulcanologia (INGV), the Italian Antarctic Research Program (PNRA), the Ocean Drilling Program (ODP), the U.S. National Science Foundation Office of Polar Programs (Grant #OPP-0111665), and the many National programs that have provided travel support for their participants.

Directors of the symposium
A.K. Cooper, F. Florindo and A. Meloni

Carbonate Diagenesis of the Cenozoic Sedimentary Successions Recovered at the CRP-1, 2 and 3 Drillsites, Ross Sea, Antarctica. An Overview

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Although the occurrence of diagenetic carbonates are well documented in the glacigenic sedimentary sequences recovered at/within the Antarctic continental margin, their formation with respect to the origin of the carbonates (biogenic, non-biogenic) has to be tested. This study is the obvious continuation of preliminary investigations recently performed on selected samples from the Cape Roberts Project (CRP) cores drilled at CRP-1, 2 and 3 drillsites. This study was designed to test the relation between the occurrence of diagenetic carbonates and the role of carbonate-rich pore fluids and to better understand their origin of the diagenetic carbonates (dissolution of calcitic biogenic tests, role and evolution of the carbonate-rich pore fluids, alteration of volcanic material).

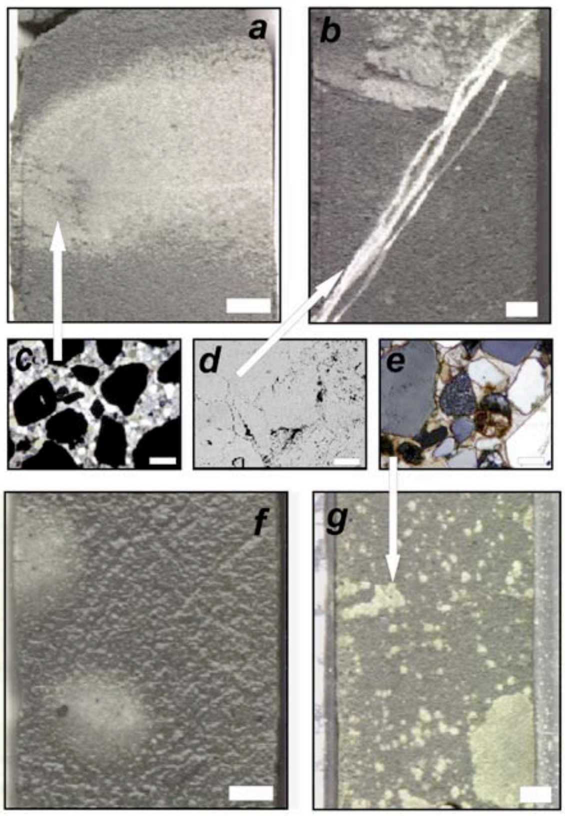

Figure 1.

Different carbonate diagenetic features were distinguished on the basis of the main fabric, texture, ultratexture, mineralogy and stable isotope composition. These diagenetic features might reflect different depositional environments in a marine setting, probably ranging from an upper sedimentary succession recording a moderate influence of glacial meltwaters to lower strata dominated by a stronger influence of glacial melting waters, as previously recorded within the Cenozoic sedimentary strata from the CRP-3 core. These data are consistent with the climatic changes inferred from the interpretations of the sedimentary facies.

Authigenic calcite is the most abundant precipitate throughout the CRP cores, showing different main fabrics (Fig. 1). Extensive carbonate cementation occurring in the lower strata, within sandstone lithologies, is represented by an early stage of fringing Fe-rich calcite or siderite and a subsequent stage of blocky crystals of no-Mg calcite (Figs. 1a, c, e and g). Fractures/faults occurring especially at the main fault system are often filled by different generations of sparry/drusy calcite (Figs. 1b and d). Fossiliferous concretions/nodules occurring in the upper part of the sedimentary strata exhibit an early marine, shallow burial cementation by fringing/sparry low-Mg calcite, related to dissolution of the calcareous biogenic tests (Fig. 1f).

Our data on carbonate cementation may suggest that changes in sediment supply may control the main fabric of the diagenetic carbonates, whereas changes in the tectonic setting control the pore fluid composition and evolution and the related calcite mineral-fills.

Late Quaternary Fluctuations in the Antarctic Ice Sheet

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The configuration of the Antarctic Ice Sheet during the Last Glacial Maximum (LGM) and its contribution to the post LGM sea-level rise have been modeled by several investigators, with widely different results (e.g. Huybrechts, 1990; Denton et al., 1991; Tushingham and Peltier, 1991; Nakada et al., 2000). These models differ considerably with regard the distribution of ice on the continent and the range of sea-level contributions from melting of the ice sheet. Testing these models calls for onshore studies that constrain former ice sheet elevations and offshore studies that constrain former grounding line positions on the continental shelf and advance and retreat histories. The maximum extent of the ice sheet is recorded by glacial unconformities, subglacial geomorphic features, and subglacial deposits. Establishing the timing of ice sheet advance and retreat is the most difficult challenge and, as a result, progress has been particularly slow in this area.

There is an emerging body of evidence from studies of the last glacial/interglacial cycle to suggest that the East Antarctic Ice Sheet (EAIS) and West Antarctic Ice Sheet (WAIS) have not advanced and retreated in concert with one another. The evidence indicates that expansion and contraction of the EAIS was diachronous around the continent (Berkman et al., 1998; Anderson, 1999). In two of the largest discharge areas, Prydz Bay and along the Queen Maud Land coast, the EAIS appears to have retreated from the shelf prior to about 20,000 years ago. Off the North Victoria Land Margin, EAIS advance and retreat was more in concert with the WAIS.

The WAIS advanced to the outer shelf during the LGM. The LGM grounding line position is best constrained in the Ross Sea and the Weddell Sea grounding line is the most poorly constrained. The WAIS retreat from the shelf began shortly after the LGM and continued into the late Holocene. The WAIS in Ross Sea and Amundsen Sea was sliding across the deforming bed, at least during the final phases of the LGM. This implies that the ice sheet had a low profile. Differences in the number and locations of grounding zone wedges and smaller grounding zone features from trough to trough implies that individual WAIS ice streams acted independently during their retreat from the shelf. The WAIS remained grounded on the outer shelf in Ross Sea and Amundsen Sea until about 12,000 years ago. There was significant retreat of the ice sheet in the Ross Sea, and possibly Weddell Sea, after 6000 yrs BP.

There was considerably more ice on the Antarctic Peninsula shelf during the LGM than previously thought. Indeed, results from marine geological studies support more recent ice sheet models that call for greater contributions of melting ice from West Antarctica, including the Antarctic Peninsula, to the post-LGM rise in sea level.

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North American Patterns of Faunal and Floral Response to the Eocene/Oligocene Antarctic Ice Sheet Development

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Multidisciplinary studies in Southwestern Washington and Eastern Mississippi document faunal and floral changes within marine sediments of late Eocene through Oligocene age. Significant changes in species composition occur from dominantly subtropical middle Eocene assemblages to more temperate Oligocene assemblages. No abrupt change occurs coincident with the Eocene-Oligocene boundary.

In the Lincoln Creek Formation of southwestern Washington, planktonic foraminifera, strontium isotope and palaeomagnetic studies provide correlation with the global time scale. The transition from subtropical middle Eocene assemblages to temperate Oligocene assemblages occurs coincident with development of the Cascade arc in response to Pacific Plate convergence with the North American Plate.

In Mississippi and Alabama, fossils from strata of the Jackson and Vickburg Stages show an Eocene to Oligocene tropical to warm temperate change in species composition. Correlation of the local strata to the global time scale uses planktonic foraminifera, radiometric dates and magnetostratigraphy. The change in fossil assemblages occurs within strata showing dramatic shallowing in water depths from bathyal to inner neritic as coastal deltas prograde into the study area essentially at the Eocene/Oligocene boundary.

Current research is focused toward understanding what component of the floral and faunal changes are in response to global climate change related to development of the Antarctic ice sheet versus those related to more local climate environmental change.

Antarctic Glacial History from Margin Drilling

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In 1996 a suite of proposals from ANTOSTRAT Regional WG to drill the Antarctic margin was refined and prioritised by an ODP Antarctic Detailed Planning Group. Its objective was to determine Antarctic glacial history directly from glacially-transported sediments, and assess the effects on sea-level change. The background was unsatisfactory - ice sheet evolution could be deduced only from low-latitude proxy measurements, the two principal of which (oxygen isotopes and sea level) disagreed, and were ambiguous. In these proposals, drilling at several sectors of the Antarctic margin was combined by numerical models of ice sheet development, and in each sector two kinds of glacial sedimentation (diamicts on the continental shelf and slope, and derived fine-grained hemipelagic drifts on the upper continental rise) were available.

Two of the four proposals have been drilled (Leg 178 to the Antarctic Peninsula in February-March 1998, Leg 188 to Prydz Bay in January-February 2000). Leg 178 demonstrated Antarctic margin drillings viability and identified its limitations, while Leg 188 resolved clearly the early history of glaciation. Leg 178 science is not complete, but imminent publication of the Scientific Results volume marks a likely end to Leg-specific contributions. The recent Leg 188 Initial Report reflects full publication of results obtained on board ship, and this meeting marks the next stage - a Leg 188 post-cruise meeting at which results are presented and exchanged.

The undrilled proposals (the Wilkes Land margin and the Eastern Ross Sea) examine the crucial intermediate stages of ice sheet evolution - how big was the Antarctic Ice Sheet during the Oligocene and across the Middle Miocene transition? Was that ice sheet sensitive to orbital insolation changes? Although ANTOSTRAT now includes additional environments and means of sampling, and the older geological record, these key questions (and others) can only be addressed by drilling margin sediments. The imminent end to ODP and hoped-for beginning of IODP, after an operational hiatus and with different drilling foci, require us to reconsider the original ANTOSTRAT objectives for margin drilling, what has been achieved and what remains. This paper begins that process, by trying to summarise the achievements of Legs 178 and 188, and commenting on the importance and viability of the undrilled proposals.

Leg 178 drilled two long (c. 600 m) holes at complementary sites on a continental rise sediment drift, duplicating the upper sections, and one shorter hole (c. 200 m) on a different drift. A continuous, high-resolution record of deposition of sediment largely derived from the adjacent glaciated margin extended back about 10 Ma. The initial magnetic polarity stratigraphy was later constrained by largely siliceous biostratigraphy. A clear glacial/interglacial lithologic variation was seen throughout in many direct and proxy measurements, implying differing transport processes through the glacial cycle and confirming the value of rise drift drilling in examining glacial history. Although individual Milankovitch cycles were identified in the uppermost sediments and hypothesised at greater depth, cyclicity at the expected frequencies has not emerged from spectral analysis. Possibly the mode of deposition, while accurately reflecting orbitally-driven variation onshore, results in non-linear sedimentation on the rise. Or the Antarctic ice sheet, lacking drive from sea-level changes created by N Hemisphere ice sheet variation, was dominantly autocyclic during the early Pliocene and late Miocene.

Leg 188 drilled c. 1000 m into Wild Drift (farther from the shelf edge than the 178 drifts), to the early Miocene (c. 22 Ma), detecting a similar facies alternation that became less prominent downward, reflecting (with changes in sedimentation rate, grain size, lithology, etc.) changes in the glacial regime in Prydz Bay. Milankovitch cyclicity was established for at least the late Miocene.

For Leg 178, drilled close to the Equinox on an exposed margin, swell was a major contributory problem, but in both regions core recovery was poor in unconsolidated diamicts of the continental shelf. Nevertheless, it was usually possible to date the recovered core using siliceous microfossils, and in places to distinguish subglacial, proglacial and glacial marine environments. Drilling in Prydz Bay has narrowed considerably the age range of likely onset of Antarctic glaciation, from palynological analysis.

Leg 188 also drilled the continental slope (not sampled during 178, because the Antarctic Peninsula slope is steep), finding rapid accumulation dominated by debris flows, which limits its value for palaeoclimate studies. Leg 178 did drill an inner shelf basin, recovering an ultra-high resolution Holocene record.

In all key respects, drilling the Antarctic margin has been successful to date, in terms of ice sheet evolution. Core recovery within diamicts on the continental shelf is poor, as was expected, but provided that low-resolution questions are asked of this drilling, it will answer. The continental rise drifts provide a less direct record, but one that is relevant, and high-resolution.

Glacial Sediment Transport and Distribution on the Antarctic Peninsula Pacific Continental Shelf and Slope - New Results from Seismic Reflection Profiles and ODP Leg 178 Drilling

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Seismic reflection profiles from 12 cruises, total length 12,000 km and from 7 research groups in 6 Countries, combined with ODP Leg 178 drilling results, provide the most extensive examination to date of glacial sedimentation on the Antarctic Peninsula outer continental shelf and slope. The two data sets are complementary, the drilling results serving to date seismically-derived units and constrain their interpretation, and the seismic profiles allowing those results to be applied across and along the continental shelf. Older interpretational schemes (in particular, that adopted for the drilling proposal and during drilling) are revised. New insights are presented concerning Antarctic Peninsula glacial history, the seismic expression of glacial sedimentation, and the controls on sediment transport and distribution by glacial ice.

The original interpretational scheme identified four seismic units on the outer continental shelf, S1 to S4. Drilling involved a transect of three sites (1100, 1102, 1103) along the axis of the most northeasterly of four depositional lobes, and a single site (1097) in an interlobe area, where the older section was accessible at lesser depth. Core recovery on the continental shelf was poor, particularly in the shallow section where the diamict matrix was too poorly consolidated to support clasts during drilling. Drilling showed that the partly aggradational S1 and underlying progradational S2 were of early Pliocene to Pleistocene age, and fully glacial. S3, aggradational in nature, perhaps reflected a lesser level of glaciation (proglacial and glacial marine diamicts were also recovered, compared with only subglacial facies from S2 and S1). One site sampled a near-conformable S3/S2 boundary, of early Pliocene age (4.6-4.4 Ma), but S3 was shown to extend back to at least 7.5 Ma. The pre-collision S4 (the AP margin underwent diachronous ridge crest-trench collision through the Cenozoic) was not drilled.

Re-examination of the seismic data in the light of drilling has produced insights that significantly change existing views of glacial sediment transport processes, and regional climatic evolution.

First, after an unsuccessful attempt to drill at the shelf edge (Site 1102), the drill-pipe camera showed a boulder bed, perhaps created by winnowing following resuspension of fines by iceberg keels. This may explain strong seismic reflectors close to palaeo-shelf breaks. The Antarctic Peninsula continental slope is very steep, and seismic records show a disrupted, probably gullied, less steep upper slope and a steeper but smoother lower slope. These are explained by small-scale failure of the upper slope, producing debris flows and turbidity currents with rain-out of the coarser component forming a more stable, clast-rich lower slope.

Second, deposition of Unit S1, as previously defined, is discontinuous between Lobes 1 and 2 (as was already known), but additionally the more extensive seismic data set shows that, whatever geometric criterion identifies it, the S2/S1 boundary is asynchronous. The synchroneity of the topset erosion and foreset truncation features within S1 (the most prominent of which forms the S1 base) is uncertain. They may reflect regional or purely local erosional processes.

Third, S3, unlike the lobe-forming S2 and S1, is continuous along the margin, with the same aggradational character. It is possible that, in addition to reflecting dramatic aggradation/progradation, evenly-deposited/lobe-focussed and less/more glacial transitions, the S3/S2 boundary also reflects a reduction in sedimentation on the continental rise which might have significant implications for our understanding of glacial evolution. We await a re-assessment of continental rise sedimentation.

Fourth, identification of the S4/S3 boundary as a diachronous "collision unconformity" may need revision. Although the level of glaciation expressed in different depositional environments is uncertain, an "onset" of Antarctic Peninsula glaciation could be as old as mid-Miocene. This might explain why a (probably glacial) S4 and the S4/S3 boundary are seen within Lobe 1 (above a 10 Ma collision zone) in the NE, no S4 sediments are seen over intermediate-age (16.7 and 19.9 Ma) collision zones, and a smooth (perhaps glacial onset) unconformity is seen high in the sedimentary section above a 30 Ma collision zone.

Determining the Glacial History of Prydz Bay, Antarctica: Observations Based on the Integration of Downhole Logging Data and Sedimentological Description from ODP Leg 188, Hole 1166

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The Cenozoic Antarctic Ice Sheet is the largest continental glacier on Earth and influences global climate and circulation. Insights into the development of the Antarctic Ice Sheet have been derived from proxy records including oxygen isotope records, deep-sea records of ice-rafted detritus, sea level fluctuations and outcrop studies on the Antarctic continent. Although still debated, its early development and growth is thought to have occurred between early-mid Eocene and early Oligocene times. Continental ice sheets deposit enormous volumes of scoured terrestrial sediment into marine basins and it is in these natural repositories that a nearly continuous record of glaciation can be found. Prior to Ocean Drilling Program (ODP) Leg 188 (O'Brien et al., 2001), drilling on the continent and continental margin had not sampled a stratigraphic section that clearly spanned and included the transition period from pre-glacial to glacial conditions.

The primary objective of ODP Leg 188 was to determine a date for the initiation of large, continent-scale glaciation in the Antarctic, and to obtain a record of the subsequent fluctuations of the Antarctic Ice Sheet during the Late Cenozoic. Three sites were drilled at the Prydz Bay continental margin: the continental shelf, trough mouth fan, and continental rise. Despite the low recovery (18.6 %), the core record from Site 1166 (continental shelf) reveals preglacial conditions in Prydz Bay and the transition from a temperate, stunted Tasmanian-type "rainforest-scrub" environment to the full-scale, polar glacial conditions of present-day Antarctica. More detailed and reliable interpretations of the entire cored section can be made by integrating the core record with parameters measured by downhole logging tools, deployed after completion of coring.

Downhole logging data provide a continuous *in situ* record of the physical, chemical and electrical properties of the rocks encountered in the borehole that can be calibrated with the recovered core material and used to infer lithology and rock properties in intervals where core recovery was low. At Site 1166, the log data obtained were of excellent quality and the results suggest that despite poor recovery, all major facies were retrieved, providing a strong foundation upon which the log data can be interpreted. The Formation MicroScanner (FMS) images are particularly useful as they provide a high-resolution visual record of the electrical properties of the drilled sequence and they allow the identification of both lithological and structural features. They clearly show the variability within the lithostratigraphic units, for example the presence and size of lonestones within the glacial diamictons, and the deformation within the organic-rich silt-sand horizons.

Towards the base of the drilled sequence, pre-glacial to early glacial units are present; these have large gamma-ray fluctuations indicative of heavy mineral K, Th, and U contents associated with high magnetic susceptibility and organic carbon values. The pre-glacial units also have lower velocity, density, and resistivity values and higher porosity values than the thick overlying deltaic sands. The sands are massive, deformed towards their base and interbedded with clay rich beds towards their top. All the logs show abrupt shifts at the boundaries between the massive deltaic sands and the underlying and overlying clay rich units, which appear from the cores to be unconformable. The overlying interbedded claystone sand sequence lacks lonestones and the glacial diamictons with interbedded glaciomarine clays and silts have generally high and variable magnetic susceptibilities that suggest high variability in magnetite concentrations, related to the presence of igneous and metamorphic clasts in the diamict. The clay rich unit within the diamict shows an increase in gamma-ray values and a sharp decrease in magnetic susceptibility related to the lack of reworked clasts bearing magnetic minerals. The log data will be used to supplement the core data and provide a more detailed reconstruction of the lithological sequence, which will serve as an aid to improve the sedimentological interpretation. Particularly the subtle variations within units will be highlighted and intervals where core recovery was low will be more accurately characterised.

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Cenozoic Antarctic Glacial History - Checks from the Margin

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The present day view of Antarctic glacial history grew out of oxygen isotope measurements of carbonate foraminifers in deep-sea cores taken a quarter of a century ago from the Southern Ocean, and by the time of the 1994 ANTOSTRAT Symposium (Siena, Italy), the main features of the Cenozoic oxygen isotope curve had been confirmed and consolidated from a number of deep-sea sites in both the Atlantic and Pacific Oceans (Fig. 1a). More recently isotopic studies of deep-sea strata have revealed a persistent 40,000 year cyclicity, the most powerful of the 3 main orbital variations influencing solar radiation, superimposed on the long-term curve. This cyclicity has been found to extend back through Pliocene, Miocene and into the latest Oligocene times (Zachos et al., 1997), and is presumed to represent the combined effects of deep-sea temperature and Antarctic ice volume. Most recently, deep-sea temperatures from Mg/Ca have been used to separate the ice volume signal from oxygen isotopes. Temperature shows a progressive decline from 12°C from the early Eocene to the present, with three periods of major ice sheet expansion, early Oligocene, late middle Miocene and late Pliocene (Fig. 1, Lear et al., 2000).

Studies of drill cores from the Antarctic margin established by the early 90's that grounded ice had breached the ancestral Transantarctic Mountains, flowing onto the continental shelf as far back as the mid Oligocene in the Ross Sea. East Antarctic ice reached Prydz Bay slightly earlier (by earliest Oligocene or possibly latest Eocene times). For some, but by no means all investigators this represented circumstantial evidence for continental ice sheets reaching the coast by the early Oligocene, though the persistence of plant microfossils in Oligocene and early Miocene core implied that the regional climate was warmer, and the ice sheets more dynamic, that that of today. The scenario of continental ice first reaching the coast at Prydz Bay and then the Ross Sea is confirmed by recent ice sheet modelling (DeConto and Pollard, in preparation).

Recent core studies of nearshore glacimarine strata off Cape Roberts on the Ross Sea margin (Fielding et al., in press) have substantiated earlier claims that these records reflect a fluctuating ice sheet margin (and sea level) from around 30 Ma. They report the Cape Roberts cores to show around 50 sequences in the period from 32 to 17 Ma, reflecting these high fre-

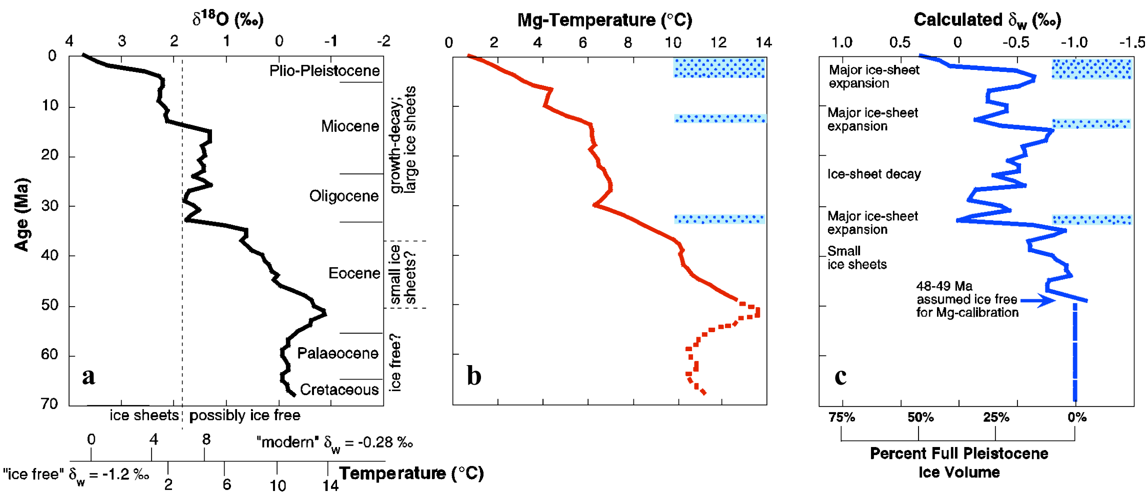

Figure 1. Deep-sea record through Cenozoic time. **a)** Cenozoic composite benthic foraminiferal $\delta^{18}O$ record based on Atlantic cores from Miller et al. (1987). **b)** Temperature through Cenozoic time estimated from Mg/Ca ratios. **c)** Variation in the $\delta^{18}O$ composition of seawater with the temperature effect removed to provide an estimate of global ice volume. Figure from Lear et al. (2000).

quency fluctuations. For one well-dated interval at 24 Ma it has been possible to show that a set of 3 cycles averaging 60 m in thickness had a frequency of no more than 100 k.y., but most likely 40 k.y. (sequences 9-11, CRP-2A, Naish et al., in press). The Cape Roberts cores also record a history of regional cooling and vegetation decline on the Ross Sea coast from a low woodland with implications of a cool temperate climate in the earliest Oligocene to a herb moss tundra typical of a subpolar climate from around 25 to 17 Ma. This progressive cooling from early Oligocene to early Miocene times is, however, somewhat at odds with the inference of long-term ice sheet decay over this period from the deep-sea record (Lear et al., 2000).

The post early Miocene glacial record from the Antarctic margin remains contentious because of difficulties in dating onshore and limited cores taken offshore. The discovery of scarce Pliocene marine diatoms in high level glacial deposits along the Transantarctic Mountains led to the hypothesis of Webb et al. (1984) that the diatoms were sourced from the Antarctic interior, with the implication that the central East Antarctica was ice-free during the middle Pliocene. This has been countered with evidence from the McMurdo Sound region of a persistent Antarctic ice sheet from mid-Miocene times to the present, and that the Sirius deposits predate this time. Reasons cited include unweathered volcanic ash dating back to 15 Ma, persistent cold climate features at high elevations in the Dry Valley region of the Transantarctic Mountains (Sudgen et al., 1999), and the antiquity of rock surfaces at high elevations (more than 10 Ma in several places, e.g. Schäfer et al., 1999). In addition, reports of marine diatoms from Antarctic snow and other rock surfaces indicate the possibility of contamination, and compromise the use of rare diatoms alone in dating these deposits. On the other side of the continent, however, fjordal glaciomarine strata with ages reported to range from Pliocene to early Miocene or late Oligocene are preserved with the oldest strata at highest elevation on the rising eastern wall of the Lambert Graben. These represent sedimentation from a polythermal glacier rather than from cold ice like the present or lower latitude temperate glaciers (Hambrey and McKelvey, 2000), and imply a coastal climate prior to the Pleistocene that was several degrees warmer than today. The work of Lear et al. (2000) provide some support for this with their combined Mg/Ca and oxygen isotope analysis of deep-sea benthic foraminifera suggesting early Pliocene global ice volume reduction to c. 15% of the full Pleistocene ice volume before major late Pliocene expansion.

Although most investigators are skeptical of the loss of all ice from the East Antarctic lowlands in the Pliocene, significant variations in the volume of the Antarctic Ice Sheet may have occurred even under the present glacial regime. A late Pleistocene high (20-m) sea level has been recorded by beach gravels on Bermuda and Barbados and is well-dated at between 390 and 550 Ka (Hearty et al., 1999). This implies not only the loss of ice on Greenland and West Antarctica, but also ~8 m of sea level equivalent ice from the East Antarctic Ice Sheet in the late Pleistocene. The actual response of the present cold Antarctic Ice Sheet, its ice shelves, and the surrounding sea ice, to changing global climate in the period prior to the Last Glacial Maximum, is not known and represents possibly the greatest challenge for the next decade. Locating key sites for investigation, and subsequent interpretation of their record will be, as in the past, enhanced by attention to climate and ice sheet models.

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An Evaluation of the Messinian Salinity Crisis: Implications of new Palynological Results on the Interpretation of Late Miocene Antarctic Ice Sheet Evolution

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New palynological data from an Atlantic margin palaeostrait in the Gibraltar Arc region provide clues to the relative influence of tectonics and sea-level changes on the onset and termination of the Messinian Salinity Crisis (MSC). On the basis of a correlation of palynological results with a high-resolution oxygen-isotope record, Warny (1999) showed that the early phase of the MSC was a result of a major Antarctic glaciation that began at ~5.75 Ma, whereas the late phase of the MSC (~5.6 to ~5.32 Ma) was predominantly due to tectonic uplift. This uplift further restricted Atlantic inflow despite a gradual but significant sea-level rise during that time frame. At the palaeostrait, dinoflagellate-cysts last appearance datums demonstrate that the end of the MSC was associated with ecological stress immediately prior to and during oxygen isotopic stage TG 5 (~5.32 Ma). Warny (1999) concluded that the termination of the MSC occurred abruptly at ~5.32 Ma as a consequence of a sea-level rise from Antarctic Ice Sheet (AIS) retreat combined with tectonic fracture of Gibraltar Arc.

If Warny's arguments that the MSC began at ~5.75 Ma as a result of a major Antarctic glaciation are correct, then direct evidence of an ice-sheet advance should exist within upper Miocene strata on the Antarctic continental shelf. Unfortunately, upper Miocene strata have not been sampled on the Antarctic outer continental shelf. However, seismic data show that a major glacial unconformity overdeepened the Ross Sea outer continental shelf is found stratigraphically above the youngest middle Miocene strata sampled at sites 273 and 272 and stratigraphically below the oldest lower Pliocene strata sampled at site 271 (Bart et al., 2000; Alonso et al., 1992). We surmise this glacial unconformity was formed at ~5.75 Ma. As the late phase of the MSC presumably was a consequence of tectonic uplift during a time when global sea level rose, then the AIS volume probably decreased during that time frame. However, the occurrence of subglacially erupted volcanics on Coulman Island and Hasslett Peninsula led Hamilton (1972) to conclude that the AIS grounded at the outer shelf in the late Miocene until at least ~5.4 Ma. We hypothesize that the overall volume of the AIS probably decreased during the late phase of the MSC while the AIS remained grounded on the Ross Sea outer continental shelf. Given that an abrupt sea-level rise probably contributed to the termination of the MSC, we hypothesize that the thinned AIS eventually decoupled and abruptly retreated from the outer shelf at ~5.32 Ma. Decoupling retreat may have caused significant AIS drawdown, and thus a latest Miocene (~TG5) sea-level rise. This, in combination with tectonic downfaulting of the Gibraltar Arc, may have caused reflooding of the Mediterranean Sea.

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Rift Basins and Volcanism beneath the Ross Sea Continental Shelf and West Antarctic Ice Sheet

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Rift Basins beneath the Ross Ice Shelf defined by marine multichannel seismic reflections surveys since 1982 (Cooper et al., 1995) are the result of tectonism associated with rifting in the late Cretaceous. Reactivation of these basins in the late Cenozoic continues to the present as evidenced by faulting (including fault scarps) extending to the sea floor. The West Antarctic rift system and its associated volcanism has been interpreted to be the result of a mantle plume. This interpretation is based on ocean island basalt composition of volcanic rocks and the vast volume of subglacial and submarine volcanic rocks defined by geophysical surveys. The West Antarctic Ice Sheet (WAIS) flows through the West Antarctic rift system and is approximately the same age as the volcanic exposures and inferred subglacial and submarine volcanic rocks. In all but a few cases, the submarine and subglacial topography determined from seismic and radar ice sounding profiles indicates that hyaloclastites were removed (eroded) as fast as they were erupted into the moving ice (Behrendt et al., 1995). A few exceptions are Holocene (on the Ross Sea continental shelf) and presently active volcanism at Mt. CASERTZ beneath the WAIS (Blankenship et al., 1993). Pillow basalts or hyaloclastites (erupted into a submarine environment) or hyaloclastites injected into the moving WAIS at Mt. CASERTZ have not been yet removed either because of the absence of ice over the continental shelf since deglaciation or insufficient time beneath the WAIS. In contrast, the high exposed volcanoes were erupted subaerially as they quickly penetrated through the 2-3-km thick WAIS and were protected from erosion by competent volcanic flows. Mt. Melbourne on the Ross Sea coast, Mt. Erebus, on Ross Island, and Mt. Takahe at about 76°S, 112°W above the WAIS are examples. Coring beneath the ice stream B by Scherer et al. (1998) recovered young diatoms and high concentrations of beryllium-10 that they interpreted as evidence of open marine environment there after a late Pleistocene collapse of the marine ice sheet. Aeromagnetic and radar ice thickness data over the divide area of the WAIS also shows high topography associated with an inferred subaerially erupted volcano, similar in geophysical respects to Mt. Melbourne. These results suggested that the eruption and uplift of the Sinuous Ridge at a time when the Byrd Subglacial Basin was deglaciated, may have forced the advance of the WAIS. Examination of the seismic reflection profiles over the Ross Sea continental Shelf (Cooper et al., 1995) shows the volcanic structures appear to be most common in the western area (associated with the Victoria Land Basin). The only aeromagnetic surveys also cover only the western area, and show about 100 volcanic centres there, including the presence of volcanic rocks at or near the sea floor beneath the northwest Ross Ice Shelf. Changes in patterns of volcanic magnetic anomalies over the western Ross Sea, northwest Ross Ice Shelf and WAIS show the complexity of the west Antarctic rift system.

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Glacial Evolution of Antarctica: Evidence from the Deep-Sea Record

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Benthic foraminiferal oxygen isotope ratios provide a detailed perspective on the glacial evolution of the Antarctic ice sheet since the early Cenozoic. Because polar ice sheets sequester the lighter oxygen isotope, their growth and decays brings about changes the $^{18}O/^{16}O$ ratio in seawater, which are preserved in the oxygen isotopic composition of foraminifera. Since the 1970s a number of studies have sought to assess Antarctic glacial evolution on the basis of foraminiferal $\delta^{18}O$ records. While only at coarse temporal resolution, these early studies revealed that Antarctica had been glaciated for most of the Cenozoic (e.g. Margolis and Kennett, 1970; Shackleton and Kennett, 1975; Matthews and Poore, 1980; Miller et al., 1987). The long term perspective of Antarctic glaciation still holds. In fact, the most recent compilation of foraminiferal $\delta^{18}O$ records supports an onset of Antarctic glaciation during the late Eocene, and, because of the improved temporal resolution, provides a detailed view of changes in Antarctic glaciation from tectonic to orbital time scales (Zachos et al., 2001).

Based on the evidence provided by benthic foraminiferal $\delta^{18}O$ values, Antarctica remained at least partially glaciated over the past 36 my (Fig. 1). Glaciation commenced with small ephemeral ice sheets during the late Eocene between about 36 Ma and 33.5 Ma. The Eocene/Oligocene boundary saw the first rapid increase in benthic foraminiferal $\delta^{18}O$ values signifying expansion of Antarctic ice to as much as 50 % of the present day ice sheet (Zachos et al., 2001). Antarctica remained glaciated until the late Oligocene when foraminiferal $\delta^{18}O$ values decreased to pre-Oligocene levels suggesting a major warming trend. Until the mid Miocene Antarctica may have been glaciated only partially, but distinct positive excursion in the $\delta^{18}O$ record indicate several periods of ice expanse. A second major phase of Antarctic ice growth occurred during the mid Miocene from ~15 Ma to ~13 Ma. Thereafter ice sheets continued to grow, but slowly, through the late Miocene. During the late Pliocene, at about 3.2 Ma benthic foraminiferal $\delta^{18}O$ values increase rapidly reflecting the onset of significant Northern Hemisphere glaciation. Superimposed on these long-term trends, fluctuations in Antarctic ice volume occurred at time scales associated with changes in the Earth's orbital geometry. Variations in obliquity in particular, which intensify the seasons at high latitudes on time scales of ~41 ky, prevail in the benthic foraminiferal $\delta^{18}O$ records since the early Oligocene regardless of the degree of glaciation (Zachos et al., 2001).

Benthic foraminiferal $\delta^{18}O$ records have provided significant insights into the history of

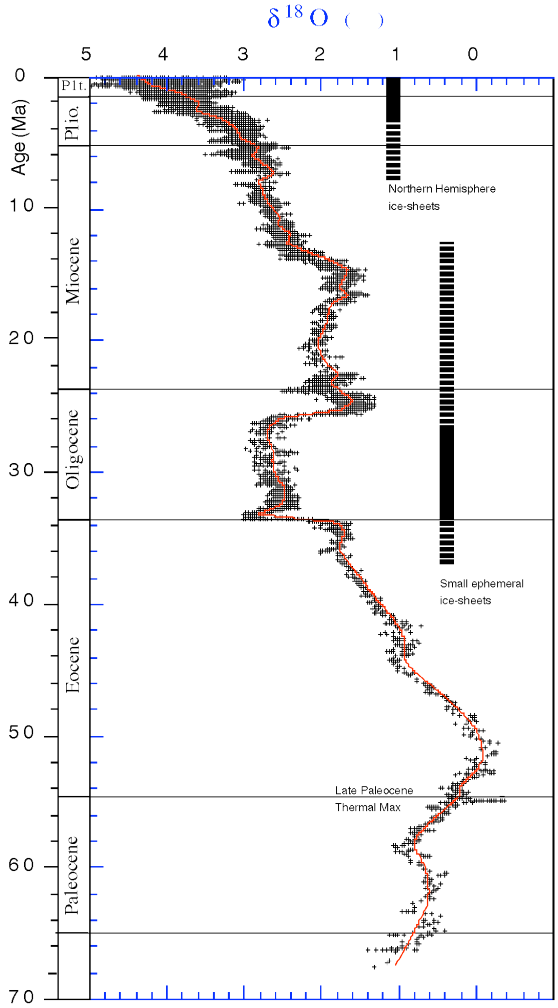

Figure 1. Cenozoic benthic foraminiferal $\delta^{18}O$ records from over 40 Deep Sea Drilling Project and Ocean Drilling Program sites as compiled by Zachos et al. (2001). Ages are relative to the time scale of Berggren et al. (1995). The dashed vertical bar is to indicate intervals of time of minimal glaciation, the solid bar highlights ice extent of at least 50 % of present (Zachos et al., 2001).

Antarctic glaciation, but the absolute magnitude of ice extent is difficult to constrain. The isotopic composition of seawater may reflect regional water mass salinity in addition to global ice volume fluctuations, and foraminiferal $\delta^{18}O$ values vary with seawater temperature changes, which fractionate oxygen isotopes during calcification. There are intervals of time when $\delta^{18}O$-based reconstructions from the deep-sea record differ from reconstructions based on other proxies. A debate exists about the stability of the East Antarctic ice sheet during the early Pliocene, when foraminiferal $\delta^{18}O$ values vary too little to accommodate a major draw-down of the East Antarctic ice sheet as suggested by reconstructions of early Pliocene sea level (Kennett and Hodell, 1993). A combination of different geochemical proxies, such as foraminiferal Mg/Ca ratios to independently constrain water temperatures, may ultimately help to refine the deep-sea record of Antarctic glaciation.

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Miocene Diatom Biostratigraphy of ODP Site 1165, Antarctic Continental Rise

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ODP Site 1165 was drilled on the Antarctic continental rise offshore of Prydz Bay (64º23'S, 67º13'E; 3537 m water depth). Holes 1165B and 1165C represent a composite section of approximately 1000 m, which is divided into three primary lithostratigraphic units (Units I, II, and III) (Shipboard Scientific Party, 2001).

An expanded section of Miocene strata (Units II and III) was recovered in the Hole 1165B/C section from ~999 to 64 metres below sea floor (mbsf). Well-preserved and abundant siliceous microfossils are present above ~606 mbsf, but are poorly preserved or absent below this level due to dissolution.

Middle Miocene cores in the Hole 1165B/C section have a poor magnetostratigraphic signal due to a low concentration of ferrimagnetic minerals, possibly as a result of diagenetic processes. Consequently, age interpretations for these cores rely primarily on diatom and radiolarian biostratigraphy, with contributions from nannofossil and planktic foraminiferal biostratigraphy. Approximately 15 primary diatom datums are recognised to divide the Miocene section into 13 zones. Several taxa, such as *Thalassiosira mahoodii*, "*Denticulopsis hustedtii* var. *aspera*," and *Denticulopsis ovata*, are considered to be biostratigraphically useful and will be utilised in a revised Miocene diatom zonation.

The lowest occurrence of diatoms noted in the Hole 1165B/C section is at -754 mbsf (Core 1165C-10R). At this level, poorly-preserved diatoms were observed in a sample from

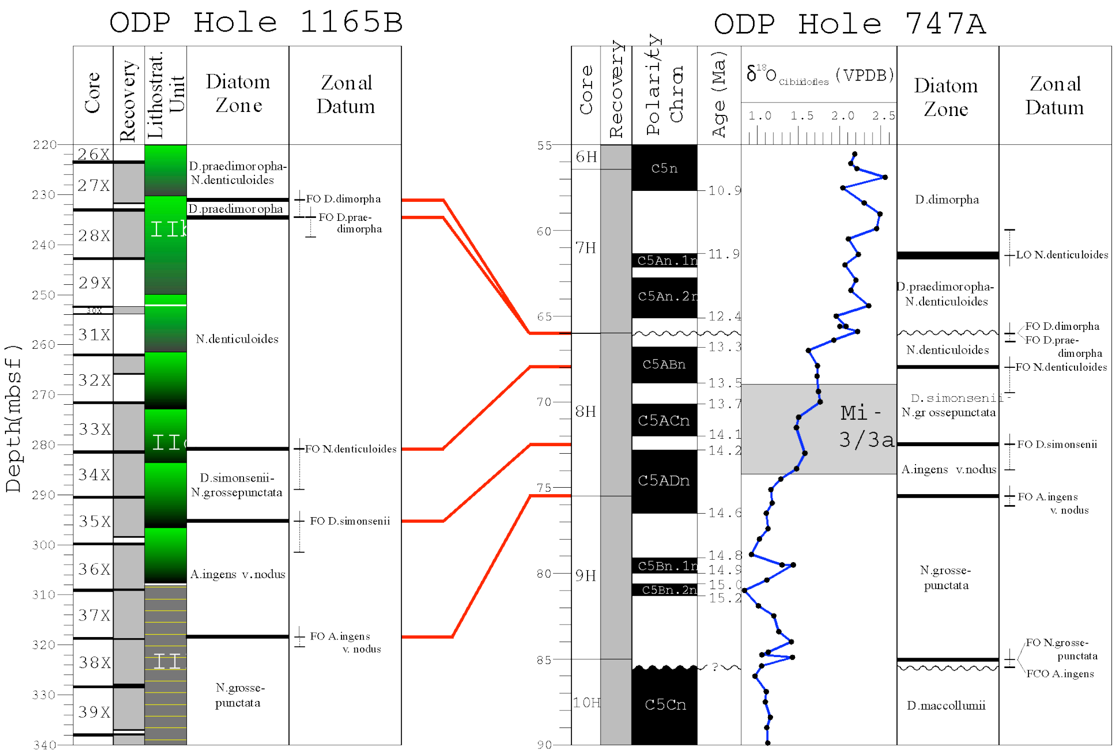

Figure 1. Diatom correlation between middle Miocene intervals of ODP Hole 1165B (continental rise; 64ºS) and Hole 747A (Kerguelen Plateau; 54ºS). The sedimentological transition from Unit III to Unit IIc in Hole 1165B occurs above the FO of *Actinocyclus ingens* var. *nodus* and below the FO of *Denticulopsis simonsenii*. Diatom correlation to Hole 747A indicates that this level corresponds to the base of the Mi-3/3a oxygen isotope event (derived from benthic foraminifera) and falls within Chron C5ADn (at ~14.3 Ma). Hole 747A data is compiled from Harwood and Maruyama (1992), Harwood et al. (1992), Heider et al. (1992), Wright and Miller (1992), and Ramsay and Baldauf (1999).

a carbonate-cemented burrow. *Thalassiosira praefraga* is present in this assemblage, which places the interval between ~754 and 492 mbsf within the lower Miocene *Thalassiosira praefraga* a-b Subzones. No siliceous microfossils were observed below ~754 mbsf during shipboard examination of core-catcher samples and selected carbonate-cemented horizons. The lower interval of Hole 1165C (~999-754 mbsf), however, is constrained to the lower Miocene by nannofossil biostratigraphy (Shipboard Scientific Party, 2001).

Approximately 12 Miocene diatom datums recognised in Holes 1165B and 1165C are reliably calibrated to the Magnetic Polarity Time Scale from previous work in other Southern Ocean drillcores. At present, the diatom stratigraphy from Hole 1165B provides a Miocene age model that is constrained within 0.5 to 1.0 m.y. No significant Miocene hiatuses (i.e. ≥1-2 m.y.) are resolved by diatom biostratigraphy.

A broad examination of the Miocene age model for Holes 1165B and 1165C reveals an uphole decrease in sediment accumulation rates. The most prominent lithologic change through this interval occurs in the middle Miocene section of Hole 1165B at ~308 mbsf (Shipboard Scientific Party, 2001). At this level, there is a transition from dark-grey fissile claystones of Lithostratigraphic Unit III (~999 to 308 mbsf) to greenish-grey diatom-bearing clay of Lithostratigraphic Unit II (~308 to 64 mbsf). Current investigations are focusing on the diatom stratigraphy through this middle Miocene transition interval, and we are attempting to establish a palaeoenvironmental framework for the diatom record by correlation to Kerguelen Plateau sections. Initial biostratigraphic assessment reveals a correlation between the lithologic change observed in Hole 1165B and the Mi-3/3a oxygen isotope event recorded in Hole 747A (Fig. 1).

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Seismic Stratigraphy from the Continental Margin in the Offshore of the George Vth Land (East Antarctica)

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In February-March 2000, a detailed marine geoscience research voyage was carried on the continental shelf and rise of the George Vth Land sector in the East Antarctic margin (Domack and Anderson 1983; Chase et al., 1987; Eittreim and Smith 1987; Eittreim et al., 1995; Hampton et al., 1987; Tanahashi et al., 1987). The voyage was included in the frame of the WEGA project, a joint Italian/Australian program.

High-resolution seismic data and piston cores, were collected. From the preliminary analysis of these new data, we recognise the high variability of the sediment character and distribution, that represent a direct record of the dynamics of the East Antarctic ice sheet and of the southern ocean currents.

Main results of the cruise can be summarised as follow:

1) The discovery, coring and mapping of a sediment drift deposit on the inner shelf, west of the Mertz glacier. The "Mertz drift" lies in 800 m water depth, it covers about 400 km^2 and is over 35 m thick. While the lower sediments are laminated, there is a 20 to 50 cm thick sandy drape at the surface. This suggest that a recent (late Holocene) change in the depositional environment has occurred, possibly related to change in the high salinity shelf water production.

2) The detailed mapping of a sediment mound on the continental rise. The mound nucleates from sea-floor irregularities, inherited from basement structures, is perpendicular to the slope and shows an asymmetric profile with

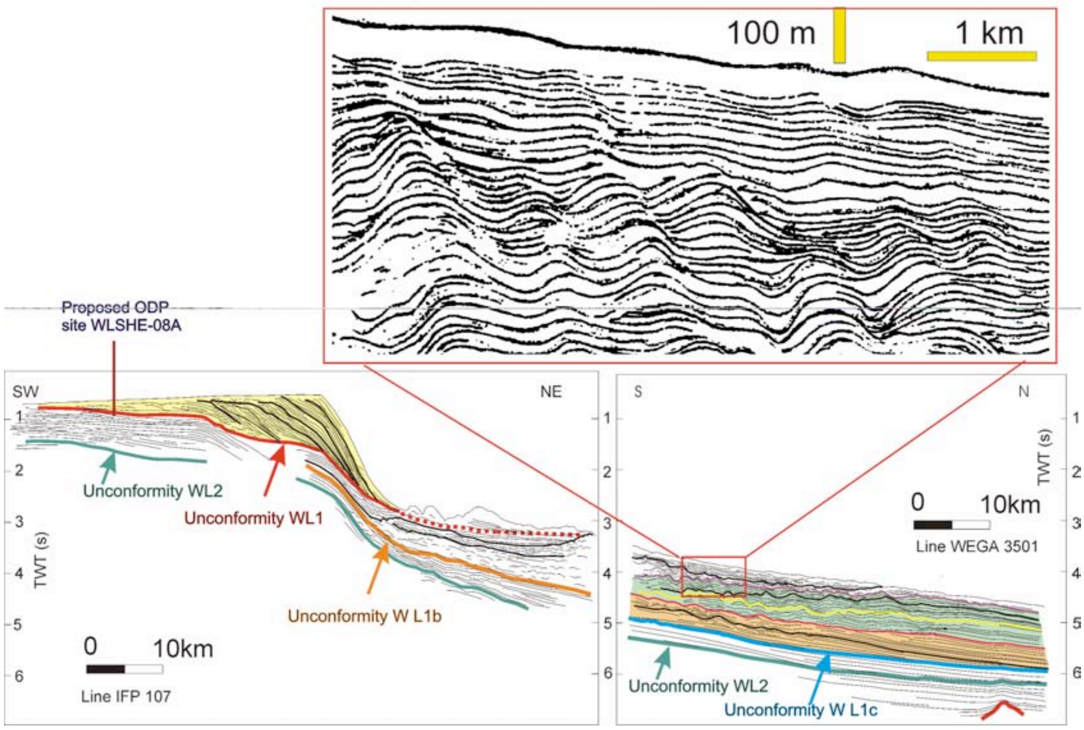

Figure 1. Line drawing from a composite seismic section across the continental margin and slope in the offshore of the George Vth land (East Antarctica). Main depositional features are: i) the regular sedimentation below unconformity WL1b, ii) the mound with sediment waves field between unconformities WL1 and WL1b, iii) the formation of the prograding wedge above WL1.

the eastern flank less steep than the western flank, which is highly eroded. The mound is about 30 km width, 150 km length and up to 3 km thick. Gravity cores from the top of the mound recovered up to 5 metres of silty-clay deposits with alternations of brown, fine laminated units and grey, massive, bioturbated units. In analogy with other circum-antarctic cores, we believe that the differences between the two types of deposits are the product of glacial-interglacial cycles.

Seismic sequences from the rise (Fig. 1) can be classified in three main groups:

a) pre - mound sequences, represented by very regular, sub-parallel, low amplitude reflections;

b) mound sequences, characterised by well developed sediment waves with maximum relief of about 50 m and average amplitude of about 2 km;

c) Post - mound sequences, that drapes the mound sequences, and attenuate the underlying sediment waves.

Important observations from the seismic data from the mound are summarised as follows: i) pre-mound geometries indicate a low energy, mainly pelitic environment, ii) mound geometries are consistent with a turbiditic system, confined by strong bottom current flowing out of the continental shelf iii) post mound sequences were deposited during the construction of the steep prograding wedge that built up the continental slope. From this last point, we can infer that the bulk of the mound sequences is older than the prograding wedge.

Starting from these considerations, we suggest that the mound formation and attenuation recorded the evolution of the Antarctic cryosphere: the mound could be the product of a high sedimentation rate related to the presence of a temperate ice sheet grounded at the sea level. Temperate ice sheets are characterised by abundant melt water that transports and deposits at sea large volume of sediment.

The upward attenuation of the drifts, recorded the transition from a temperate to a polar setting. Polar ice sheet, similarly to the present one, are characterised by a reduced volume of sediment transport that is deposited close to the grounded line. During glacial advances the ice sheet reached the shelf break and deposited prograding wedge.

This model explains also the diachronicity between the slope and rise development.

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The Eocene-Oligocene Boundary in the Ross-Sea (Antarctica) Based on Downhole Measurements

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The CRP-3 drillhole of the Cape Roberts Project (northern McMurdo Sound, Ross Sea, Antarctica) investigated Neogene to Palaeogene climatic and tectonic history of the western margin of the Victoria Land Basin, by obtaining continuous core and downhole logs. Well logging of CRP-3 has provided a complete and comprehensive dataset of *in situ* geophysical measurements down to the bottom of the hole (c. 940 metres below sea floor). Evaluation and interpretation of the downhole logging data was performed using the multivariate statistical methods of factor and cluster analysis. The factor logs mirror the basic geological controls (i.e., grain size, porosity, clay mineralogy) behind the measured geophysical properties, thereby making them easier to interpret geologically. Cluster analysis of the logs groups similar downhole geophysical properties into one cluster, delineating individual logging or sedimentological units. These objectively defined units, independent of core analyses, are helpful in differentiating lithological and sedimentological variations such as grain-size, sediment provenance, and glacial influence. For CRP-3, the three factor logs derived from the downhole measurements indicate grain-size (lithology), diamict/conglomerate occurrence (glacial influence), and provenance. By cluster analysis of the three factor logs, it was possible to divide the borehole into three main sections (Fig. 1). The upper section down to about 230 mbsf is dominated by mudstone with clearly different physical properties from deeper mudstones. Below 230 mbsf, sandstones are dominant. The cluster analysis identifies two types of sandstones, differentiated mainly by their magnetic properties, which are correlated to core-based detrital mode provenance variations. The lower sandstone cluster is dominant between 630 mbsf and 790 mbsf. The 630 mbsf change, which corresponds with a major change in sediment source from Victoria to Taylor Group, marks the Eocene/Oligocene boundary. Comparison of these results with the seismic stratigraphy shows that the 630 mbsf change is not distinguished by seismic sequence analysis. This finding will have consequences for the entire Ross Sea seismic stratigraphy.

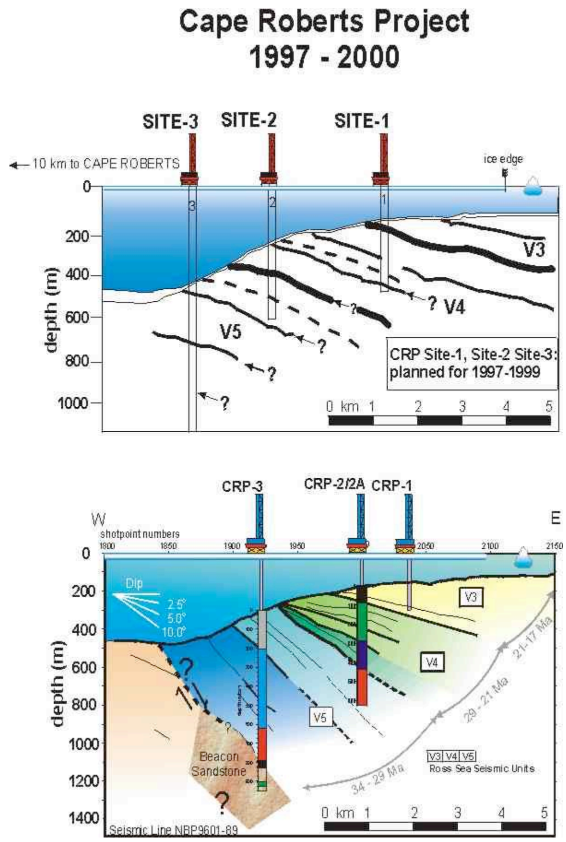

Figure 1. Upper part: seismic cross section as known at the beginning of the project in 1997. The real source of the reflections and the age of the seismic units V3, V4, and V5 is unknown. Lower part: by cluster analysis of the downhole measurements of the drill-holes CRP-2 and CRP-3, it was possible to characterise and differentiate the seismic units. In general they mark different sediment provenances and sedimentation processes.

Plio-Quaternary Sedimentation on the Wilkes Land Continental Rise

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The Wilkes Land continental slope is characterised by several submarine canyons that develop into mounds and channels system in the continental rise. The mounds have approximately a north-south elongation, perpendicular to the margin. Proximal mound relief is up to 1000 m decreasing to about 300 m in the middle part. The submarine canyons represent the sediment drainage system supplied by the continental shelf margin ice-sheet, that feed the mound depositional system. Turbidity currents can be considered the main process for sediment supply to the rise, but the overall depositional facies are due to the interplay between turbidity and bottom currents (Escutia et al., 1997).

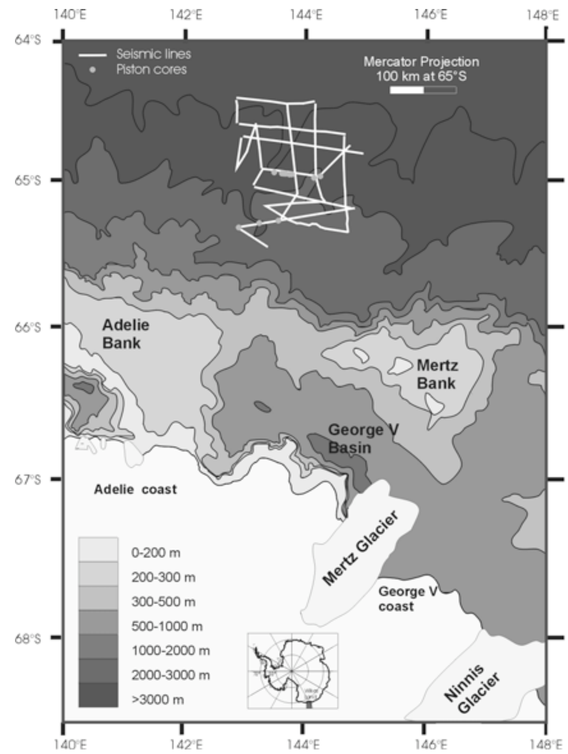

Figure 1. Location map of the continental margin of Wilkes Land showing the seismic lines and piston cores collected during the joint Australian and Italian WEGA Project in February-March 2000.

The geophysical and geological survey carried on in February-March 2000 by the joint Italian and Australian WEGA Project, onboard the R/V Tangaroa, acquired about 1000 km of multichannel seismic reflection and single channel seismic (Fig. 1). Eleven piston cores were collected along two transects parallel to the margin moving across the channel-mound system. Whole cores were analysed on board with a multisensor core logger for physical (magnetic susceptibility and density) and acoustical properties, and split cores where visually described, X-rays investigated, and sampled for clay mineral analysis. X-ray and visual investigations allow the identification of five sedimentary facies:

1) Massive mud: homogenous mud, locally intensively bioturbated, with sparse clasts (IRD);

2) Laminated mud: parallel and/or cross lamination, with laminae from 1-2 mm (X-ray dark laminae) to 1-2 cm-thick (X-ray light laminae), and occasionally sparse clasts (IRD). The boundary from massive to laminated facies is sharp;

3) Massive debris: structureless and unsorted debris (gravel and pebble) within a muddy matrix;

4) Laminated-to-massive mud: repeated intervals of finely laminated mud gradually passing to structureless mud with sparse clasts (IRD). The boundary between massive and laminated mud is sharp;

5) Turbidite: normally graded coarse sand with sparse mud chips.

The cores recovered from the gentle side of the mound show massive and laminated sediments, whereas in the steep side of the mound the sediments are characterised by massive debris overlain the laminated-to-massive facies. The turbiditic sequence was recovered from a small terrace close to the talweg of the channel. By comparison with the facies described in the mound of the continental rise of the Pacific margin of Antarctic Peninsula (Lucchi et al., in press) we relate the massive facies to an interglacial period, whereas the laminated facies is related to a glacial stage.

The clay mineral analyses indicate illite and smectite as main components with opposite down-core trends, whereas chlorite occurs in small and fairly constant amount (<20%). Kaolinite is detected only in traces. Variation in the clay mineral assemblage occurs at the main change of facies.

Physical and acoustical properties are influenced by several parameters such as grain size, sorting, sediment composition, presence of IRD, etc. Main changes in physical properties not always coincide with facies and/or glacial-interglacial alternations. Nevertheless, the down-core sequence of peaks and trough in their logs are an useful tool for core to core correlation.

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Deep Sea Sediment Consolidation Through the Glacial History of the Pacific Margin of the Antarctic Peninsula

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The hemipelagic drifts of the proximal continental rise of the Antarctic Peninsula Pacific margin are a mud-dominated sedimentary environment fed primarily by the terrigenous input of the ice sheet during each advance to the continental shelf edge, and secondarily by the rain of planktic and benthic micro-organisms. Among these, siliceous micro-organisms prevail.

The analysis of porosity and bulk density profiles at ODP Leg 178 Sites 1095, 1096, and 1101 (see details in Volpi et al., this volume) indicates that the sediment drifts succession is mostly underconsolidated. Underconsolidation is outlined by anomalous porosity trends, which include a porosity minimum at shallow depth, constant porosity with depth, or even increasing porosity with depth. As a consequence, these sections retain a very large amount of interstitial fluids at the expenses of pore volume reduction. In all three sites the sediments compact normally in the upper part (about 60 to 150 m) that corresponds to the Quaternary. The loss of porosity decreases, or even stops, in the Pliocene, and is maintained in the Upper Miocene. Only at Site 1095 a sharp decrease in porosity, matching increasing bulk sediment density and increasing compressional velocity, occurs towards the base of the hole, at about 500 mbsf.

The main lithological and sedimentological changes downhole, that can be correlated among the three sites, are the content of biogenic silica, and the sedimentation rate. In the Quaternary, the biogenic silica content is low (5% or less) due to the progressive cooling of the region, which affected sedimentation in terms of increasing average sea ice coverage, limiting primary productivity. The bulk sedimentation rate is also lowest in the Quaternary, due to the trapping of terrigenous sediments in the margin's aggrading glacial wedges. These environmental conditions are favourable to normal consolidation in deep sea sediments. The highest primary productivity of the Late Miocene and Early Pliocene, reflected in biogenic silica accumulation up to 20-25%, coincides with high sedimentation rate in the deep

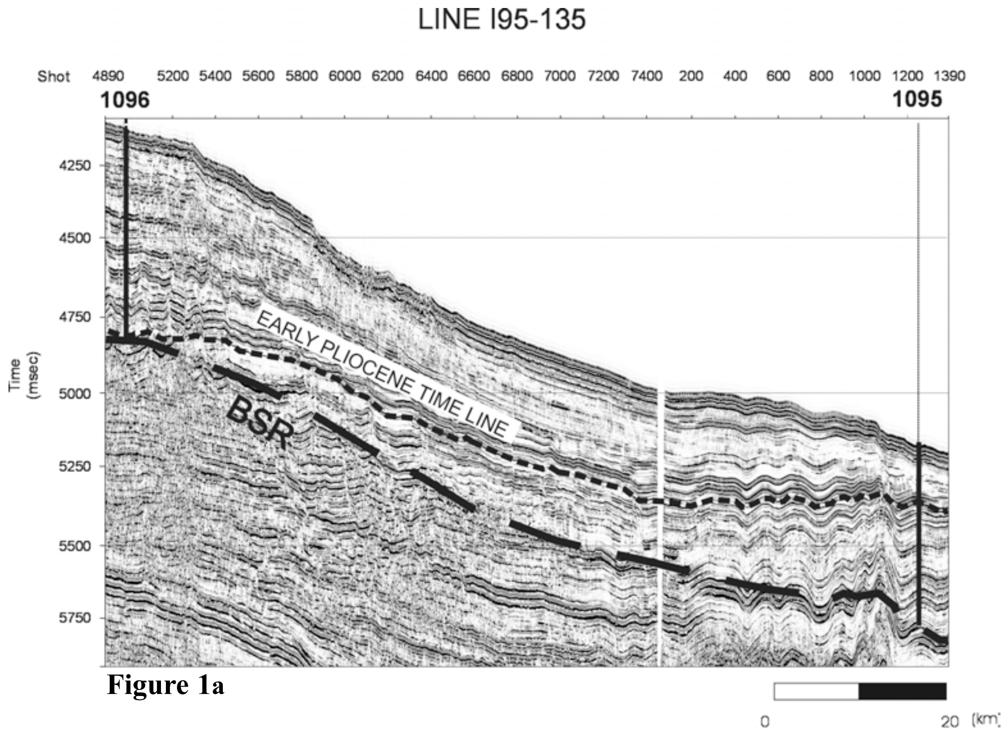

Figure 1a

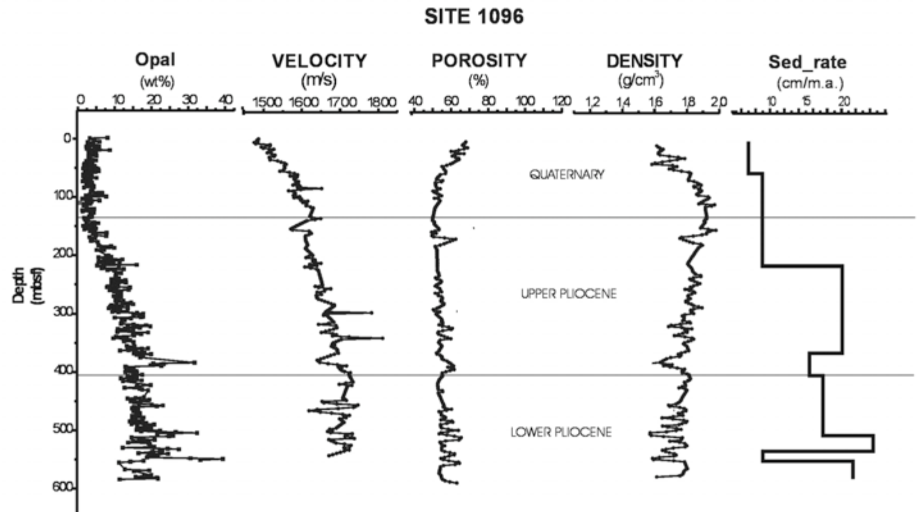

Figure 1b

Figure 1. a) multichannel seismic reflection profile in direction perpendicular to the margin connecting Sites 1096 and 1095. The silica diagenesis BSR is outlined with a thick dashed line. A time line (thinner continuous line) is indicated for reference. Note that the BSR cuts across sediment layering. Note also the lower sedimentation rate at Site 196 compared to Site 1096. **b)** Example of relationship between physical properties, biogenic silica, and sedimentation rate at Site 1096. The BSR here does not intersect the drilled section.

sea, allowed by a rapidly growing, prograding glacial margin. We relate the lack of porosity loss in this time interval as a primary consequence of the presence of rigid siliceous particles in the sediments which prevent consolidation as it normally occurs in clay-rich sediments (Bryant et al., 1981).

Finally, the sharp porosity decrease at the base of Site 1095 is explained by the presence of a silica diagenetic front (Opal A to CT transition). On multichannel seismic data (Fig. 1) we identified a subtle change in sediment reflectivity that correlates with a silica diagenesis BSR on the margin shown earlier in more proximal locations of this margin (see Lodolo and Camerlenghi, 2000). The BSR corresponds to a change in amplitude more than frequency and phase among the three seismic attributes analysed. Sediments below this boundary behave as overconsolidated due to the diagenetic cementation of sediment grains by silica.

The results of this study should be taken in consideration here and elsewhere on the Antarctic margin in the reconstruction of mass balances and sedimentary budgets. The anomalous porosity may account for up to 30% volumetric differences with respect to normally consolidating sediments. The error induced in mass balance calculation could therefore be significative.

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An Antarctic Seismic Data Library System for the 21st Century

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The Antarctic Seismic Data Library System for Cooperative Research (SDLS) was designed by members of the Antarctic geoscience community to facilitate open access to multichannel seismic reflection data, and to promote collaborative research based on these data. The SDLS was formally adopted in 1991 under the auspices of the Scientific Committee on Antarctic Research (SCAR) and mandates of Antarctic Treaty Consultative Meeting Recommendation XVI-12 (SCAR, 1991). Since that time, library branches have been established in countries worldwide, and more than 50,000 km of digital data have been provided to the SDLS by data collectors in 10 countries.

The library system is not a data bank for permanent data storage like the World Data Center (WDC), but is a dynamic library where data resides temporarily for use by all members of the research community in collaboration with data collectors. Data are available at the SDLS during the period between 4 and 8 years following data collection, after which they go to the WDC. The SDLS system protects intellectual property rights of data collectors (for 8 years) and gives open access to data, required by the Antarctic Treaty, to facilitate timely and multinational geoscience research products. This abstract outlines suggestions to update the data-access technology used by the SDLS, while retaining the basic tenets and guidelines upon which the library system was adopted and now operates (SCAR, 1991).

In the early 1990's when the SDLS was developed, the computer technologies used then included stand-alone desktop computers and early writeable CD's, which are by today's standards primitive. The World Wide Web did not exist at the time. We propose an updated SDLS design that incorporates a variety of new features and capabilities using modern technology and new standards for the organization and dissemination of geospatial data. Some of the features of this new design include:

• The new SDLS will be principally Web-based, allowing on-line access to digital datasets. Security and access to data will be controlled according to the terms of the original SDLS agreement, either by limiting on-line access to sensitive data files (such as the SEG-Y files, detailed shotpoint maps, and high-resolution images) or by storing those files on off-line media (e.g. DVD) that are only accessible at the SDLS library locations.

• The new SDLS will include not only the binary seismic datasets (SEG-Y), but also images of the profiles in standard formats (e.g. jpeg, gif, tiff) suitable for viewing and printing without specialised seismic processing software.

• The new SDLS will include spatially referenced location figures at a standard projection and scale to enable the convenient production of location maps. The use of consistent map parameters and layered map elements will facilitate the ease with which data from different datasets can be combined and interpreted.

• The new SDLS "library" locations will consist of mirrored Web sites with catalogs of SDLS data holdings. These sites will not necessarily hold all of existing data files. Initially, data will be held in a combination of on-line and off-line formats in response to data security and data transmission issues. The new SDLS will establish a common set of descriptors about each dataset (a "content standard") in order to provide more consistent and complete documentation about datasets in the library. A prototype for this standard specifically designed for SDLS data is proposed.

The renovated SDLS, like its predecessor, will be a community research tool that relies on active "care and feeding" by data collectors and users for its ultimate success.

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Early and Middle Miocene Advances of the Antarctic Ice Sheet across the Ross Sea Continental Shelf

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According to conventional interpretations of proxy data, the Antarctic Ice Sheet experienced rapid growth and attained continental scale after the middle Miocene Climatic Optimum (Flower and Kennett, 1995). Indeed, the stratigraphic record on the Ross Sea continental shelf contains strong evidence that extensive ice sheets existed during the middle Miocene (Anderson and Bartek, 1992). Middle Miocene units on the Ross Sea continental shelf contain glacial unconformities on at least three stratigraphic levels (Bart and Chow, 2001) suggesting concurrence with the inferences of Flower and Kennett (1993) that middle Miocene glaciation occurred in a step-wise fashion. Yet, the earliest middle Miocene advances appear to have occurred during the Climatic Optimum. Moreover, seismic results correlated to palaeontologic and lithologic control at Deep Sea Drilling Project (DSDP) sites 272 and 273 indicate a major episode of glacial erosion and deposition affected the shelf in the early Miocene (i.e. >18 Ma). Given that the climatic transition occurred between ~15 to ~17 Ma, the cause and style of glaciation in the early Miocene might be different from that which occurred in the middle Miocene (Stroeven, 1996). To investigate this possibility, we are integrating recently acquired seismic data with lithologic and chronologic control at DSDP sites and with pre-existing seismic data to compare the stratigraphy on early Miocene and middle Miocene units (i.e. units 10 and 9 respectively from Anderson and Bartek, 1992). Our initial results suggest that there are no major differences between the two units. Both units 10 and 9 show well-developed prograding foresets over large areas, and they do not differ in terms of internal geometry and foreset angles. This suggests that full-bodied ice sheets probably existed on the Ross Sea continental shelf before, during, and after the middle Miocene Climatic Optimum.

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Cyclicity in the High-Resolution Physical Properties Record from the Cape Roberts Project (Victoria Land Basin, Antarctica) and Implication for Sedimentation Rate

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The Cape Roberts Project was a cooperative venture developed by Australia, Germany, Great Britain, Italy, New Zealand, The Netherlands and United States to core Cenozoic siliciclastic sediments in the Victoria Land Basin (Antarctica), during the Austral Spring of years 1997, 1998 and 1999. Initial results were expected to investigate palaeoclimate changes through the Paleogene and Neogene and to record the tectonic/erosional history of the Transantarctic Mountains.

The composite cored section consists of a repetition of lithofacies, from diamictite-conglomerate to fine-grained sandstone and mudstone; these are organised in multiple stratigraphic sequences which record a complex interplay of ice sheet advance/retreat and corresponding changes in relative sea level.

A distinctive high-frequency cyclic pattern is reflected in the low-field magnetic susceptibility and wet bulk density records. In order to investigate the presence of small-scale cyclicity, the analysis of these physical properties associated with detailed sedimentological study are conducted on fine-grained intervals, where the sedimentary record prove to be more complete and less affected by depositional unconformities.

The physical properties data series have recorded high-frequency changes in the depositional processes, as response to periodic sea-level fluctuations, and in the weathering processes occurring in the source area, and they are here interpreted as highly-sensitive palaeoclimate indicators. Therefore, the analysis of their fluctuations will give an important help in unravelling the high-resolution climatic history of continental glaciers and, at a larger scale, of the Antarctica Ice Sheet.

Frequency analysis methodologies are applied to the physical properties data series for these selected portions of the cored sections. The results demonstrate the presence of predominant sets of periodicities, which in turn are suggestive of a forcing mechanism controlling the deposition. Moreover, the comparison with the eccentricity, obliquity and precession perturbations (100 ky, 41 ky and 21 ky respectively) provides important evidence that these small-scale sedimentary cycles can be in tune with Milankovitch orbital periodicities (Cape Roberts Science Team, 1998; 1999; 2000; Claps et al., 2000; Florindo et al., submitted; Niessen et al., 1998).

The recognition of orbital control on the cycles recorded in these fine-grained intervals allows to refine the sedimentation rates evaluated for these portions of the drilled section. These estimates will be compared with those obtained through other independent stratigraphic methods and correlated with them, in order to provide an integrated and more precise time evaluation. This approach demonstrates to be of instrumental importance in particular where the stratigraphic control might be less than desirable.

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Methane Diagenesis and Authigenic Carbonates in Continental Rise and Shelf Sediments, ODP Leg 188 Sites 1165 and 1166, Offshore Antarctica (Prydz Bay)

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ODP Leg 188 coring on the Antarctic Prydz Bay continental rise, slope, and shelf obtained sediments records the transitions from preglacial to glacial, and deep- to shallow- water conditions (O'Brien et al., 2001). Site 1165 cored Miocene and younger pelagic and hemipelagic drift sediments in water depth of 3537 metres. Cores from Site 1166 on the continental shelf (475 m water depth) include organic carbon-rich rocks of Cretaceous (Turonian) age deposited during temperate climate conditions that supported onshore swamp vegetation. Carbonate nodules were collected from both Sites 1165 and 1166, and show mineralogic and isotopic evidence of growth under contrasting diagenetic conditions.

Carbonate nodules from Site 1165 are calcite with minor quartz and feldspar with $\delta^{13}C$ values ranging from –49.7 to –8.2 ‰. The nodules with the most negative $\delta^{13}C$ values are at depths of 273 to 350 mbsf and must have precipitated from carbonate derived from subsurface anaerobic methane oxidation. Siderite nodules from lithostratigraphic Unit IV (276 to 315 mbsf) at Site 1166 contain feldspar, mica and carbonate-apatite and have $\delta^{13}C$ values ranging from –15.3 to –7.6 ‰. These nodules probably represent early diagenetic carbonate precipitation during microbial methanogenesis.

Sediment accumulation rates at Site 1165 rates monotonically decrease from 130 m/m.y. in the early Miocene to 15 m/m.y. during the Plio-Pleistocene. This long-term decrease in sedimentation rate and organic carbon input has resulted in subsidence of the sulfate-methane interface from depths on the order of 10-20 mbsf during the early Miocene to a present depth of 150 mbsf. Present concentration gradients of sulfate and methane imply downward diffusive flux of dissolved sulfate of 1.2 mol^{-2} kyr^{-1}, and upward diffusive flux of dissolved methane of 0.5 mol m^{-2} kyr^{-1}. The nodules (or layers) are on the order of 2-cm thick and contain 60-70% $CaCO_3$, representing an accumulation of 3.5 mol m^{-2} of calcite, or about 7000 years worth of upward-diffusing oxidised methane.

Neither water nor gas samples could not be obtained from indurated rocks of Site 1166 in which the siderite nodules occurred. These older rocks probably represent a nearshore restricted marine or lagoonal depositional environment. The presence of both pyrite and apatite in nodules suggests nearshore or fluctuating salinity conditions. The $\delta^{13}C$ range (–15.3 to –7.6 ‰) and the mineralogy (Fe-rich, implying absence of sulfide activity) are consistent with siderite precipitation during the early stages of methanogenesis.

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Early Stages of East Antarctic Glaciation - Insights from Drilling and Seismic Reflection Data in the Prydz Bay Region

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Early stages of glaciation in East Antarctica (i.e. Eocene to mid-Miocene) are recorded in Ocean Drilling Program (ODP) cores from Legs 119, 120 and 188 and extensive seismic-reflection data from the continental margin of the Prydz Bay region. We focus on Leg 188 drilling (O'Brien et al., 2001) and new seismic interpretations to infer evolution of the Antarctic cryosphere and palaeoenvironments.

The Lambert Graben – Amery Ice shelf now drains nearly 20% of East Antarctic ice into Prydz Bay. Glacial diamictons in drill cores from ODP Sites 739 and 742 on the continental shelf document that glaciers extended onto the shelf in early Oligocene time. The transition from preglacial to glacial conditions was recovered at the nearby ODP Site 1166. Here, a sequence of preglacial Turonian fluvio-lacustrine and lagoonal deposits are unconformably overlain by sandy fluvial-deltaic units of mid-late Eocene age. These are overlain by late Eocene to early Oligocene glaciomarine deposits. Ages are from Paleogene diatoms, pollen, spores, and dinoflagellates and Cretaceous palynomorphs. Pollen and spores indicate that vegetation in Late Cretaceous was Austral conifer woodland in humid and mild-temperature conditions, and in mid-late Eocene was Nothofagus cool temperate rainforest or scrub with subcanopy flora (Macphail and Truswell, 2000).

Seismic reflection profiles near the drill-sites show disrupted and discontinuous units overlain by layered and prograding sections, suggestive of marginal marine and fluvio-deltaic deposits that have been transgressed by glaciomarine sediments and diamictites from nearby glaciers. The late Eocene-early Oligocene glacial rocks are unconformably overlain by late Miocene and younger glacial diamicton topset beds of the extensive outer-

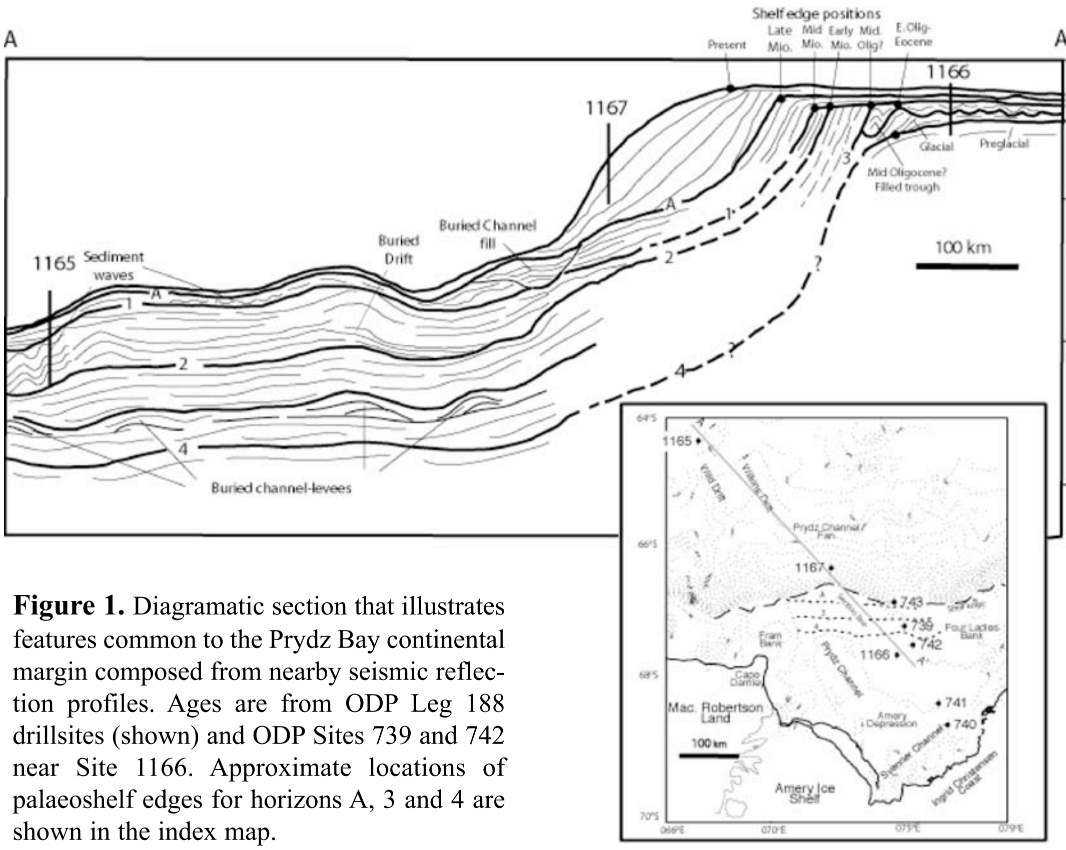

Figure 1. Diagramatic section that illustrates features common to the Prydz Bay continental margin composed from nearby seismic reflection profiles. Ages are from ODP Leg 188 drillsites (shown) and ODP Sites 739 and 742 near Site 1166. Approximate locations of palaeoshelf edges for horizons A, 3 and 4 are shown in the index map.

shelf prograding sequences. Hence much of the Paleogene and Neogene sections have been eroded from the inner shelf near the drillsites (and from onshore) during post-early Oligocene ice advances, which have also resulted in progressive overdeepening of the continental shelf.

The Paleogene sedimentary sections of the mid-shelf areas are incised by troughs up to 15 km wide, now buried and best preserved near the former palaeo-shelf edges (3, 4; Fig. 1). Troughs are more prominent in western than eastern Prydz Bay. They are missing (eroded away) to the south, but may have originated from the Lambert Graben. One prominent trough, 13-km-wide, 600 m deep, N-S trending, lies 4 km west of ODP Site 739 at the early-Oligocene palaeo-shelf edge. The trough location and onlap geometry of the infill suggests that the trough is a canyon head that was cut during a large sea-level lowstand (mid-Oligocene?) and later filled with likely glacially-derived sediments. The Paleogene troughs in the west and likely fluvio-deltaic deposits in the east suggest that the areas were low-lying, near sea-level and subject to subaerial exposure and glacier cover during glacial periods (sea-level lowstands).

Seismic reflection profiles across Prydz Bay show that from early Oligocene to late Miocene times, extensive sigmoidal sequences and topset beds prograded the shelf edge about 30-40 km seaward, and went mostly straight across the front of the Bay (unlike today's convex shape). These glacial/interglacial sequences have not been sampled. However, tracing reflections from early Miocene (near base of hole) and middle Miocene (Unit II/Unit III) horizons sampled at ODP Site 1165 on the continental rise to the slope suggests that about $^{1}/_{2}$ to $^{3}/_{4}$ of the total shelf progradation occurred since early Miocene time, and that shelf aggradation abruptly increases in middle Miocene time (in concert with distinct lithostratigraphic changes at Site 1165).

The drilling and seismic data illustrate a progressive cooling of climatic conditions in the Prydz Bay region from Late Cretaceous into Paleogene time, and subsequent gradual(?) increase in episodic ice movements that excavated and prograded the continental shelf during Paleogene to mid-Miocene times. Clear evidence of large post-Oligocene glacier fluctuations is recorded in onshore fjordal deposits (Hambrey and McKelvey, 2000), outer-shelf sequences, and deep-ocean cyclic sediments (Site 1165; O'Brien et al., 2001).

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The Seismic Stratigraphic Record in the McMurdo Region, what can it Tell us about Glacial and Tectonic Events?

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Seismic reflection data from the McMurdo Sound region and drill core data have been used to try and understand the interaction between tectonic processes, in particular vertical deformation, and glacial events. Two major tectonic features have affected the McMurdo Sound region, the uplift of the Transantarctic Mountains and inferred associated subsidence of the Victoria Land Basin since about 55 Ma, and the evolution of the Ross Island volcanic centre since about 5 Ma.

Ross Island is marked by a bathymetric moat around its perimeter. Seismic reflection data around Ross Island show flat lying sedimentary layers under the moat that are underlain in turn, at a marked angular unconformity, by sedimentary layers dipping towards the island. These and other geophysical data have been modelled by the isostatic response of the Ross Sea lithosphere to the volcanic load of Ross Island, applied at about 5 Ma (Stern et al., 1990).

Simple depositional modelling of the seismic stratigraphy along several seismic reflection profiles across McMurdo Sound indicates that along the western margin of the Victoria Land Basin, uplift events of the order of a kilometre as well as subsidence events of the order of several kilometres have occurred (Davey and Henrys, 1999). The major uplift event appears to have occurred at about 15 Ma, coincident with the onset of major ice sheet formation. Further east, towards the centre of the Victoria Land Basin, it is not possible to recognise any uplift events in the overall subsidence history.

The tectonic subsidence of the western margin of the Victoria Land Basin has been estimated from the physical properties and ages of the sediments in drillcore from the recent Cape Roberts Project using backstripping techniques. Simple subsidence was assumed, and no allowances made for any uplift events, therefore, minimum subsidence and subsidence rates are derived. A total tectonic subsidence of about 660 m was derived for this location between 34 Ma and the present, with two main trends. A fast subsidence of about 140 m/m.y. occurred from about 34 Ma to 32.5 Ma, the younger time corresponding to ca. 115-120 m bsf at CRP-3 site. A slower period of subsidence of about 23 m/m.y. is observed from 32.5 Ma to 21 Ma. Preliminary studies on the CRP-3 core did not detect the occurrence of any significant unconformity at 115-120 mbsf (Cape Roberts Science Team 2000). However, there is a significant increase in the number of the stratigraphic sequences, erosional events, and diamictite and conglomerate layers below this depth, and the change in the subsidence rate from fast to slow is consistent with the geometric pattern of the seismic reflectors observed on the profile across the drill site. Extrapolation to the present indicates a much slower subsidence rate at the CRP drill sites since the formation of the unconformity at 21 Ma.

Seismic sections across the Victoria Land Basin (Cooper et al., 1987; De Santis et al., 1994) show that, toward the east, the sequences younger than 19 Ma are also tilted and eroded, and that a significant amount of the sediments deposited into the basin is younger than 19 Ma. These data suggest that several episodes of fast extensional tectonics and associated subsidence also occurred in and after Miocene time, and gradually migrated toward the eastern sector of the Victoria Land Basin (De Santis et al., 1994). Back stripping modelling of a seismic profile across the basin has estimated the amount of stretching and the tectonic subsidence that occurred during this phase. Preliminary results indicate a pre-existing depressed region coincident with the Victoria Land Basin at the start of extension in about Eocene/Oligocene time.

A depressed region for most of the Victoria Land Basin since the Eocene suggests that erosional events resulting from grounded glacial advances will not be recorded in the seismic stratigraphy, apart from along the western Victoria Land Basin margin, until at least the development of the major ice sheet at about 15 Ma. Major seismic stratigraphic features will record only the major tectonic events, inferred to be related to subsidence associated with the evolution of the Transantarctic Mountains. Since that time, glacial erosional events, associated with expanded ice sheets that may erode to depths of several hundred metres below sea level, are recorded on the seismic data.

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The Early Glacial History of Antarctica: A new Modelling Perspective

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Introduction

The Paleogene glaciation of East Antarctica and the sudden shift to cold conditions over high southern latitudes near the Eocene/Oligocene boundary marks one of the most fundamental reorganisations of the global climate system in the Cenozoic. Evidence of circum-Antarctic ice rafted debris and foraminiferal stable isotope data suggest that the growth of a continental-scale East Antarctic ice sheet occurred within a brief ~200 kyr period around 33.5 Ma and earliest Oligocene ice volume was paced by orbital obliquity (Zachos et al., 1996; Lear et al., 2000).

The initial growth of a continental-scale ice sheet on East Antarctica is often attributed to the opening of ocean gateways between Antarctica and Australia and Antarctica and South America, leading to the organisation of an Antarctic Circumpolar Current (ACC) and the "thermal isolation" of Antarctica (Kennett, 1977). However, linkages between the formation of an ACC and the sudden growth of East Antarctica ice near the Eocene/Oligocene boundary remain ambiguous. Tectonic reconstructions place the timing of the opening of Drake Passage several million years after the Eocene/Oligocene Boundary (Barker and Burrell, 1977; Lawver and Gahagan, 1998). In addition, the diminished southward advection of warm surface waters close to Antarctica may have reduced moisture convergence and snow accumulation over the continental interior, diminishing the potential for rapid ice sheet growth (e.g. Oglesby, 1989; Prentice and Mathews, 1991).

Additional forcings that could have contributed to Paleogene cooling and the expansion of Antarctic ice include declining atmospheric CO_2 (Berner, 1994; Pearson and Palmer, 2000), orbital parameters affecting the seasonal distribution of insolation, and feedbacks within the atmosphere-ocean-cryosphere-biosphere system. In order to test the relative importance of these climatic forcing mechanisms and feedbacks, we have begun running suites of coupled Global Climate Model (GCM)-dynamical ice sheet simulations through entire 41,000-yr obliquity cycles, using a new global palaeogeographic reconstruction of the latest Eocene and prescribed atmospheric CO_2 concentrations ranging from 8x to pre-industrial values. Unlike prior simulations of ancient Antarctic ice sheets using dynamical ice sheet models driven by Energy Balance Models (EBMs) or empirical parameterisations based on modern climatologies (Huybrechts, 1993; Hyde et al., 1999), our new GCM-ice sheet coupling scheme allows us to examine the three dimensional response of climate and ice sheet dynamics to changing climatic boundary conditions in the context of the Paleogene. The interactive nature of our coupled modelling scheme enables us to examine thresholds and feedbacks within the atmosphere-ocean-cryosphere system.

Implications of Initial Model Results

Our model results suggest that declining pCO_2 and orbital parameters may have been the most important forcing factors in the rapid build-up of East Antarctic ice around ~33.5 Ma. A threshold in the long-term decline of Cenozoic atmospheric CO_2 may have been crossed (~700 ppmv) near the Eocene/Oligocene boundary, when significant ice began to accumulate during an ideal orbital configuration producing cool Antarctic summers (Fig. 1). In our model, the first significant ice accumulates in the Gamburtsev Mountains region and in the highlands of Dronning Maud Land, within a 10 kyr window of favourable orbital parameters. As orbital parameters change over the next 20.5 kyr, causing warmer Antarctic summers, significant thinning occurs around the margins of both the proto- Gamburtsev and Dronning Maud Land ice sheets. However, the ice sheets have enough mass to survive until the return of a more favourable orbital configuration. After 41,000 years (one obliquity cycle), a single, continental-scale East Antarctic Ice Sheet has formed, with the region of maximum thickness having moved from the Polar Plateau/Gamburtsev Mountains to Wilkes Land.

Our results suggest that the Cenozoic decline in atmospheric CO_2 strongly increased the sensitivity of Antarctic climate and snow accumulation potential to orbital forcing. The opening of Southern Ocean gateways, leading to the organisation of the Antarctic Circumpolar Current (ACC) and Antarctic Polar Frontal Zone

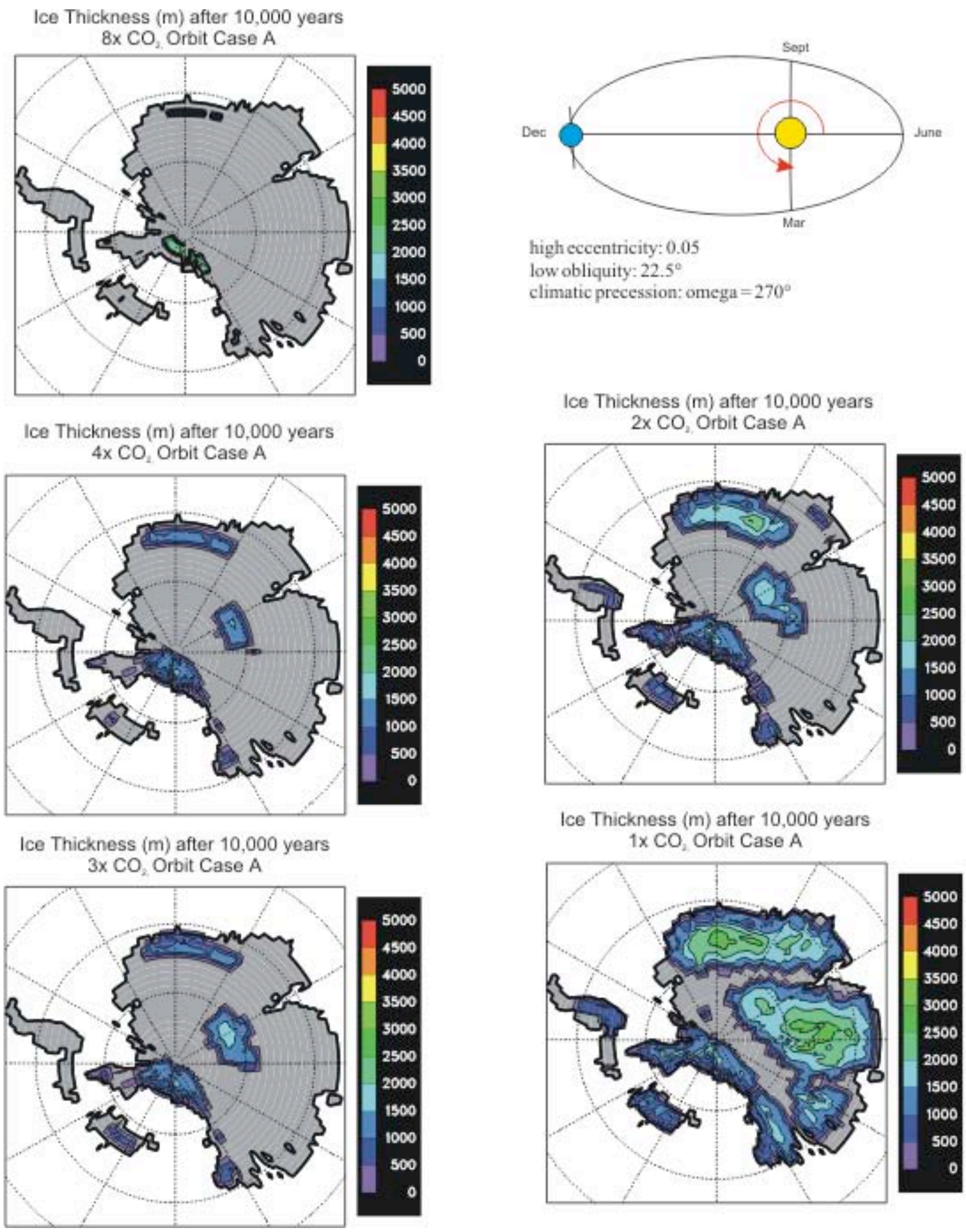

Figure 1. GCM-ice sheet model simulations of Antarctic glacial inception for 8x, 4x, 3x, 2x, and 1x CO_2. All simulations were started with ice-free (isostatically equilibrated) Antarctic topography. Orbital parameters were prescribed to represent an "ideal" orbital configuration for ice sheet growth (high eccentricity, low obliquity and aphelion coinciding with Antarctic summer). Each simulation was run for 10,000 years to approximate the time period that the favourable orbital parameters would be valid.

may have played an important role in the transition from a temperate to a cold polar ice-cap in the Miocene, but may not be a prerequisite for initial ice sheet development in the Paleogene. We will test the role of the ACC in the development of the East Antarctic ice sheet in future modelling exercises.

At levels of atmospheric CO_2 greater than 2x present, our model predicts some continental ice in the polar continental highlands, significant in volume (2-5 x 10^6 km^3), but not large enough to reach sea-level. During the Eocene, such small East Antarctic ice sheets could have existed. They would have been orbitally paced, producing sea-level changes on the order of 10s of metres and affecting mean ocean $\delta^{18}O$, but not producing significant IRD and allowing temperate terrestrial ecosystems to thrive in coastal regions and in continental lowlands.

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2-D Backstripping Modelling of Three Antarctic Continental Margins (the Ross Sea, the Antarctic Peninsula and the Prydz Bay Examples)

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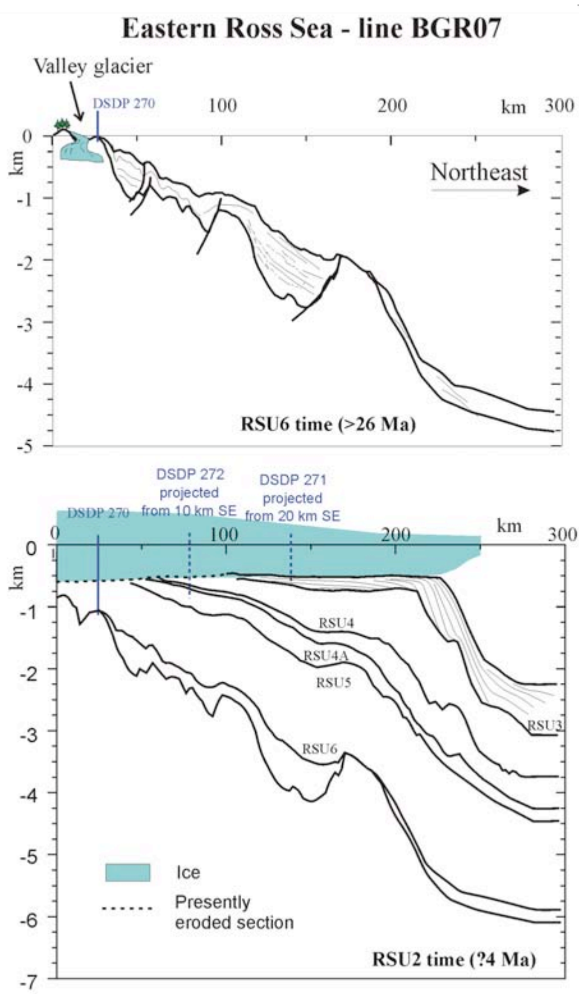
The continental shelf around the Antarctic margin is often overdeepened and landward deepening, due to the spatial distribution of erosion and deposition at the base of grounding ice during multiple ice sheet advances and retreats (e.g. Cooper et al., 1991). We attempt to reconstruct the history of the seafloor profile with the aim to indentify the time when it changed significantly from shallow and seaward deepening, as we assume it was prior to the repeated advances of thick grounded ice, to the present day shape. We present models of palaeo-bathymetric profiles throughout the Cenozoic in the Eastern Ross Sea (De Santis et al., 1999), in the Antarctic Peninsula (Camerlenghi et al., in press) and in the Prydz Bay (La Macchia and De Santis, in press). These profiles are obtained by applying a reverse modelling of post-rift flexural backstripping (Steckler and Watts, 1978) and thermal subsidence (Mckenzie, 1978) to cross-sections derived from selected depth converted, multichannel seismic data. The general paucity of stratigraphic constraints prevents to estimate precise values of palaeo-water depth. Nevertheless, major changes in shape of continental shelf and slope can be recognised in the early Pliocene in the Antarctic Peninsula (about 4.5 Ma) and in the eastern Ross Sea (about 4 Ma) and in the late Miocene in the Prydz Bay, when the continental shelf becomes overdeepened and landward deepening. Drill sites prove that both sequences lying above and below this observed major palaeobathymetric change are of glacial origin. This means that widening and overdeepening of the continental shelf mark a significant variation in grounded ice sheet size and dynamics. We suggest that between the mid to late Miocene and the early Pliocene, the East Antarctic Ice Sheet (EAIS) first and then the West Antarctic Ice Sheet (WAIS) gradually reached their maximum extension on the continental shelf, deeply eroding the inner parts and building up large prograding wedges at the shelf edge. Since then, this peculiar palaeogeography combined with a decreased sedimentation rate, due to a change to a polar glacial regime could have resulted in a progressive sediment starved environment (Barker, 1995; De Santis et al., 1999; Barker et al., in press). This result supports other evidences obtained by drilling, for a gradual transition to fully glacial conditions during the upper Miocene (e.g. the drilling in the Prydz Bay, O'Brien et al., 2001). One of the most important implications of our reconstruction is that although temperate glaciers and ice caps formed in Antarctica since the Eocene, both in the interior of the continent and in shallow, coastal areas, polar conditions were reached only between the mid Miocene and the early Pliocene.



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Palaeomagnetic Constraints from the Livingston Island (South Shetland Islands, Antarctica) and Implications for the Neogene Evolution of the Bransfield Strait

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A palaeomagnetic study of the Miers Bluff turbiditic Formation and Tertiary dykes and andesites outcropping on Livingston Island, South Shetland Islands (Antarctic Peninsula) has been carried out (Fig. 1). Analysis of the isothermal remanent magnetisation (IRM) reveals that the main magnetic carrier in both lithologic units is a low coercivity phase, most likely corresponding to magnetite. Saturation is almost achieved at 0.15 T, and the subsequent alternating field demagnetisation shows a sharp drop at 50 mT. Anisotropy of low-field magnetic susceptibility (AMS) was used to determine the fabric of the studied rocks. Data is compatible either with a sedimentary origin for the fabric or, and most likely, with a weak tectonic overprint of an original sedimentary fabric.

Natural remanent magnetisation (NRM) of the samples was measured on a GM400 three-axes SQUID magnetometer housed in a three-pair Helmholtz coil (noise level 7 μA/m). Standard cylindrical 2.54 cm palaeomagnetic samples were progressively demagnetised in a TSD-1 furnace or in a GSD-1 tumbling AF demagnetiser (Schonstedt). Least-squares fits to the linear demagnetisation trajectories for both the low- and the high-temperature components in each sample were made by principal component analysis. Sandstones and siltstones from the Miers Bluff Formation, have intensities in the 0.1 to 2 mA/m range. NRM is generally unstable and very often shows erratic paths on orthogonal plots. Only three out of six sites have shown stable magnetisations. A low temperature component is unblocked at 350°C and has no consistent directions between sites. The maximum unblocking temperature for the characteristic remanent magnetisation component (ChRM) is 580°C, revealing the presence of magnetite as the main magnetic carrier of these rocks. Most of the samples display north-west and upward directions.

Dykes show higher and more stable magnetisation than the turbidites. Both thermal and alternating field methods succeed in deciphering the magnetic components of the dykes samples. Typically there is a viscous component which is completely removed at 250°C, followed by the ChRM up to 600°C. Some samples show an intensity decrease at 350°C, which might indicate the presence of some iron sulfides. A contact test was carried out at locality LBA3 (Johnsons Dock). The sampled dike is 130 cm thick and intrudes the turbidites of the Miers Bluff Formation, dipping to the West. Samples from the turbidites hosting the dyke were taken at different intervals from the dyke, covering a distance of about 8 m. Results show that turbidite samples collected close to the dyke have ChRM directions similar to those for the dyke, revealing a secondary origin of the magnetisation. Samples more distant from the dyke display different magnetisation directions. The test reveals that the origin of magnetisation in the Miers Bluff Formation is most likely related to the dyke emplacement.

A regional progressive fold test was carried out for the Miers Bluff Formation Sites. This test reveals a maximum grouping of the ChRM directions at 0% of unfolding, thus indi-

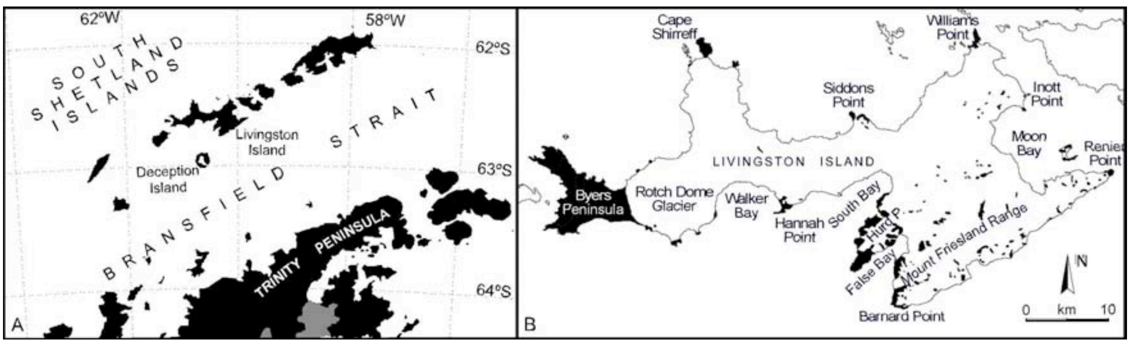

Figure 1. Location of the study area in Livingstone Island.

Table 1. Antarctic Peninsula paleopoles (data from Grunow, 1993)

Age (Ma)	Lat (S)	Long (E)	α_{95}
175	46	237	6.4
155	64	124	7.1
140	60	50	9.5
130	74	182	5.9
110	71	201	8.1
100	85	103	6
90	86	152	7.5
50	78	21	7.5

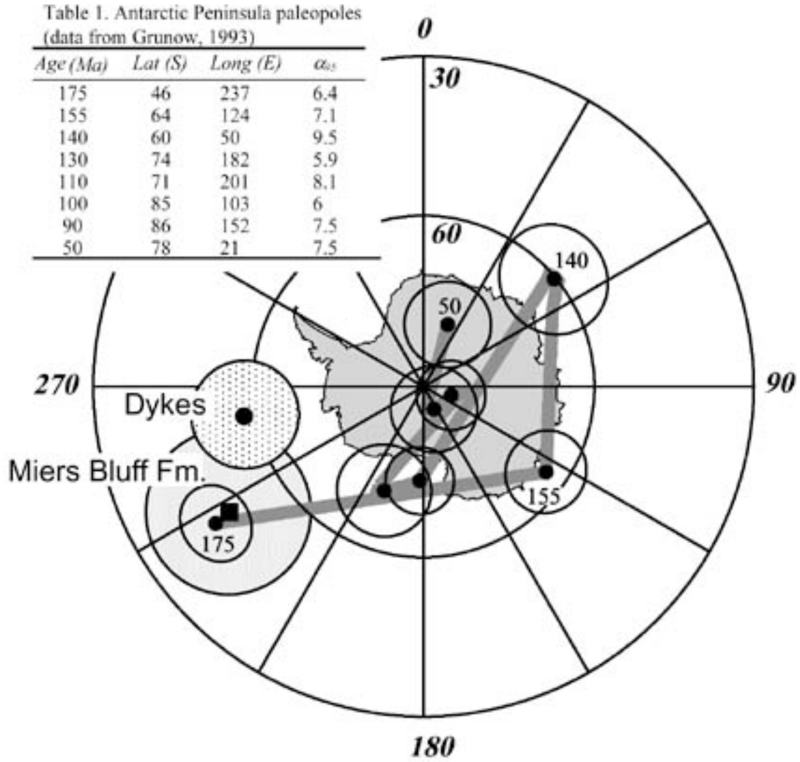

Figure 2. Apparent Polar Wander Path for the Antarctic Peninsula (data from inset table). Numbers show ages in million of years. The mean paleopoles for the studied rocks are also represented.

cating a secondary origin of the magnetisation. Additionally, both the dykes and the Miers Bluff Formation have north-westerly and upward ChRM directions and do not reveal any statistical angular difference. These observations allow us to conclude that the turbidites from the Miers Bluff Formation have a secondary magnetisation, and that this may be the same age as the Tertiary dikes. Thus, a thermoviscous remagnetisation is proposed as the mechanism responsible for the magnetisations in the turbidites. This remagnetisation event could be related to the Tertiary emplacement of the dykes.

Another conspicuous feature of the ChRM directions is the mean magnetic inclination. In contrast to existing palaeomagnetic results from Byers Peninsula, the inclination values we obtained are very low compared to the APWP for the Antarctic Peninsula (Fig. 2). The Miers Bluff Formation and the dykes display an average inclination of 51° and 53°, which produce a latitude of the Virtual Geomagnetic Pole of 49° and 58° respectively. A possible explanation for such an anomalous inclination is a regional tilting of Livingston Island during the Tertiary. Previous tectonic studies of the Island reveal the existence of tectonic tilting in the Hurd Peninsula on the basis of microstructural analysis of the Miers Bluff Formation. Thus, a regional tilting of the studied block would explain the observed palaeomagnetic directions. Such a tectonic event is compatible with the opening of the Bransfield Strait during the Tertiary and its related extensional tectonic regime.

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Seismic Expression of Sediment Mound Deposits on the Continental Rise off the Wilkes Land

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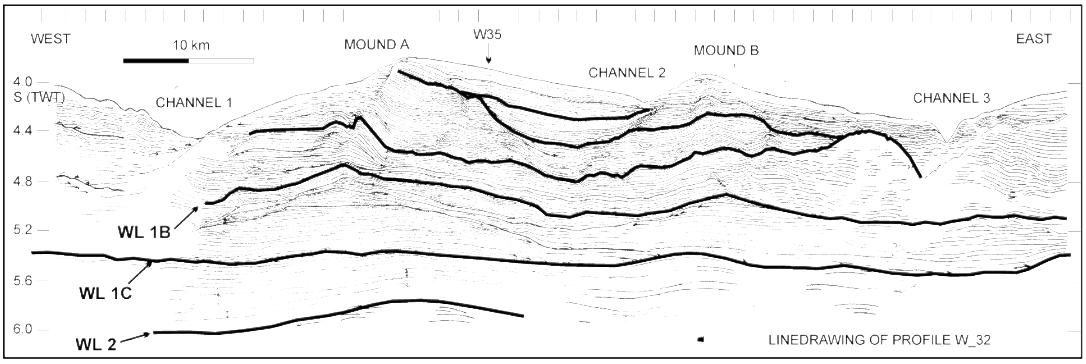
A joint Italian and Australian cruise (within the frame of the Wilkes Basin Glacial history, WEGA project) collected geological and geophysical data from sediment mounds deposited in the continental rise off the Wilkes Land (Brancolini et al., 2000). The aim of the project is establishing the origin and the age of the deep water sediment mounds, intimately related to the glacial history of the Wilkes basin, in the adjacent continent. This poster is complementary to Brancolini et alii's oral presentation and presents some illustrations of seismic facies from reflection, multichannel, high-resolution data set from the sediment mounds surveyed by the WEGA project. A bathymetric map constructed by plotting the WEGA data shows three mounds "A", "B" and "C". The mounds A and B have ca. 150 of length and 40 km of width (c. 6000 km^2), are elongated perpendicular to the margin, trending SW-NE. The present depth of the mounds crest ranges from 2300 m to 3500 m, the crest dips ca. 0.5º downslope. The mounds are asymmetric, with the western flank steeper than the eastern (looking downslope) and are separated by channels (channel 1 and channel 2) that show different characters (see Figure). Channel 1 separates today mound A from mound C and clearly cuts throughout the sedimentary section. This erosional feature and its filling are interpreted as a channel-levees complex of turbiditic origin, that developed after the main growth stage of the mounds A and C. The channel 1 and its asymmetric levees migrated eastward through time. Channel 2 is a large depression that separates mound A from mound B. The flanks of channel 2 are smooth. The reflectors below the channel 2 appear to be continuous and sub-parallel to the sea floor. A faint, concave seismic surface can be detected below the channel 2. Reflectors that fill this feature either pinches out against its sides or continue throughout them, without changing amplitude and frequency. This geometric configuration suggests to us that channel 2 has a different and more complex origin than that of channel 1. Channel 2 likely formed throughout the erosion and deposition caused by the interplay of turbiditic flows and contour currents, sweeping the depression between the two mounds A and B, during and after the main growth stage of the mounds. Like the channel 1, the channel 2 migrated eastward through time.



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Sediment Texture and Palaeobathymetry Changes off Cape Roberts during the Late Oligocene

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The Late Oligocene (c. 24 Ma) was a period of relative global warmth, lacking northern hemisphere ice sheets and sustaining only partial glaciation in Antarctica (Flower, 1999). Nevertheless, Oligocene oxygen isotope records from the deep sea fluctuate with a periodicity of ~40 ky, consistent with the obliquity component of orbital forcing (Paul et al., 2000), reflecting variations in temperature or ice volume or some combination of the two. Here we suggest a way of estimating changes in relative water depth through a 40 ky cycle of coastal sediment deposited at the edge of an Oligocene Antarctic ice sheet.

Core from the Cape Roberts Project (CRP) hole 2A includes three well-preserved sediment cycles, thought to be deposited over a period of 120 ky (Naish et al., submitted). Within each cycle particle size varies systematically upcore from well-sorted fine sand to a poorly-sorted mud (Fig. 1). Comparison of textural patterns within one of the cycles (sequence 11; Naish et al., submitted) with potential modern analogues shows that the pattern is very similar to a textural trend of fining with increasing water depth off prograding wave-dominated coasts today (Fig. 1). Two such coastal locations (Petone and Peka Peka, Fig. 1b,c) with substantially different wave climates show essentially the same offshore-fining textural pattern. Petone beach is a low energy coast where significant wave heights (Hsig) exceed 0.5 m less than 10% of the time. In contrast, Peka Peka is more exposed and is subject to a much more vigorous wave climate (Hsig exceeds 1.0 m approximately 10% of the time). The key sedimentological difference between the two locations is the depth at which the sediment changes from pre-

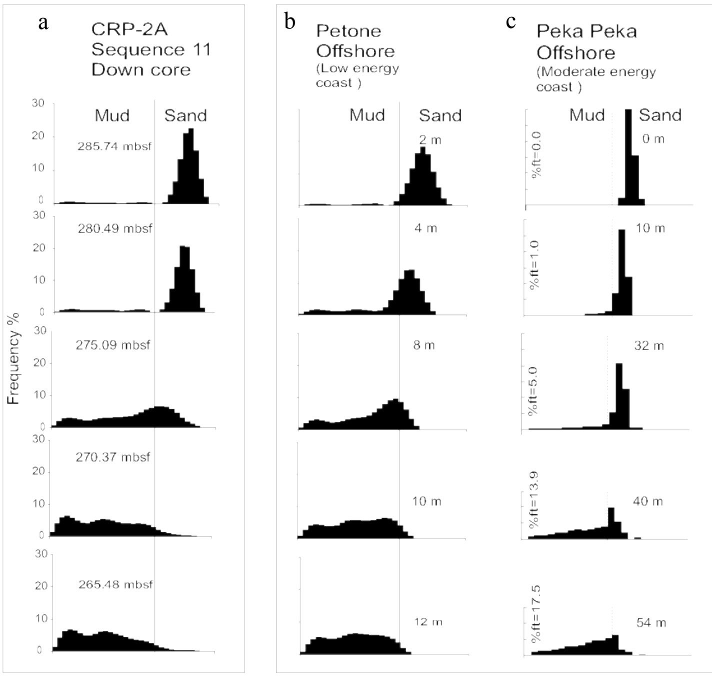

Figure 1. Particle size distributions for modern and ancient coastal sediments. **a)** Downcore from part of sequence 11, CRP-2A drill core, Antarctica. **b)** Transect offshore from a modern low energy beach (Petone, New Zealand). **c)** Transect offshore from a modern moderate energy beach (Peka Peka, New Zealand). Note the similarity in particle size between modern coastal sediments and inferred coastal sediments from Cape Roberts. Also note that the depth of transition from predominantly sandy to muddy sediment in the modern environment is related to the prevailing wave climate and occurs in very shallow water (~6 m) at Petone and much deeper (~35 m) at Peka Peka. CRP-2A and Petone samples were analysed using a Malvern Instruments laser particle size analyser. Peka Peka samples were analysed by sieve/sedigraph (Perrett, 1990). Ft = percent finer than 10 phi.

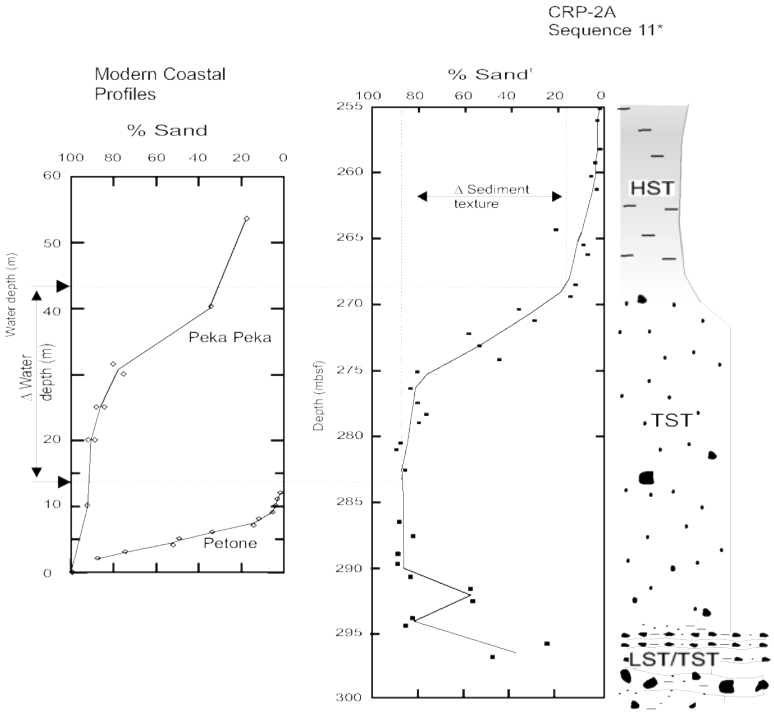

Figure 2. Textural variations, expressed as % sand, versus water depth (note reversed depth scale) off two modern wave dominated coastal settings compared with % sand variations from a single sea level cycle in the CRP 2A drillcore. By assuming the wave climate at the drill site was similar to that off Peka Peka (rather than the low energy setting at Petone) we suggest the 70% decrease in sand between early transgression (TST) and highstand (HST) is equivalent to a relative change in water depth of ~40 m.

*Modified after Naish et al. (submitted)
[t] sand expressed as the volume percent between 56 and 600 μm

dominantly sand to mud. Off Petone this transition occurs at ~6 m below sea level (mbsl) but is not reached until 35 mbsl off Peka Peka. We attribute this disparity to the difference in wave energy incident on the sea floor (although we acknowledge sediment supply may also influence sediment texture). Consequently, we suggest for a coastal sedimentary sequence deposited in a given wave climate and with a reasonable sediment supply, sediment texture varies predictably with water depth.

The palaeogeography of the area surrounding the CRP-2A drill site is thought to be similar to that of today (i.e. a microtidal, open coast with reasonable sediment supply from the adjacent Transantarctic Mountains; Barrett, submitted), and the coast was ice-free except during glacial maximums. In addition, seismic data suggest that the strata cored by CRP-2 accumulated within a prograding near-shore sediment wedge (Fielding et al., 2000). We consider sequence 11 at Cape Roberts to have deposited in prograding, open coastal conditions and have quantitatively compared the variations in sediment texture with those from a modern open wave-dominated coast (Fig. 2). Although lowstand diamictites are not represented in the modern beach profile, we suggest that late lowstand and subsequent transgressive sediments were deposited in shallow water, probably less than 15 m deep. Extending this comparison we also suggest highstand represents a water depth of ~50 m off Cape Roberts and the overall relative sea level change at the drill site during the deposition of this cycles was approximately 35-40 m.

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13,000 Years of Decadal-to-Millennial Oceanographic Variability along the Antarctic Peninsula: ODP Site 1098

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The Antarctic Peninsula is highly sensitive to climate change and is currently experiencing rapid and unusual warming. In 1998, the Ocean Drilling Program triple-cored the Palmer Deep (site 1098: 64°51'S, 64°12'W), a large depression off the west coast of the Antarctic Peninsula, to examine Holocene oceanographic variability (Shipboard Scientific Party, 1999). More than 50 m of diatomaceous muds and oozes and muddy diamictons were recovered, comprising the first high-resolution, continuous, Late Pleistocene through Holocene sediment record from the Antarctic continental margin. As part of a multi-proxy analysis of the site 1098 cores, we analysed biogenic opal, organic C and N concentrations, and $^{13}C/^{12}C$ and $^{15}N/^{14}N$ isotopic ratios of sedimentary organic matter every 2.5-3 cm downcore (1600 samples, sample interval of about 8 years). Our chronology is based on 36 AMS radiocarbon dates. The upper 42 m of core spans approximately the past 12,500 years with sedimentation rates ranging from 0.3 to 1 cm/year. Biogenic opal contents range from 2 to 10% during the deglacial section of the core (>11,500 yr BP) and vary from 15 to 40% in the section younger than about 8500 yr BP. Opal content varies significantly at several time scales, including 70, 140, and 220 years. Large-scale rhythmicity with a period of about 1600-2000 years is also observed throughout the Holocene. Sedimentary organic $\delta^{13}C$ ranges from -26 to -21 ppmil, consistent with diatom-derived organic matter from Antarctic coastal seas. Enriched ^{13}C values generally, but not always, correspond with high opal contents, suggesting the occurrence of several different types of open water/sea ice algal bloom systems. Sedimentary $\delta^{15}N$ increases downcore (from about 3 to about 5.5 ppmil), consistent with diagenetic loss of ^{14}N. Regular inversions suggest an environmental signal as well, possibly a noisy record of relative nutrient utilisation in surface waters. $\delta^{13}N$ and $\delta^{15}N$ are highly coherent at periods of about 60 and 140 years. Most proxies are coherent with opal content in the 200-240 year period band. We interpret multidecadal through millennial variability in these 5 biological tracers as resulting from significant changes in marine productivity, probably modulated by a combination of changing sea ice regime (extent and seasonality) and upper water column properties (e.g. mixed layer depth and circulation). We relate our Holocene record with other similar resolution climate records from the Antarctic Ice Sheet and the tropical ocean.

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Seismic and Downhole Signatures of Glacial Sequences from the Antarctic Peninsula Continental Shelf: ODP Leg 178, Site 1103

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ODP Leg 178 drilled a transect of three sites, Sites 1102, 1100 and 1103, across a thick prograded wedge on the Antarctic Peninsula continental shelf, with the aim of understanding the significance, in terms of glacial history, of the changes in depositional geometry within the wedge (Barker et al., 1999). Excessive heave (>2 m) for shallow water drilling conditions in the outer continental shelf at Site 1102 prevented penetration of more than 7 m. Landward, Site 1100 drilled to a depth of 100.9 metres below sea floor (mbsf) but core recovery was very poor (4.3%). Site 1103 was drilled to a depth of 362.7 mbsf. Recovery from the upper 247 m was only 2.3%, but improved to 34% in the lower 115 m where the matrix became hard. Standard ODP downhole logging was done at Site 1103 only, from the base of pipe at 84 mbsf to 242 mbsf. Changes in the formation character within downhole logs and recovered cores have been correlated to reflection events or packages in the seismic data by deriving a time-depth relationship from the downhole sonic velocity and density logs, and from whole core measurements. Based on the available suite of downhole logs (magnetic susceptibility, gamma-ray logs, porosity, resistivity, density, and sonic velocity), we have differentiated five units with differences in relative grain-size, clay/matrix content and compaction. However, because of the low-resolution of the seismic signal (~20 m wavelength), the correlation of these units with the acoustic signal is limited to the analyses of the major formation packages. Between 84-210 mbsf, changes with depth in the formation character result in overall shifts of the acoustic character of the glacial formations, from discontinuously stratified to transparent. We infer the upper discontinuously stratified acoustic unit (84- ~145 mbsf) to consist of lithologic packages (~ 10-20 m thick) with highly variable grain-sizes (sand to gravel or larger size?) and matrix content. The lower transparent acoustic unit (~145- ~208 mbsf) is dominated by generally finer-grained sediments (coarse silt to coarse sands?), than the overlying unit with more constant matrix content. The strong and continuous reflector at 210 mbsf corresponds with a large change in velocity corresponding with a highly resistive layer that is well imaged in the FMS image logs. Strong and traceable reflections that are horizontally stratified between 210 and 242 mbsf (where downhole data ends), and that are seaward dipping between 247 (where a higher percentage of core recovery starts) and ~295 mbsf, also correspond with significant changes in formation velocities apparently linked to changes in compaction trends. Below 247 mbsf we can directly relate changes in lithology and physical properties of the formation to the acoustic signal. There is a shift in the acoustic character with depth from high-amplitude stratified reflectors below 247 mbsf to discontinuously stratified reflectors below ~295 mbsf. Clast poor diamict is the dominant lithology on the cores recovered from the sedimentary sequence above 295 mbsf. Stratified sandstone, muddy sandstone and siltstone, and diamict are the lithologies recovered from the sedimentary sequence below 295 mbsf. In the absence of a continuous sedimentary record, linking the formation character at Site 1103 with the seismic data is a useful tool for understanding the acoustic character of the glacial sequences deposited at this site, and for extending our interpretations regionally across the Antarctic peninsula continental shelf.

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Architecture of Litho/Sequence Stratigraphic Units in the Cenozoic of the Cape Roberts Area, and Correlation with CIROS – Implications for Basin History in the Victoria Land Basin

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The pre-Pliocene succession penetrated by CRP-1, -2/2A and –3 constitutes a near-continuous, vertical stratigraphic section through the Victoria Land Basin in McMurdo Sound. Previous research has established that the array of lithofacies represents mainly coastal, shallow marine (glacimarine) and proglacial environments, and that the arrangement of lithofacies is cyclical on a variety of scales. A sequence stratigraphic model has been established to assist in the interpretation of the succession (Fielding et al., 2000). Most of the sequences recognised within this framework are thin (<30 m; Fig. 1), condensed and strongly top-truncated. Furthermore, below c. 480 metres below sea floor (mbsf) in CRP-3 no cyclicity can be recognised and the succession is dominated by alternating units of sandstone and conglomerate/breccia. In two intervals, however, packages of considerably thicker and more complete sequences are preserved, allowing a fuller investigation of the processes driving this cyclicity (Figs. 1 and 2). Naish et al. (in press) propose that the upper of these packages was controlled by 40 ky and/or 100 ky orbital cycles.

Both of these intervals are also interpreted by Fielding et al. (submitted) to coincide with periods of accelerated tectonic subsidence, which provided the increased accommodation necessary to preserve thicker and more complete sequences (Figs. 1 and 2). The lithostratigraphic units recognised from the cores are found to correlate well

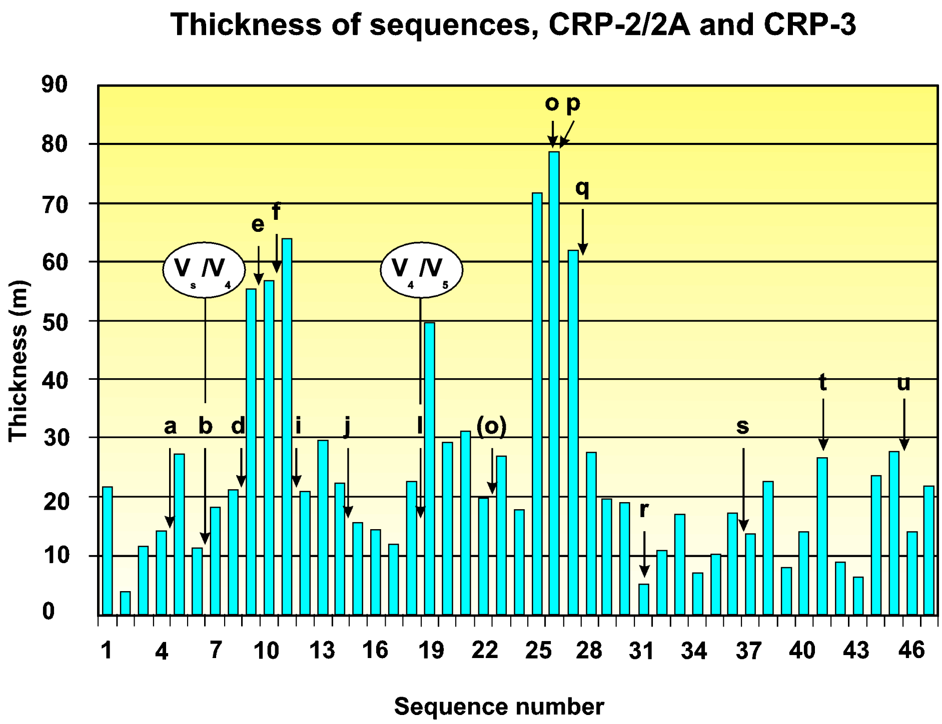

Figure 1. Plot of the distribution of sequence thickness in CRP-2/2A and CRP-3, showing the coincidence of sequence boundaries and other horizons with seismic reflectors (from Cape Roberts Science Team, 2000). The uppermost sequence in CRP-3 (Sequence 25) is constructed on the assumption that the basal part of CRP-2/2A, the underlap between the two holes, and the uppermost part of CRP-3 all lie in one sequence. Note the occurrence of two packages of thick and relatively complete sequences in the middle of CRP-2/2A and top part of CRP-3.

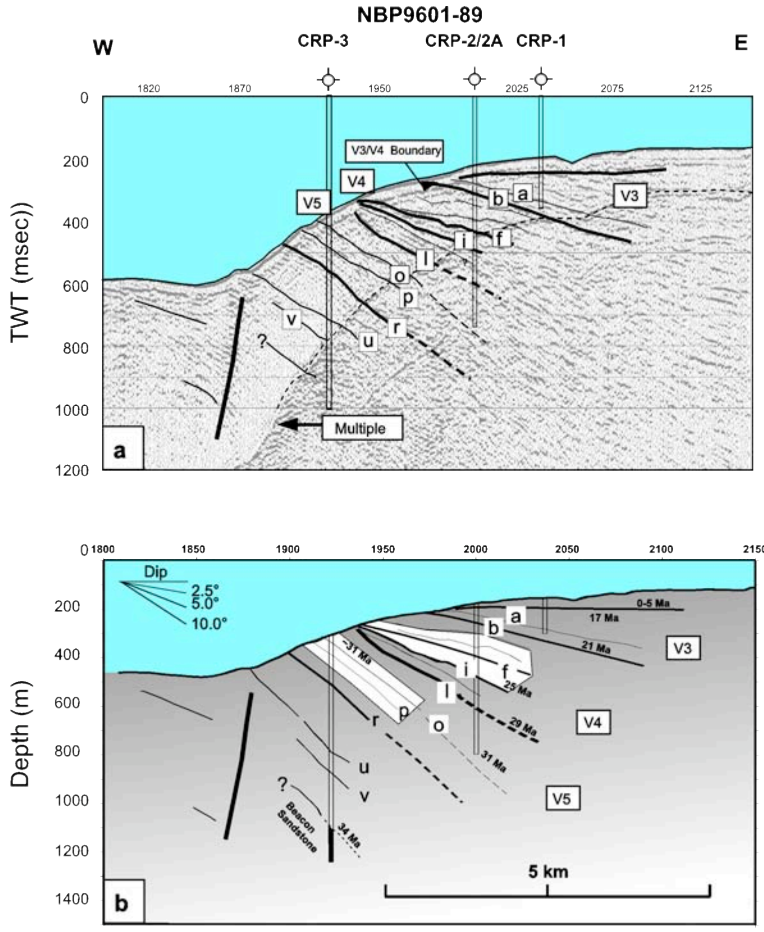

Figure 2. Seismic reflection line NBP9601-89 (Cape Roberts Science Team, 2000) with interpretation of major reflectors, and a line drawing of those interpretations to illustrate the cross-sectional geometry of major stratigraphic packages.

with events recognised on seismic reflection data, permitting a more detailed investigation of the underlying geological controls on the succession. While the lower package appears to have a tabular cross-sectional geometry on seismic reflection data, the upper package shows a pronounced eastward-thickening, wedge geometry, suggesting a period of asymmetrical, half-graben subsidence. Hence, it may be possible to separate tectonic from glacio-eustatic/climatic influences on the succession. Correlations with equivalent stratigraphy to the south, in the CIROS area, are also facilitated by these relationships.

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A new High-Resolution Magnetostratigraphy from Eocene-Oligocene Sediments, Maud Rise, Weddell Sea, Antarctica

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Development of the Antarctic cryosphere resulted from progressive thermal isolation produced by middle-late Eocene and Oligocene plate movements that enabled deep water circumpolar circulation via seaways south of Australia and South America (Kennett, 1977). Integrated magnetostratigraphic and environmental magnetic study of Paleogene sediments from the Antarctic margin is aimed at developing an accurate view of the timing and nature of the onset of continent-wide glaciation in Antarctica. Cores were obtained near the crest of Maud Rise, Weddell Sea, during ODP Leg 113 (Fig.1), to obtain continuous records through the Upper Cretaceous and Cenozoic (Barker et al., 1988). A medium-resolution magnetostratigraphic investigation was carried out previously on these sequences (Spiess, 1990), but parts of the magnetostratigraphic interpretation have been called into question by biostratigraphers. U-channel samples were from ODP Holes 689B, 689D, 690B, and 690C (Leg 113), at the ODP East Coast Repository, NewYork, where the cores, since the recovery, have been stored. We have made a high-resolution magnetostratigraphic and environmental study of Eocene-Oligocene of these u-channel samples using a pass-through cryogenic magnetometer with measurements at 1-cm intervals (4-cm spatial resolution). The different cores can be tied together via magnetostratigraphy and, with greater resolution, via sediment magnetic properties. For intervals with well-constrained continuous deposition, spectral analysis techniques were applied to environmental magnetic parameters to test the possibility of the existence of a cyclic signature. This investigation reveal a strong and regular cyclic pattern and frequency analyses indicate climatic control of fluxes of magnetic particles to Maud Rise. The environmental magnetic record is also being analysed to determine whether it provides information about changes in weathering regimes on the Antarctic continent by comparison with clay mineralogy data.

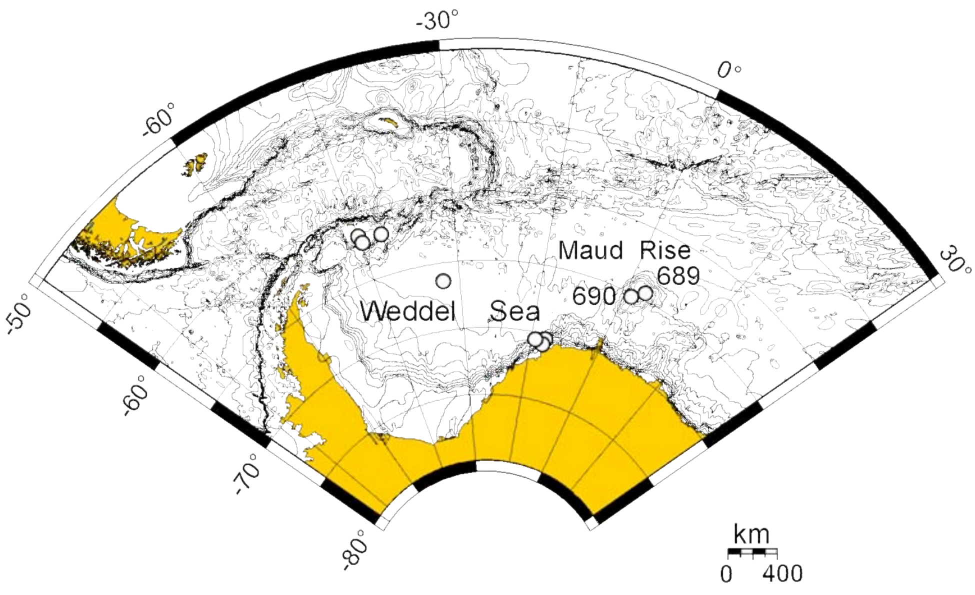

Figure 1. ODP Leg 113 - Drilling Locations.

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Magnetostratigraphy and Environmental Magnetism from ODP Site 1165, Offshore of Prydz Bay, Antarctica

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Drilling at ODP Site 1165 (continental-rise drift section) yielded a relatively continuous 1000-m thick sedimentary section of Early Miocene to Pleistocene age terrigenous and hemipelagic deposits with only a few minor disconformities. Aiming to develop a magnetic polarity stratigraphy the archive core halves from Holes 1165A, 1165B and 1165C were measured at 4-cm intervals with the shipboard pass-through cryogenic magnetometer (2-G Enterprises, model 760R). Additional 614 oriented discrete samples (standard 8 cm^3 plastic cubes), were collected from the working halves and AF demagnetised up to 100 mT to verify the reliability of the whole core measurements. This study was integrated with rock magnetic analyses (thermomagnetic and coercivity spectrum analyses) to quantify estimates of the down-core variation in composition, concentration and grain-size of the magnetic minerals. These variations often can be used as proxies for changes in the palaeoenvironmental conditions of a sedimentary basin and its surrounding regions.

A magnetostratigraphy was determined for Holes 1165B and 1165C, for the intervals 0-94 metres below sea floor (mbsf) and c. 365-999 mbsf. Between c. 94 and 365 mbsf, polarity reversals are unresolvable (see below). A near-complete record of the polarity intervals from the Brunhes Chron (C1n) to Chron C6Ar (early Miocene) was determined with the Pliocene-Pleistocene and the Miocene-Pliocene boundaries at 6.97 and at 54.60 mbsf, respectively

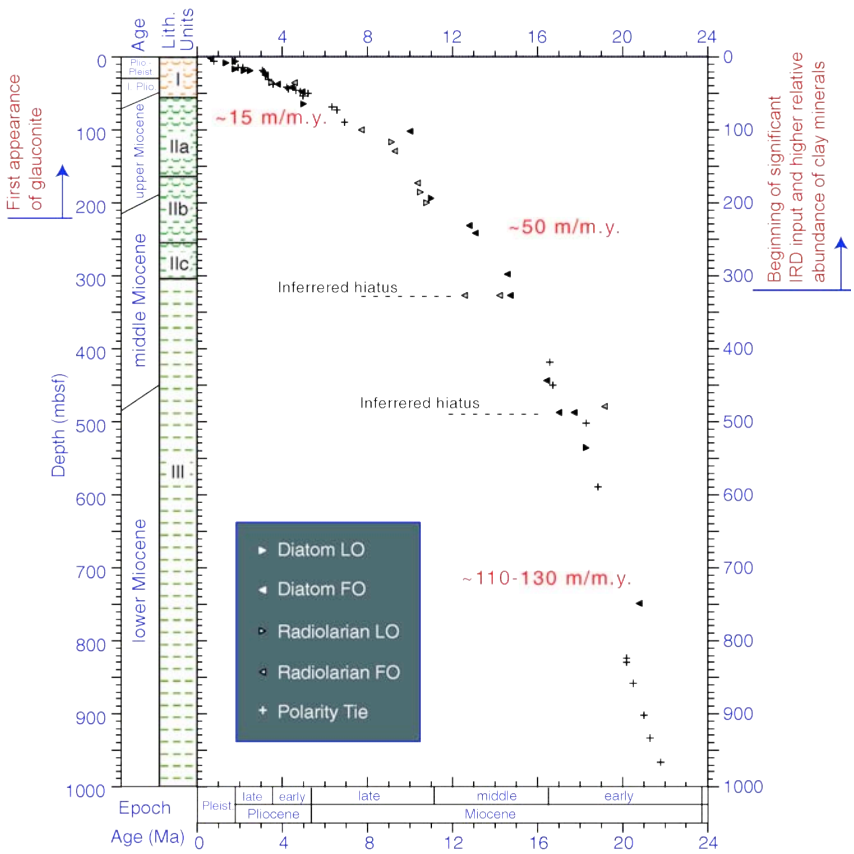

Figure 1. Age-depth plot for the composite section represented by Holes 1165B and 1165C based on biostratigraphy and magnetostratigraphy. FO = first occurrence; LO = last occurrence.

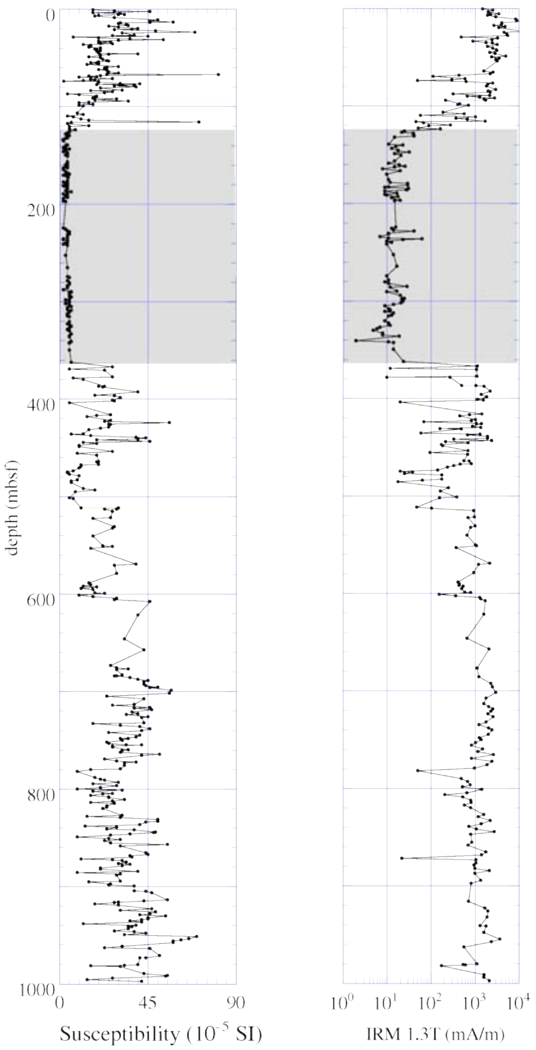

Figure 2. Down-core variation of concentration-dependent parameters (k, IRM) at Site 1165. The area in grey represents the interval, between ~125 and 365 mbsf, depleted in magnetic minerals.

(Shipboard Scientific Party, 2001).

The polarity record and biostratigraphic ages , when combined, yield an age versus depth model that shows relatively rapid sedimentation in the early Miocene (c. 110-130 m/m.y.), slower sedimentation in the middle to late Miocene (c. 50 m/m.y.), and slow sedimentation from the late Miocene to now (c. 15 m/m.y.) (Fig. 1). The bottom of Hole 1165C (999.1 mbsf) is c. 21.9 Ma.

On the basis of the magnetic properties and the behaviour during the demagnetisation treatment, the sedimentary sequence drilled at Site 1165 can be divided into three main intervals (Fig. 2). The highest values of the concentration-dependent parameters are recorded in the upper c. 94 mbsf (interval I) of the core. In this interval the magnetic mineralogy is dominated by magnetite. Between 94 and 125 mbsf the concentration dependent parameters decrease to the lowers values of the following interval II. This interval, between c. 125 and 365 mbsf, corresponding to an increased frequency of greenish-grey diatom clay layers and the highest concentrations of dissolved silica, is characterised by extremely low concentration-dependent values due to the dissolution of magnetite by reaction with high concentrations of dissolved silica (Garrels and Christ, 1965; Florindo et al., submitted). The interval between c. 365 and 512 mbsf, is characterised by parameters which indicate frequently changing high and low magnetic mineral concentrations and represents a transitional zone to the lower-most interval III which contain almost the same high ferrimagnetic concentrations as encountered in the upper-most interval I.

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Magnetostratigraphy of Late Eocene - Early Oligocene Strata from the CRP-3 Core, McMurdo Sound, Ross Sea, Antarctica

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The Cape Roberts Project was successfully completed in the Austral Spring of 1999 with drilling of the 939.42-m CRP-3 drill-hole, located 2-km west of the CRP-2/2A drill-hole. The CRP-3 core comprises a 790-m Cenozoic (glacio-) marine sequence separated from underlying Devonian basement rocks by a c. 30-m-thick dolerite conglomerate of undetermined age. Here, we present the results of a palaeomagnetic study, including correlation to the magnetic polarity time scale (MPTS) and an age model for the Cenozoic sequence recovered in CRP-3. The palaeomagnetic behaviour of the Cenozoic sedimentary sequence is generally stable, and magnetite is the main magnetic carrier. The magnetic polarity stratigraphy of the Cenozoic sequence in the CRP-3 core is subdivided into four magnetozones: R1 is an upper interval of dominantly reversed polarity (0-340.8 mbsf), N1 has dominantly normal polarity (340.8-627.3 mbsf), R2 has dominantly reversed polarity (627.3-760.2 mbsf), and N2 has normal polarity (760.2-788.8 mbsf) (Fig. 1). Magnetozones R1, N1, and R2 also contain thin intervals with opposite polarity, which are interpreted to represent either short polarity intervals (corresponding to "tiny wiggles" identified on marine magnetic anomaly records) or geomagnetic excursions. Above 340 mbsf, diatom and calcareous nannofossil biostratigraphy and $^{87}Sr/^{86}Sr$ ages suggest that magnetozone R1 correlates with Chron C12r of the MPTS. Below 340 mbsf, we tentatively correlate magnetozones N1 and R2 with chrons C13n and C13r of the MPTS, respectively. However, below R1, the magnetic polarity record is not constrained by biostratigraphy or $^{87}Sr/^{86}Sr$ ages. This correlation implies that the Eocene-Oligocene boundary (33.7 Ma) in the CRP-3 core should lie within the upper part of lithostratigraphic sub-Unit 13.1, between 650 and 700 mbsf. Lack of independent chronostratigraphic constraints makes it difficult to interpret the age of the basal part of the CRP-3 Cenozoic sequence, but the magnetostratigraphy suggests a minimum age of Chron C13r (c. 34 Ma).

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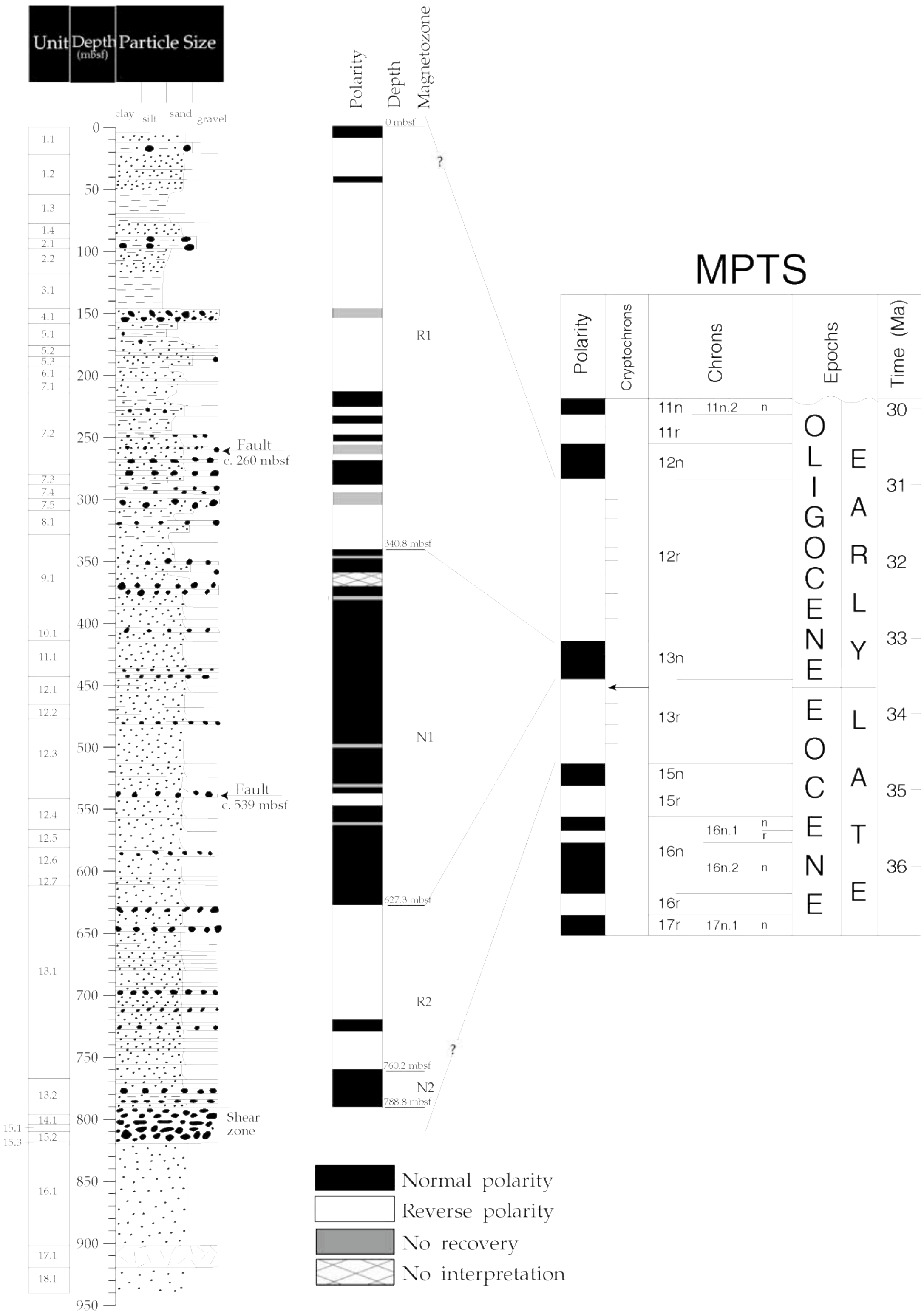

Figure 1. Correlation of the CRP-3 magnetic polarity zonation with the magnetic polarity time scale (MPTS) of Cande and Kent (1995) and Berggren et al. (1995). Correlation of the dominantly reversed polarity magnetozone R1 (0 to ~340 mbsf) to the MPTS is well constrained by diatom assemblages, with additional data from calcareous nannofossils and $^{87}Sr/^{86}Sr$ age determinations.

Glacial Development in the Prydz Bay Region as Witnessed by Geotechnical and Mineralogical Properties of Leg 188 Sites 1166 and 1167

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The Ocean Drilling Program Leg 188 to Prydz Bay is the second leg to Antarctic continental margin that has been drilled as a result of an initiative taken by ANTOSTRAT (O'Brien et al., 2001). The strategy outlined in this initiative was to pinpoint the glacial growth around the continent by drilling key locations to allow the full range of ice sheet development to be understood and possibly also dated (Barker et al., 1998).

Site 1167 on the continental slope was drilled on a fan shaped apron of glacigenic sediments at the mouth of the Prydz Bay Trough that forms the offshore extension of the Lambert Graben and that was the probable location of ice streams during periods with more extended glacial coverage than at present. The site is therefore well suited to monitor sedimentation associated with the advance and retreat of the Antarctic Ice Sheet in this region. The present work will use mineralogy and geotechnical tests to improve stratigraphic control and the understanding of the glacial development of the Prydz Bay region.

Figure 1 summarises the main results from the clay mineralogical analyses and also shows the six mineralogical units that have been defined (M1 to M6). Unit M1 corresponds to the hemipelagic sediments of lithological Unit 1 (O'Brien et al., 2001). It is characterised by a high illite content and a low

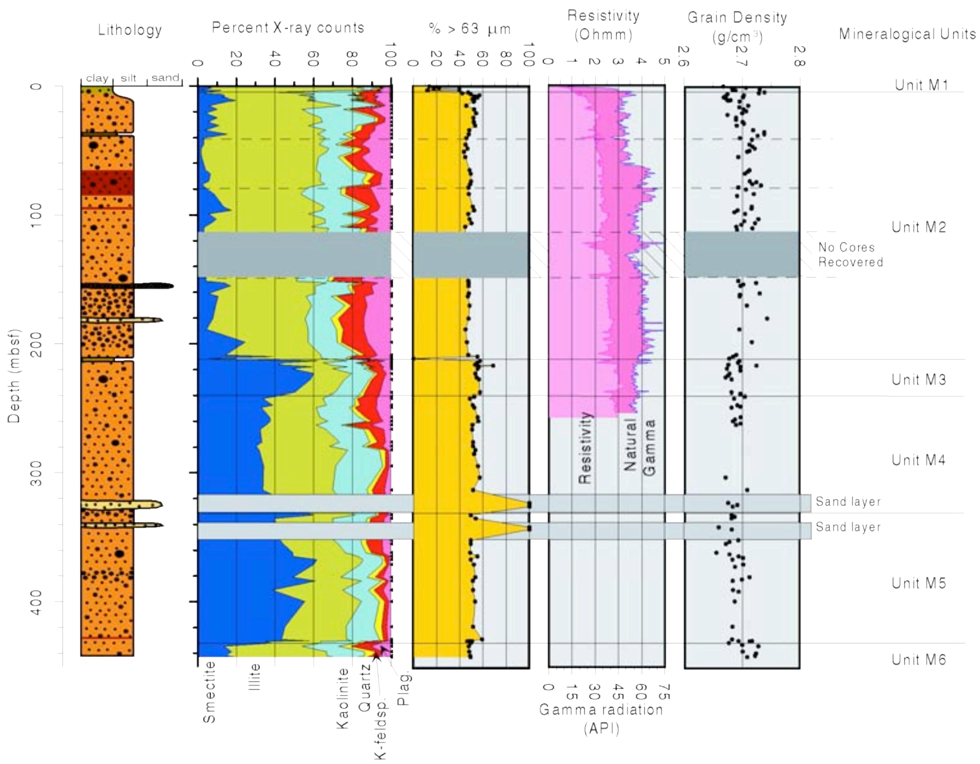

Figure 1. The left hand column shows the lithology (O'Brien et al., 2001) of Site 1167. The clay mineralogy at Site 1167 is shown as percent X-ray counts, no weighting has been applied to the results so the plot only indicates relative concentrations of the six mineral groups identified. Traces of chlorite were present in all samples and are included in the kaolinite results. The dots on the right hand side of the mineralogy panel show where analyses were performed. The nest panel shows the sand content obtained by sieving while preparing samples for clay mineralogy. The down hole logs and grain densities are from O'Brien et al. (2001). The mineralogical Units M1 to M6 are shown on the right, with horizontal unbroken lines indicating their extent. Dashed lines indicate tentative subunits in Unit M2.

smectite (less than 10% X-ray counts) content. Unit M2 from about 5 mbsf (metres below sea floor) to 210 mbsf has less illite but more kaolinite than Unit M1. The dashed lines on the figure indicate where Unit M2 may have sub-units defined by minor or less persistent changes. The most significant change in the drilled section is the transition from Unit M2 to M3 where there is a considerable increase in the smectite content (up to about 50 % X-ray counts) at the expense of illite (down to 20% X-ray counts), and a reduction in the plagio-clase content. There is also drop in the grain density, and an increase in the sand content at this level (Fig. 1). The smectite contents varies from about 35% X-ray counts in Unit M4 to between 40 and 50 % X-ray counts in Unit M5 and drops once to about 18% X-ray counts in Unit M6. This bottom most unit is similar to Unit 2 with respect to both sand content and grain density as well as the mineralogy.

An increase in smectite content at the expense of the illite content was observed at ODP Leg 119 Sites 739 and 742 (Hambrey et al., 1991) at the transition to Oligocene sedi-ments. The transition observed in the present work, however, probably has a mid Pleistocene age (O'Brien et al., 2001) and may therefore represent a period during which glacial erosion of the top Oligocene deposits on the shelf took place. Ongoing work on samples from Site 1166 on the continental shelf will address this problem in more detail. However, the Oligocene diamictons found at Site 742 and 739 have apparently been eroded at Site 1166 lending support to the concept above. Preliminary results from geotechnical tests from this site indicate that there has been a maximum load on the pre glacial sediments equivalent to about 1400 m of sediment, i.e. the site was covered by a sediment column 1100 m thicker than that of the present, and that much of the erosion took place on the sur-face defined by the pre glacial to glacial transi-tion.

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Morphometric Analysis of Benthic Foraminifera: A Potential Proxy for Palaeoclimate Reconstruction in the Cenozoic Ross Sea

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Many organisms show a good correlation between their test shape and the environment in which they live. To a certain degree, this applies also to benthic foraminifera, which have been shown to develop morphological adaptations depending on several environmental parameters (see Murray, 1991, Boltovskoy et al., 1991). However, intraspecific morphometric changes in benthic foraminifera may derive from either adaptation to ecological factors or evolutionary trends. Temporary adaptations to environmental parameters are likely to result in reversible changes while heritable changes result in stable intraspecific modofications and, possibly, in the evolution of new taxa.

The morphometric analysis of *Globocassidulina subglobosa*, *Melonis barleeanus*, and *Stainforthia* cf. *schreibersiana* from CRP and CIROS-1 cores (Victoria Land Basin, Ross Sea, Antarctica) has revealed discrete morphological adaptations of these species through time. Observed morphometric variability mainly occurs in terms of size changes through time, from the late Eocene lower sequence in CIROS-1 core to the Early Miocene CRP-3 core.

Similarly to what observed in recent benthic foraminifera, morphometric changes shown by the studied species from CIROS-1 and CRP cores are likely related to a complex interaction of several environmental parameters including salinity, dissolution, $CaCO_3$ availability, primary productivity, and dissolved oxygen content. However, a comparison with palaeotemperature reconstructions based on clay minerals (Erhmann, 1997) and rock magnetic properties (Sagnotti et al., 1998, Sagnotti et al., in press) from the same intervals, indicates that bottom water temperature likely was a predominant factor in controlling the test size of *G. subglobosa* and *S.* cf. *schreibersiana*. In particular, smaller sized *G. subglobosa* would be associated to cooler intervals whereas larger-sized test population showing greater size variability would develop under warmer bottom water conditions. The opposite trend is observed in *S.* cf. *schreibersiana*, which develops larger-sized tests under cooler conditions.

The size measurement of selected benthic foraminiferal emerges then as a potential proxy for palaeoclimatic reconstruction in the Ross Sea region. Moreover, the identification at different stratigraphic levels of populations showing different test size ranges in the same species may be of use for regional biostratigraphic correlations.

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Oligocene Biota and Palaeoenvironment of King George Island (South Shetland Islands), West Antarctica

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Antarctica, the central segment of Gondwanaland, contains an important record of past biota, environments and climates. Changes in the Antarctic environments are reflected in fossil record. Knowledge of the events leading to the isolation and cooling of Antarctica in the Cenozoic is necessary to the understanding of the evolution of both the fossil and the modern-day Antarctic biota.

On King George Island (South Shetland Islands) the Early Oligocene Low Head Member (up to 20 m thick) of the Polonez Cove Formation consists of glaciomarine strata formed during the Polonez Glaciation i.e. the largest Cenozoic glaciation in the Antarctic Peninsula area (Birkenmajer and Gazdzicki 1991, Birkenmajer et al., 1991). At that time the continental ice-sheet crossed the Bransfield Strait and reached the South Shetland Islands Archipelago. The marine palaeoenvironment controlled by calving ice-sheet hosted a cold-water invertebrate fauna.

The pectenid lumachelles, which are common in this region, are especially rich in fossils represented mostly by sessile and vagile benthos. In addition to the pectenids the biota includes calcareous nannoplankton (partly recycled), diatoms, benthic and planktonic foraminifera, polychaete worms, bryozoans, brachiopods, gastropods, corals, ostracods, echinoderms as well as isolated, abioforic stromatolites (up to 8 cm in diameter). The occurrence of such coquinoid beds, interbedded with shales and fine-grained sandstones, indicates a sudden temporary change from low- to high-energy events and may be interpreted as proximal shelly tempestites.

On the basis of a suite of planktonic foraminifera including *Globigerina angiporoides* and *Chiloguembelina cubensis* as well as calcareous nannoplankton (*Reticulofenestra umbilica* and *Chiasmolithus altus*), this sequence can be dated as early Oligocene. This age is in accordance with the Strontium isotope dating of stromatolites from the studied sequence.

The Low Head Member biota assemblage indicate favourable conditions for live in shallow marine environments during the final stage of the Gondwanaland breakup and onset of the Late Eocene-Early Oligocene continental glaciation in the West Antarctica.

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Eocene-Pleistocene Palaeoceanographic Reconstructions - A View from the ODP Leg 177 Transect across the Southern Ocean

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ODP Leg 177 (Dec. 9, 1997 - Feb. 5, 1998) recovered more than 4000 m of sediment from seven sites along a north-south transect from 41°S to 53°S. The sediments from this core transect, which represents the first to be drilled across the Antarctic Circumpolar Current (ACC) document the palaeoceanographic evolution in the Atlantic sector of the Southern Ocean from the middle Eocene to the Holocene and its relationship to the development of the Antarctic cryosphere. Leg 177 cores, for which spliced composite sections were constructed, represent the most complete sections yet obtained from the Southern Ocean.

A 340 m sequence of middle Eocene to lower Miocene sediments, drilled at the Subantarctic Site 1090 with a recovery rate of more than 90%, includes cyclic variations in biogenic and terrigenous compounds. The record documents one of the major climatic shifts during the Cenozoic, the transition in Earth's climate from a warm- ("hothouse") to a cold-climate ("icehouse") mode. This shift was marked by the build-up of ice on the Antarctic continent and major palaeogeographic changes in the Southern Ocean. Geochemical tracers indicate that export production increased in the middle Eocene, a period marked by a gradual increase of coarser grain sizes in the non-biogenic sediment fraction. Major changes in the sedimentation pattern occurred around the middle/late Eocene boundary reflecting significant reorganisation of oceanic circulation as well as climatic and sea level changes. Increasing accumulation rates of biogenic opal mark the establishment of an early biogenic opal deposition in the northern Paleogene Southern Ocean. Such deposition may be related to the establishment or steepening of oceanic frontal systems in response to the cooling of the Antarctic continent. The latter is documented by the clay mineralogy indicating a shift from predominantly chemical to physical weathering and an increase in coarser grain sizes.

The development of Southern Ocean thermal isolation during the middle and late Miocene records was reconstructed from sections obtained at Sites 1092 (northern Polar Front Zone) and 1088 (northern Subantarctic Zone). Species fluctuations of diatoms indicate distinct changes in the latitudinal thermal differentiation, displaying increased thermal gradients in the late middle Miocene around the middle/late Miocene boundary and after the middle late Miocene. These events are closely linked with changes in ice volume. Isotope studies of the "middle" Pliocene recovered at Site 1092 confirm previous results that the East Antarctic Ice Sheet was not or not significantly reduced during the so-called "Mid-Pliocene Warming".

A major success of Leg 177 was the recovery of complete and expanded sections at 5 sites on a transect between 41° and 53°S that document the Pleistocene palaeoceanographic development at millennial to centennial resolution. These records fill a critical gap in the distribution of sites needed to decipher the global climate evolution at high time-resolution and to understand climate driving processes. Estimates of sea surface temperatures (SST), stable isotope and IRD measurements point to a rather cold and stable Southern Ocean environment during most of the early Pleistocene. At this time, massive opal deposition determines the sedimentation in the central region of the Atlantic sector of the Southern Ocean. This leads to the formation of laminated diatom ooze ("diatom mats") as a result of effective export of biogenic opal from surface waters having presumably an effect on the global carbon cycle. After c. 0.9 Ma, the magnitude of interglacial/glacial variability increased and a 100-kyr climate cyclicity was initiated, in response to a major increase in the ice volume around the so-called "Mid-Pleistocene Revolution". Maximum interglacial/glacial variability characterised by distinct latitudinal shifts of the Southern Ocean isotherms and areas of high export productivity were established during the past 400 ka. These changes are accompanied by major variations in sea ice coverage. The observed climatic changes lead the northern hemisphere ice volume change by several thousand of years which documents the driving role of processes in the Southern-high latitudes for global climate development. SST estimates obtained from Pleistocene interglacials do not point to a warming of the Southern Ocean that could be indicative for a partial or total destabilisation of the West Antarctic Ice Sheet. This also accounts for Marine Stage 11, which was suspected to be a potential candidate for such draw-down of Antarctic continental ice. High-resolution records of SST and sea ice variability show that millennial-scale climate variability is a common pattern of the Pleistocene climate development of the southern-high latitudes. This accounts not only for glacial periods, when millennial variability is at its maximum, but also for interglacial periods.

Sediment Transport onto the Continental Rise along the West Antarctic Continental Margin

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Sedimentary sequences on continental rises are generally characterised by deposition of combined pelagic and terrestrial material, as well as bottom-current and mass-wasting induced erosional events. The deposition of continental rise sediments along Antarctic continental margins is, in particular, controlled by glacial-interglacial cycles and the related fluctuations in sediment transport from the continental shelf and slope. A continuous seismo-stratigraphic record from 63°-103°W along the Antarctic continental rise provides useful information on the history of interrelated deposition, erosion and bottom-current systems along a large part of the West Antarctic continental margin.

A continuous multi-channel seismic (MCS) transect >2200 km long has been compiled along the continental rise of the West Antarctic margin from the northern Antarctic Peninsula to the Amundsen Sea basin (Fig. 1). During a number of expeditions from 1985 to 2001, several research institutions such as OGS, BAS, AWI and VI acquired these and numerous adjacent MCS profiles. The data are of excellent quality and show detailed stratigraphic sequences and clear basement structures.

A key observation illustrated by this transect is a series of sediment drifts that shows a considerable variation in size along the rise of the West Antarctic margin (e.g. Rebesco et al., 1997; Nitsche et al., 2000). Most of these sediment drifts have their long axes oriented perpendicular to the slope and are asymmetric in cross section, with most of the steep flanks facing west or southwest. Results from ODP Leg 178 (Shipboard Scientific Party, 1999) confirm that the drifts are composed of fine-grained sediments derived from turbidity flows originating on the continental slope. The seismic data, together with swath imagery over parts of this area, show deep-sea channels between the drifts. These channels are the transport paths of the turbidity currents from which fine-grained sus-

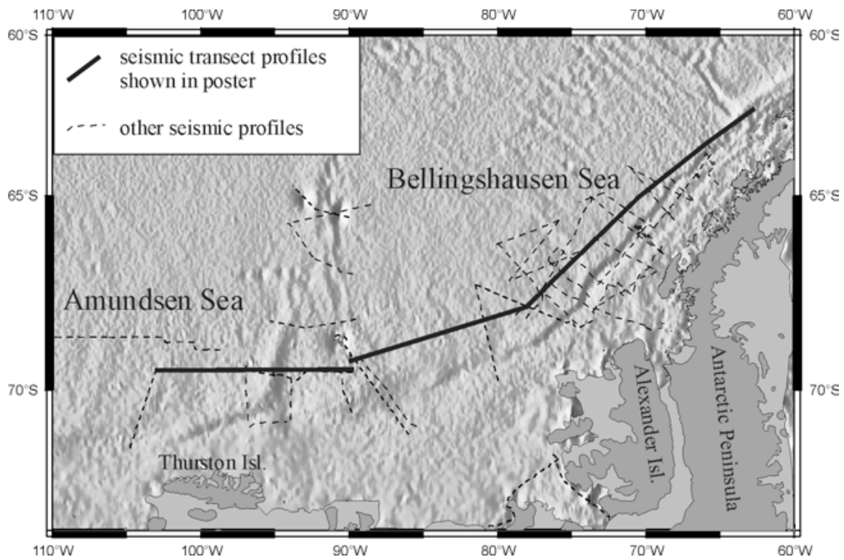

Figure 1. Location map of a combined 2200 km long multi-institutional multi-channel seismic transect along the continental rise from the northern Antarctic Peninsula to the Amundsen Sea basin. The satellite-derived gravity field is from Laxon and McAdoo (1998).

pended material is entrained by bottom currents and deposited on the drifts. Some drifts appear to have nucleated above basement ridges, even though most topographic relief had been eliminated by deposition of an extensive turbidite apron prior to growth of the drifts.

This transect provides an unique view of variations in the dynamics of sedimentary transport deposition and erosion along the continental rise of the eastern West Antarctic margin. It contains a detailed record of erosion in a number of ice drainage basins as well as of bottom currents during the development of the West Antarctic Ice Sheet.

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Evidence for Palaeoclimatic Variability at the East Antarctic Continental Rise (ODP Site 1165) Inferred from Spectral Analysis of High-Resolution Core Logging Data

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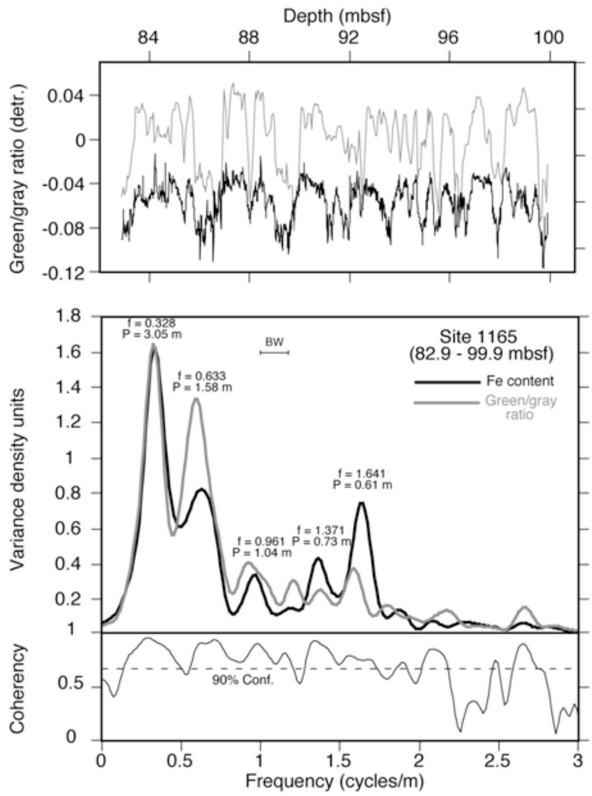
The late Miocene was a time of maximum ice volume since the evolution of the Antarctic ice shield. Large shelf ice areas developed in East Antarctica and for the first time also in West Antarctica (e.g. Kennett and Barker, 1990). In contrast the Early Pliocene exhibits a climatic optimum around 4.8 to 4.1 Ma that started with an ice retreat at about 5.2 Ma (e.g. Hodell and Warnke, 1991). Superimposed on these large scale climate trends were shorter period fluctuations in the extent and volume of the ice shield as indicated by IRD and isotope records from subpolar drilling locations (e.g. Warnke et al., 1992). Studies on changes in oceanic circulation and ice sheet growth during late Miocene - early Pliocene times in proximal East Antarctic locations are limited until now by low core recovery and disconformities.

During ODP Leg 188 (Prydz Bay) high quality APC and XCB cores containing nearly complete sections of Middle Miocene to Early Pliocene age were drilled at Site 1165 (Shipboard Scientific Party, 2001). The recovered cores allow a detailed, high-resolution characterisation of sedimentary cycles and can provide indications for ice advances of the Lambert glacier system into Prydz Bay, for the extent of sea ice, and for changes in oceanic circulation.

We analysed colour spectra, multi sensor core logs (bulk density, magnetic susceptibility), and XRF-scans (Fe, Ti) measured at a resolution of 1 to 5 cm. These records show cyclic amplitude changes with depth at cm to m scale and reflect variations in the amount of terrigenous and biosiliceous material. Opal measurements on selected samples indicate a range of 5 to 30 % for the biogenic component. A multiple linear regression approach combining discrete opal data and continuous core logging records was

Figure 1 a

Figure 1 b



Sedimentation rate: 3.5 cm/k.y.

WAVELENGTH (m):		PERIOD (k.y.):
3.05	→	87.1
1.58	→	45.1
1.04	→	29.7
0.73	→	20.8
0.61	→	17.4

Figure 1 c

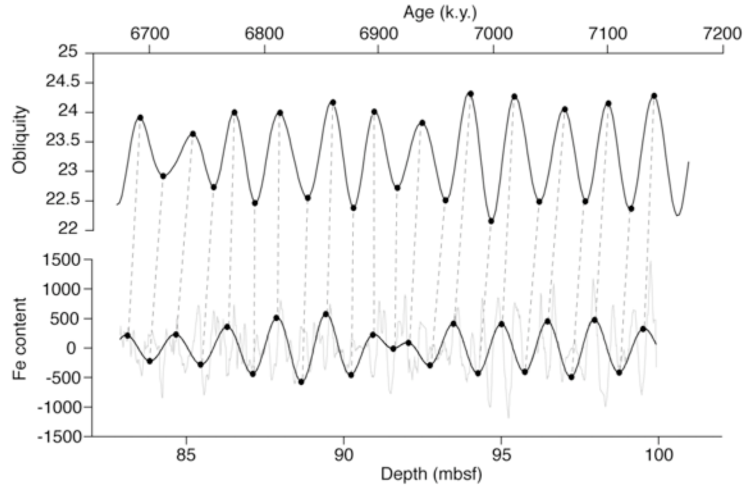


Figure 1. The stratigraphic potential of sedimentary cycles at ODP Site 1165 is illustrated by an example from the interval 83 to 100 mbsf. **(a)** Continuous colour (green/grey ratio, 5 cm interval) and XRF measurements (Fe intensity, 1 cm interval) of high quality were analysed. To remove large scale trends from these records the 3m running average has been subtracted from the measured data. **(b)** Spectral analyses of these records have been performed in the depth domain. Both parameters show high coherencies in all significant spectral bands. The identification and evaluation of the cyclicity based on shipboard bio- and magnetostratigraphic data suggests that the depositional facies are influenced by Milankovitch periodicities of 100, 41, 23, and 19 ky (table at the right). **(c)** The construction of an age model is based on the correlation of orbital obliquity and the filtered (bandpass centred at 1.5 m) iron (Fe) record. The original (detrended) Fe data are shown in the background.

used to estimate percent biogenic silica at a high resolution. Maximum silica values are typical for greenish sediments indicating biogenic hemipelagic sedimentation under warmer climate conditions.

Spectral analyses in the depth domain together with shipboard bio- and magnetostratigraphic data demonstrate that the cyclic sedimentation occurs at Milankovitch periodicities, and hence is controlled by Earth's orbital variations. The detected obliquity and precession cycles are in turn used to improve the shipboard sedimentation rates. Refined sedimentation rates together with the opal estimations allow quantifying changes in the fluxes of biogenic opal and terrigenous material at a high resolution.

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Late Oligocene - Early Miocene Glaciomarine Sedimentation from Offshore Drilling in the SW Ross Sea, Antarctica: Implications for Glacier Fluctuations and Climate

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Renewed offshore drilling from 1997 to 1999 in the SW Ross Sea by the seven-nation Cape Roberts Project has recovered three cores representing a cumulative thickness of c. 1500 m of Oligocene-early Miocene strata. Together with data from earlier drilling, notably CIROS-1 (702 m of core recovered in 1986), we now have a unique long-term record of shallow-marine glacigenic sedimentation at the margin of a rift basin bordering a mountain range that was breached by outlet glaciers from the interior of an ice sheet. This paper focuses on the late Oligocene – early Miocene record, which is of particular interest in that it preserves sedimentary facies that represent warmer ice and climatic conditions than is evident in Antarctica today.

Emphasis is placed on describing the characteristic facies associations in a laterally continuous nearshore sediment wedge in relation to the glacier termini supplying the sediment. The paper contrasts two settings for shallow marine glacigenic sedimentation. One cored in CIROS-1 lies on the axis of the flow centreline of an outlet glacier, the Ferrar Glacier, whereas the other, cored in CRP-1 and CRP–2/2A, is offset from the line of a second outlet glacier, the Mackay Glacier. These settings provide examples of the main glacial depositional processes that occurred near the edge of the uplifted rift margin of the Transantarctic Mountains.

Sedimentary facies are highly variable, and include diamictite, conglomerate, breccia, sandstone, siltstone, mudstone and rhythmite. Complex facies associations are identified which, combined with seismic stratigraphic data, indicate an alternating proximal and distal marine record of glacigenic sedimentation, including phases of ice-grounding and variable degrees of ice-rafting. Contrasting sand and mud facies reflect variations in wave influence and water depth. Considerable reworking by gravity-flow processes and submarine currents is also evident.

These facies, together with palaeoecological data, provide clear evidence of a climatic regime unlike that of today, but one that resembles today's High-Arctic, where the glaciers are commonly polythermal. Sedimentation is influenced not only by direct deposition from glacier ice, and by glaciofluvial input to the marine environment, but also by coastal marine processes.

Synthetic Seismograms Linking ODP Sites 1165 and 1166 to Seismic Profiles, Continental Rise and Shelf of Prydz Bay, Antarctica

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Synthetic seismograms provide a crucial link between lithologic variations within a drill-site and seismic reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Using a combination of core and log data, we have created synthetic seismograms for ODP Sites 1165 and 1166, drilled during Leg 188 (O'Brien et al., 2001), to help understand the nature of the regional seismic reflectors identified from seismic surveys of the area. Each synthetic seismogram is based on convolution of an impedance log with an appropriate source wavelet. It is not modified to account for either energy loss due to spherical divergence of the source impulse during propagation in the subsurface or any processing steps that may have been applied to the seismic sections.

The seismic profile crossing Site 1165 was collected aboard the JOIDES Resolution during approach to the site, using a single 80 in^3 water gun source. The impulse from the water gun was noisy, with a ~30 ms precursor, which added difficulty to the interpretation of the synthetic. The synthetic seismogram was generated using a combination of log- and core-based density measurements as well as core-based velocity measurements. Log velocity data were generally of poor quality and only half of the hole was logged due to an obstruction. To compensate for this, the density log was edited and converted into a pseudo-velocity log. The pseudo-velocity log was then combined with *in situ* corrected core velocity measurements from the unlogged intervals to make a composite velocity log for the entire hole. This velocity log was used to create the synthetics. Seismic reflections are produced by changes in impedance, or the product of velocity and density, but the two are virtually identical in character for this synthetic seismogram, because the density log was used to create most of the velocity log. Furthermore, downhole changes in density and

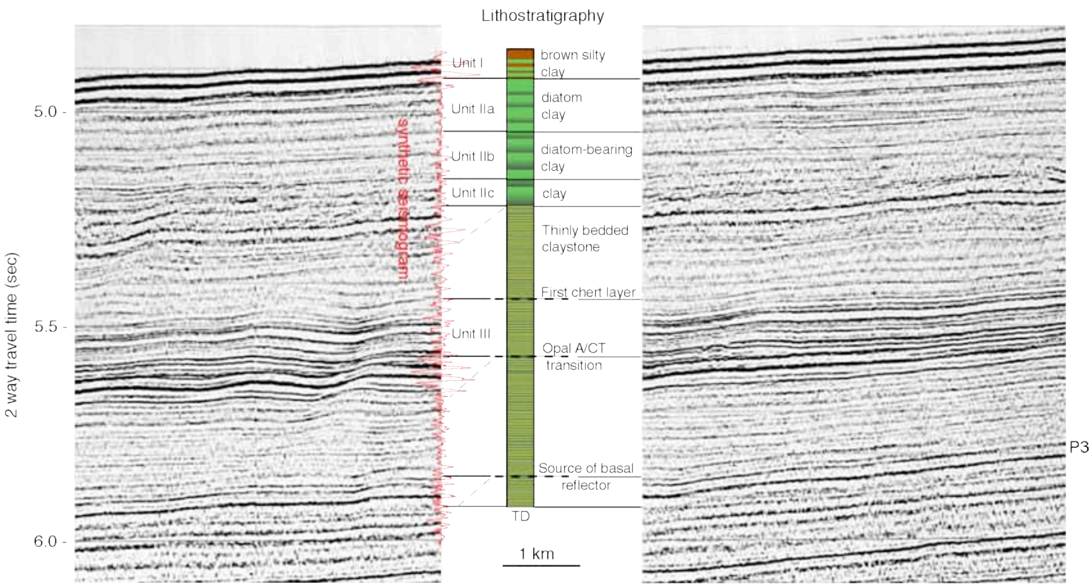

Figure 1. Synthetic seismogram, lithostratigraphy and shipboard generated seismic section for Site 1165. Grey dashed lines represent the end of source wavelet propagation across a given boundary.

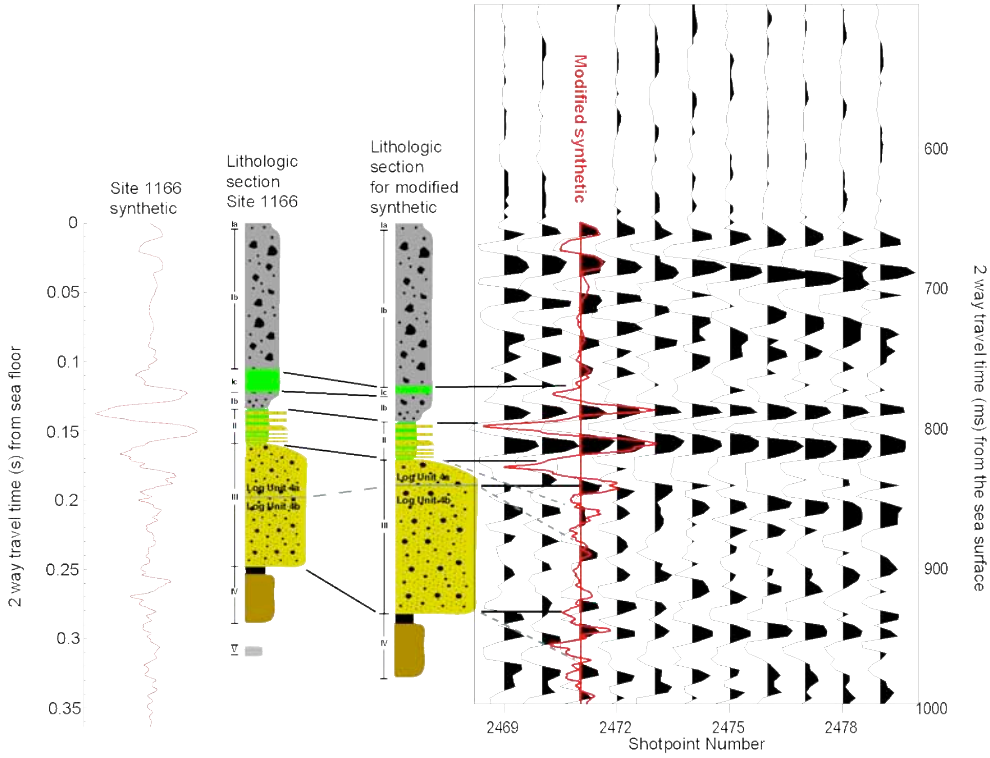

Figure 2. Comparison of synthetic seismogram for Site 1166 and synthetic modified to match SP 2471 on seismic line BMR33-23p3. The lithostratigraphic section is modified the same as the synthetic for SP 2471. Grey dashed lines represent the end of source wavelet propagation across a given boundary.

velocity are both predominantly controlled by changes in porosity, so changes in one should be matched by changes in the other.

A close character match is seen between the synthetic seismogram and the original seismic section (Fig. 1). Analysis of the synthetic indicates that a regional reflector at ~5250 ms below the sea floor, which can be traced beneath the continental slope of Prydz Bay, corresponds to the lithologic transition from Unit II to Unit III at 305 mbsf in the core. A prominent reflector package from ~5560 ms to ~5660 ms represents the diagenetic opal A/CT transition (~600 mbsf); its prolonged seismic signature results from the long source wavelet as it crosses the large impedance contrast at the diagenetic front. The reflector at ~5900 ms, which was the target reflector for drilling, is estimated to result from an impedance contrast at ~907 mbsf (~5845 ms), in Core 1165C-26R, which had only ~40% recovery. This is somewhat shallower than originally thought either on board the ship or from pre-drilling estimates. The core showed no visible lithologic change, but an increase in downhole velocity is noted in the pseudo-velocity log below this depth. In addition, XRD and smear slide data suggest a large drop in total clay and increase in silt content below this depth.

Site 1166 was drilled approximately 1 km southwest of seismic line BMR 33-23p3. The synthetic seismogram for this site (left column of Figure 2) was created using both core and log velocities; both were reliable at this site. The resulting synthetic seismogram shows a strong character match to the seismic line. However, since the drill site lay ~1 km off the seismic line, individual reflectors on the synthetic seismogram are offset significantly from corresponding reflectors on the closest portion on the seismic line. These differences imply significant lateral changes in bed thickness.

The series of reflectors on the original synthetic from 0.106 s to 0.190 s below the sea floor (bsf), which correspond to the reflectors between ~0.78 s and ~0.87 s on the seismic profile, are the result of the combined influence of a suite of thin, lithologically distinct beds spanning from the base of Lithostratigraphic Unit IB to the top of Lithostratigraphic Unit III. The onset of source-wave propagation across the Unit Ib/Ic boundary occurs at 0.106 s bsf, while the trailing edge of source-wave propagation from the Unit II/III boundary occurs at 0.19 s bsf, even though the boundary itself lies at 0.155 s bsf. The basal reflector at ~0.95 s on the seismic section occurs in the original synthetic as a prominent reflector at 0.26 s bsf and is the result of the Unit III/IV transition.

Both the basal reflector and the reflector packet from 0.106 s bsf to 0.190 s bsf occur at different travel times than the equivalent reflectors on the seismic line due to lateral thickness changes associated with the 1 km offset between the drill site and the seismic line. In order to estimate these bed thickness changes, individual lithologic units of the impedance log for Site 1166 were differentially stretched and compressed, and a new synthetic seismogram was created to match Shotpoint 2471, the nearest shotpoint to the site. This new synthetic seismogram indicates that Unit I is 7% thinner at Site 1166 than at Shotpoint 2471 on the seismic line. Similarly, Unit II is 9% thicker and Unit III is 33% thinner at Site 1166 than Shotpoint 2471. Furthermore, a reflector that occurs along the seismic line at 0.21 s bsf can only be reproduced if Unit III is subdivided into two subunits as suggested by the wireline logs (Logging Subunits 4a and 4b) and these two subunits are stretched independently of each other. If Unit III is treated as a single unit, then this lower reflection cannot be reproduced accurately.

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Marine Palynology of the Cape Roberts Drill-Holes, Victoria Land Basin, Antarctica

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The entire core recovered from the three Cape Roberts drillholes (CRP–1, CRP-2/2A and CRP-3) was sampled for marine palynomorphs. Assemblage details are summarised in Figure 1. Samples from the Quaternary section contain rare marine palynomorphs, most of which are reworked from older underlying strata. A few dinoflagellate cysts (dinocysts) considered to be *in situ* were recovered from a carbonate rich interval between 31.89 – 33.82 metres below sea level (mbsf) in CRP-1 (Wrenn et al., 1998).

Rich marine palynomorph assemblages were recovered from the older (Miocene and Oligocene) sediments in CRP –1 and CRP 2/2A (Hannah et al., 1998, 2001). Similar assemblages were documented in the top 162 m of CRP–3 (Hannah et al., in press). Below this level most samples are either barren or yielded only sparse floras. One exception is a spike of increased productivity between 781.36 – 788.69 mbsf.

Most marine palynomorph species recovered are new and the majority remain undescribed. The assemblages can, however, be subdivided into three broad taxonomic groups:

- Prasinophyte algae, predominantly *Cymatiosphaera*.
- Acritarchs, dominated by species of *Leiosphaeridia* with the fusiform acritarch *Leiofusa* being an important component of the assemblages in the bottom part of the CRP-2/2A and the upper part of CRP–3. Two peaks in spinose arcitachs have been recorded in CRP–1 (48.35 – 58.43 and 99.01 –78.15 mbsf) which could be environmentally significant.
- Dinocysts, both *in situ* and reworked. The *in situ* forms increase in diversity down hole in CRP-1 and maintain this level to the bottom of the rich assemblages in CRP–3. More than 20 new species of dinocysts, including several species of *Lejeunecysta*, have been recognised and are currently being analysed. Many reworked species are attributable to the well known Paleogene assemblage referred to as the Transantarctic Flora (Wrenn and Hart, 1988), the key elements of which were originally described by Wilson (1967) from the McMurdo Sound region. The absence of *in situ* taxa from this assemblage is thought to have time significance, restricting the maximum age of the base of the sequence to latest Eocene / earliest Oligocene (Hannah et al., in press).

The Cape Roberts marine palynomorph assemblages assist considerably in filling the gap in the stratigraphic record between the recent dinocyst assemblages documented from the southern Indian Ocean (Marret and Vernal, 1997) and the Weddell Sea (Harland et al., 1998), and the Eocene?- earliest Oligocene Transantarctic Flora (see Hannah et al., in press, for references to the distribution of this flora).

The suite of marine palynomorph assemblages documented in the Cape Roberts Core represents an opportunity to develop a new robust biostratigraphy for southern high latitudes. The marine palynomorph flora is often the dominant microfossil group present in the cores and well preserved floras were recovered from most facies, usually with a significant yield. A preliminary biostratigraphic scheme has been developed. Seven biozones cover most of the Oligocene – Miocene strata and are based largely on *in situ* dinocysts (Fig. 1). Species of *Lejeunecysta*, which are used in the definition for six of the biozones, are particularly significant.

More detailed taxonomic and biostratigraphic studies of the flora, including an assessment of the significance of the common acritarch and prasinophyte taxa, could lead to further refinement of the zonation.

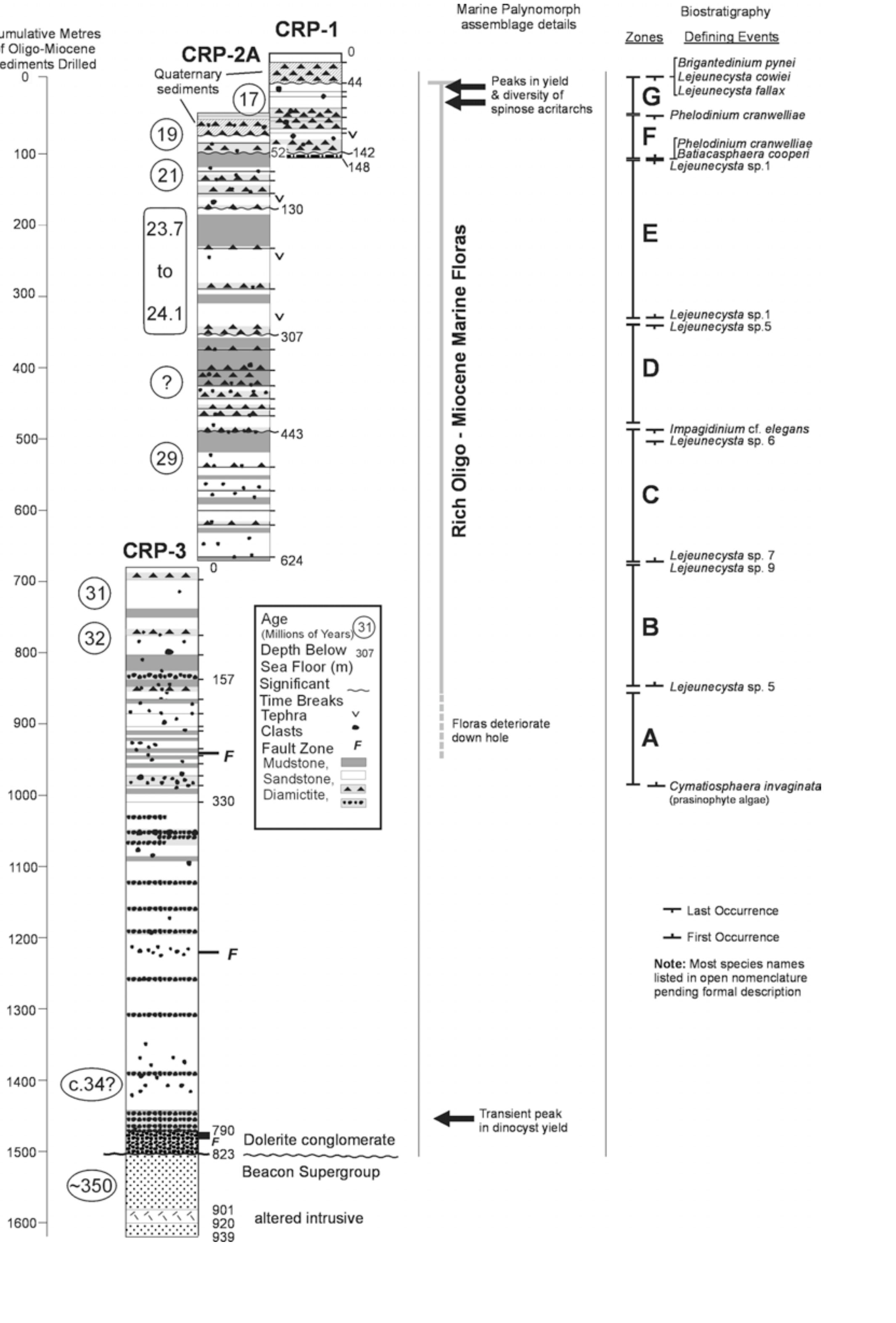

Figure 1. Summary of marine palynomorph distribution in all three Cape Roberts drillholes. To the right of the composite well log (from Cape Roberts Science Team, 2000) is a column indicating where the best Oligo-Miocene floras were recovered, along with some additional assemblage data. The column to the far right outlines a preliminary biostratigraphy for the sequence.

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Composite Cretaceous and Cenozoic Diatom Biozonation for the Antarctic Shelf, with Correlations to the Southern Ocean

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Siliceous microfossils, particularly marine diatoms, offer valuable biochronological control for sediments of the southern high-latitudes. Southern Ocean diatom biostratigraphy is well established for the late Eocene to Recent. A biostratigraphical framework is developing for the Antarctic continental shelf based on drill core data, which indicates that a single zonation cannot be applied to both regions. However, many diatom taxa are common to both regions and can be used to correlate cores in the two areas. Intervals on the shelf with the best control include the late Eocene to early Miocene and the Plio.-Pleistocene. The late Eocene through middle Miocene is currently divided into 28 biostratigraphic zones based on diatom events. A separate zonation for this same time interval is developed from a composite of biostratigraphic events of other siliceous microfossil groups (ebridians and silicoflagellates) and includes 12 zones. Significant gaps exist in the upper middle and upper Miocene stratigraphic record on the Antarctic shelf. The latest Miocene through Pleistocene record is moderately well known from drill core and piston core records and a zonal framework of 10 zones is presented. Further refinement of this zonal scheme will result from the recovery of additional sequences through future drilling. This paper reviews the existing siliceous microfossil data from the Antarctic Continental shelf and presents a composite biostratigraphy. Requisite dating from magnetostratigraphy, tephrachronology and Sr dating provide an improved chronostratigraphic framework for these zonal schemes. We are currently applying this zonation to existing drill cores that were dated previously by a largely inadequate biostratigraphic scheme. For example, DSDP Leg 28, Hole 271, is now known to have recovered a Pliocene record down to Core 24 in this hole, and an uppermost Miocene record at the bottom of the hole (Hayes et al., 1975). Significant reworking from a late Miocene source is noted throughout the entire sequence. Application of standard biostratigraphic approaches is difficult in many sequences due to the high amount of reworking and assemblage age mixing noted in some intervals. Several resistant, abundant and time diagnostic taxa are identified that can be used to interpret the reworking history and separate the distinct sources and ages. Future work will enable a better assessment of the ages of sequences cored by DSDP in the Ross Sea in the mid 1970s, as well as the suite of piston cores. The next phases of stratigraphic drilling (ANDRILL, SHALDRIL) will be armed with a substantially better biochronostratigraphic framework based on siliceous microfossils than was available for the DSDP, DVDP, CIROS, MSSTS and Cape Roberts Project drilling initiatives.

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"Ocean Drilling" over the Next Decade: Prospects for the Antarctic

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The current Ocean Drilling Program (ODP) will end in September 2003. There will be no further drilling in the Antarctic region under this program. A new program, the Integrated Ocean Drilling Program (IODP) will follow on, beginning in October 2003. The new program envisions the use of multiple vessels to carry out a broader program of scientific research. Japan will provide a riser equipped vessel, currently under construction, and expected to be operational by about 2006-2007. The United States will provide a vessel with capabilities similar to the present JOIDES Resolution, to become operational in late 2004 or 2005. Europe is currently proposing to provide alternate drilling platform capabilities from late 2003. These alternate platforms might include specifically outfitted polar vessels, jack-up rigs, geotechnical vessels, remotely operated coring tools, anchored barges, and others.

The experience of Antarctic drilling through the ODP was hampered by a rule set by JOIDES that no leg could be scheduled until the results of the previous leg in the Antarctic region were known. Because of the planning process during the ODP this meant a delay of at least three years between each of the Legs proposed by ANTOSTRAT. The total ANTOSTRAT program of five legs would have required a minimum of 15 years to complete. The potential flexibility of the new program may allow a different mode of operation.

In order to participate in this new venture, I recommend that the Antarctic community develop a ten year plan outlining the scientific goals of drilling offshore in the Antarctic region. The original theme of the ANTOSTRAT drilling program, to understand the glacial history of the Antarctic and thereby reconcile the discrepancies between the interpretation of the oxygen isotope record in terms of global ice volume and the stratigraphic coastal-onlap -offlap sequences in terms of global sea level, can form a solid base. The ODP drilling has demonstrated that the glacial history of Antarctica is complex. Understanding the climatology of the polar regions is critical to understanding the "Cenozoic climatic deterioration".

A ten year plan should include indications about the types of platform best suited to carry out the operations. Experience with the JOIDES Resolution demonstrated that it was not optimally configured for drilling in the shallower seas proximal to the continent. A ten year plan should also show how offshore and onshore and ice drilling complement each other. Finally, the plan should make it evident why further offshore drilling should be undertaken in the next decade rather than postponed to the more distant future.

Correlation of Seismic Reflectors with Cape Roberts Drillholes, Victoria Land Basin, Antarctica

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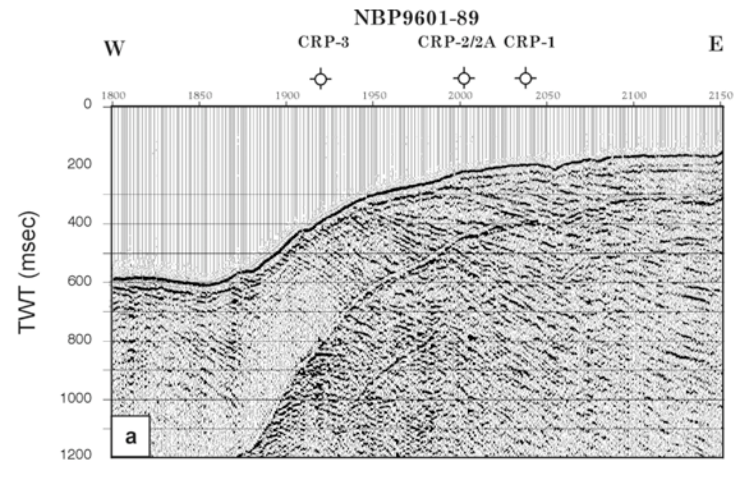
Seismic reflection data collected on the Antarctic margin provide the essential spatial context for determining the high-resolution history of ice margin and water depth changes away from drill hole data. To date, however, very few examples from drilling (integrated lithologic core descriptions, down hole logs, and physical rock properties) coupled with high-resolution seismic data, exist on the continental shelf of Antarctic to fully exploit the potential of thousands of kilometres of multi-channel (Brancolini et al., 1995) and single-channel (see Anderson, 1999) reflection data available. Recent coring of 1500 m of Cenozoic strata from the western margin of the Victoria Land Basin off Cape Roberts (CRP1, CRP-2/2A, and CRP-3) have recorded the variations of the Ross Sea margin of the East Antarctic ice sheet from 34 to 17 million years ago (see Cape Roberts Science Team, 1998, 1999, 2000 and Fig. 1). Preliminary analysis of lithology and palaeontology of the cored strata show them to comprise numerous unconformity-bounded glacimarine sequences, each of which is considered to represent an advance and retreat cycle of the East Antarctic ice sheet margin. Interpretation of seismic reflection data intersecting the drill holes indicates that the thicker glacial cycles can be picked individually in seismic sections (Bücker et al., 1998; Henrys et al., 2000; Henrys et al., submitted). Although the resolution of reflecting horizons is limited to around 10-20 m in the best case, individual horizons can be traced several kilometres along strike (parallel to the ancient coastline), and many hundreds of metres along dip (normal to the coast). These data, combined with seismic data recorded down the well at CRP-3, represent a significant opportunity to characterise the seismic signal and quantitatively express the resolution present in much of the present seismic data bases (maximum frequency: 100 Hz).

We have attempted to match both vertical incidence and shot gather reflection data using synthetic seismograms derived from core properties. In the synthetic seismograms the computed reflections represent only the information sampled in the borehole. Differences between the synthetic seismograms and the seismic reflection data can arise because the Fresnel zone of the reflection data takes in a larger area than just the bore hole (about 100 m radius at 1 s) and therefore includes reflections generated by rocks and structures surrounding the bore hole. Given the limitations of the data we have been able to establish that most seismic events are close to, or are associated with, stratigraphic sequence boundaries. For example, the highest impedances are encountered where diamictite lithologies, representing the base of a sequence cycle (Fielding et al., 1998), are present. Continuous layers of this lithology yield bright and laterally continuous reflectors. We also note, however, that diamictites do not always correspond to a



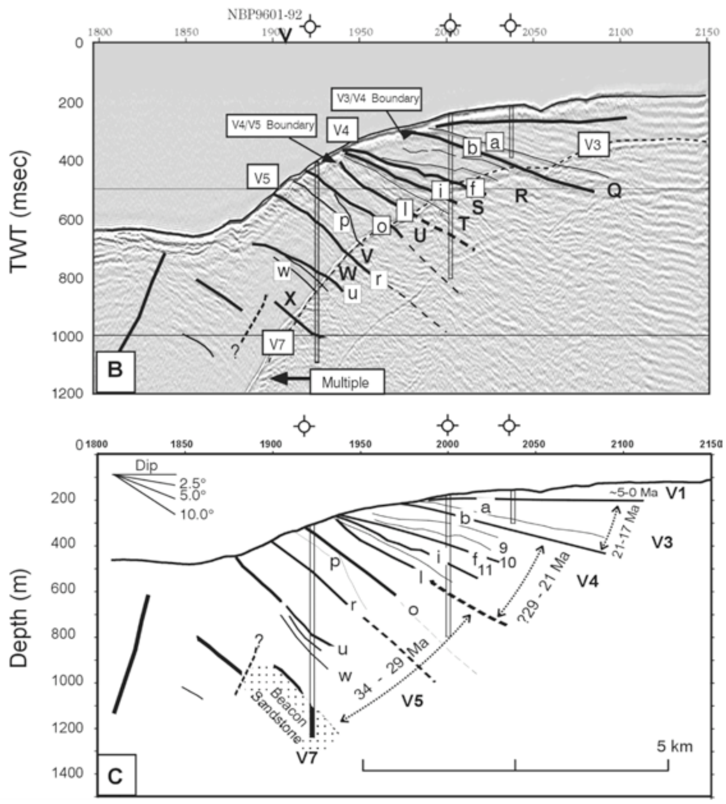


Figure 1. Seismic section for dip line NBP9601-89 **(a)**, with interpretation of stratigraphic units together with major seismic reflector events identified in CRP-1, CRP-2/2A and CRP-3 **(b)**, and depth **(c)**.

significant velocity or impedance change and in some cases strong and continuous reflectors have no associated change in velocity. In an effort to understand better the seismic response of stratal packages we have computed both 1-dimensional and 2-dimensional numerical models that include vertical and spatial variations in thickness and impedance contrast.

Calculations of synthetic seismograms highlight the need to acquire new closely spaced high-resolution (> 100 Hz) multi-channel seismic data sets, in future, to establish the geometry of depositional sequences. These data will also be needed to confidently locate future drill holes, and are necessary to advance the climate history of Antarctic margin.

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Late Miocene to Quaternary Deposition of Biogenic Opal and Clay Minerals on the Continental Rise West of the Antarctic Peninsula

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Neogene to Quaternary records of biogenic opal and clay mineral deposition are presented for a sediment drift on the continental rise west of the Antarctic Peninsula, which was drilled at Sites 1095 and 1096 during Ocean Drilling Program (ODP) Leg 178 in the Bellingshausen Sea (Barker et al., 1999). The opal contents in the drift deposits were used to reconstruct long-term palaeoproductivity changes. Since phytoplankton production in the polar Southern Ocean mainly depends on sea-ice coverage the opal fluctuations also reflect variations in sea-ice extent in the Bellingshausen Sea linked to palaeoceanographic and palaeoclimatological changes. The clay mineral compositions of the drift sediments recovered at Sites 1095 and 1096 were analysed in order to reconstruct the supply of detrital components to the continental rise, and thus the ice dynamics in the Antarctic Peninsula region.

Slightly enhanced opal concentrations during most of the late Miocene and relatively high opal contents during the early Pliocene are interpreted to indicate less sea-ice coverage in response to warm climatic conditions in the Antarctic Peninsula area. The contribution of heat from the northern-source deep-water ("Northern Component Water", NCW) into the Southern Ocean seems only to have played a subordinate role during that period of time, but a slight decrease in opal contents during the Messinian stage indicates sea-ice expansion in the Bellingshausen Sea to be triggered by an assumed reduction of NCW flow. The early onset of the Pliocene warmth in the Antarctic Peninsula area might in turn point to a positive feedback of regional Antarctic climate on global thermohaline circulation. A decrease of the opal concentrations in the drift sediments between 3 and 1.8 Ma is likely to reflect sea-ice expansion in response to the reduction of NCW flow, caused by the onset and intensification of Northern Hemisphere glaciation. Throughout the Quaternary, an increasing trend of opal production in the Bellingshausen Sea might indicate a regional warming, not yet observed in other parts of the Southern Ocean.

The clay mineral assemblages of the upper Miocene to Quaternary sediments recovered at Sites 1095 and 1096 are dominated by smectite, illite, and chlorite, with kaolinite occurring in trace amounts. The analysis of a surface-sample data set facilitates the assignment of these clay minerals to particular source areas on the Antarctic Peninsula, and thus the reconstruction of transport pathways. In the ODP cores, clay mineral composition cyclically alternates between two endmember assemblages. One assemblage is characterised by <20% smectite and >40% chlorite. The other assemblage has >20% smectite and <40% chlorite. Illite fluctuates between 30% and 50% without a significant affinity to one endmember assemblage. By comparison with a late Quaternary sediment sequence from nearby gravity core PS1565, the clay mineral fluctuations can be ascribed to glacial and interglacial periods, respectively. The cyclic changes in the clay mineral composition suggest that glacial-interglacial cycles, repeated ice advances and retreats, and changes in the Antarctic ice volume were already a main control of the global climate in late Miocene time, some 9 Ma ago. In contrast to the opal record the clay mineral record of the drift sediments only exhibits slight long-term changes, which probably result from regional differences in glacial supply of terrigenous debris derived from the particular source areas on the Antarctic Peninsula.

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Discovery of Potentially Pre-Quaternary Deposits on Ice-Free Area of Lützow-Holm Bay - Evidence of Amino-Acid Geochronology and Biochronology

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During the Japanese Antarctic Research Expeditions (JARE), a study of the coastal palaeoenvironmental history during the late Quaternary of the Lützow-Holm Bay region has been carried out since 1991, basically using chronostratigraphy of elevated marine deposits. Over the recent years, the studies on geochronology of amino-acid epimerization of fossil bivalvia and biochronology of fossil ostracoda and bivalvia provided new chronological information that confirmed the existence of elevated marine deposits containing pre-Quaternary fossils in this region.

Age determination of the deposits, using Accelerator Mass Spectrometry carbon-14 dating of fossil bivalvia and foraminifera, showed the following bimodal distribution of age categories: 2-8 ka (Holocene) and 30-46 ka (the last interstadial, latest Pleistocene) (Miura et al., 1998). However, amino-acid geochronological analysis for fossil bivalvia recovered from the deposits of East Ongul Island and the northernmost Langhovde (Fig. 1) produced D-alloisoleucine/L-isoleucine (D/L) ratios clustering into the following three different age groups: Group 1 (0.010-0.015), Group 2 (0.024-0.066), and Group 3 (0.146-0.361). These results indicate that the fossil group producing the latest Pleistocene carbon-14 ages should be further divided into two new amino-acid age categories (Groups 2 and 3) while the fossils of Group 1 correspond to those producing Holocene carbon-14 ages. Additionally, the relatively high D/L ratios of Group 3 were provided solely from Mizukuguri Cove, northernmost Langhovde (Fig. 1), and some of the ratios are similar to those reported from early Pleistocene or late Pliocene marine deposits of Vestfold Hills, Prydz Bay region (Hirvas et al., 1993).

In addition, biochronological analysis of fossil ostracoda recovered from the deposits of Mizukuguri Cove revealed the presence of *Leptocythere* sp. Previous identifiable specimens from this species were only reported from the late Pliocene "*Pecten*-conglomerate" of Cockburn Island (Cockburn Island Formation of Jonkers, 1998), Antarctic Peninsula (Szczechura and Blaszyk, 1996). Furthermore, scallop shell fragments of the genus *Zygochlamys*, which is typically produced by the "*Pecten*-conglomerate" (Jonkers, 1998), were collected from the land surface around Lake Zakuro, northernmost Langhovde (Fig. 1). Thus, pre-Quaternary (probably late Pliocene) marine deposits or marine fossils (even though they were deposited by reworking) exist on the northernmost Langhovde.

Finally, the southern habitation limit of the living species *Hiatella antarctica* (Philippi) is known to be around South Georgia (Hedley, 1916) and Macquarie Island (David, 1934), but in our study, *Hiatella* sp. was only observed among the fossil bivalve shells of Group 3. Therefore, this suggests a considerably warmer coastal marine environment during the habitation period of this species (late Pliocene) than that of the present or that during the depositional periods of elevated marine deposits of other locations in Lützow-Holm Bay (Holocene and

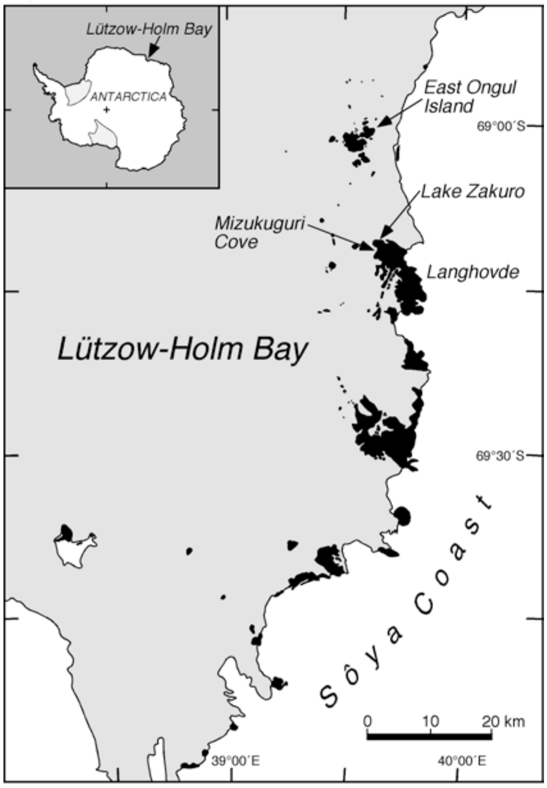

Figure 1. Map of the eastern part of Lützow-Holm Bay showing several major ice-free areas (black).

latest Pleistocene).

Based on these results from the Lützow-Holm Bay region, the following perspectives must be envisioned:

(1) coordinated palaeoenvironmental study covering the whole stratigraphic interval of the late Cenozoic using late Pliocene to Holocene marine deposits exposed on land and submarine sediment cores recovered from the fast sea ice area in the Lützow-Holm Bay region;

(2) comparative study on late Cenozoic palaeoenvironmental history in relation to glacial fluctuation among the Lützow-Holm Bay region, the other Antarctic coastal regions, and the Antarctic inland regions such as the Sør-Rondane Mountains.

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A Late Quaternary Submarine Slide in the Central Bransfield Basin, Antarctic Peninsula

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Numerous studies illustrate that high-latitude, ice-sheet-dominated, continental margins are more prone to large-scale mass-movements than lower-latitude margins. Major slope instabilities are well-documented along the northern hemisphere, glacial margins of the Norwegian Sea (e.g. Storegga Slide) and the Svalbard-Barents Sea and of Greenland and eastern Canada. However, similar slope-instabilities along the Antarctic Margins seem to be much more scarce. Here, we present the first detailed analysis of a Late Quaternary slide along an Antarctic margin.

The Gebra Slide is situated along the Trinity Peninsula margin in the Central Bransfield Basin, Antarctic Peninsula (Fig. 1). The slide scarp, clearly revealed by multibeam bathymetric data, extends over a length of about 30 km, from 1500 to 2000 m of water depth on the lower slope, well below the slope break which is here at about 750 m. The head of the slide is formed by an amphitheatre-shaped set of scarps with an elevation of 100 m. Further upslope, but still detached from the slope break, a second less-developed set of scarps suggests a multi-stage retrogressive mass-wasting process. The slide scarp area covers about 230 km^2.

Seismic reflection (airgun) profiles show that the associated deposit covers about 315 km^2 of the western King George basin. Its typical acoustically transparent to chaotic seismic facies suggests it is essentially a debris flow deposit. The deposit is draped by the recentmost hemipelagic sedimentary unit. According to seismic-stratigraphic correlations, we put the age of the main sliding event at about 13,500 a B.P., around the last deglaciation in this part of the Antarctic (Banfield and Anderson, 1995). The volume of this debris flow (21 km^3) agrees very well with the disappeared volume higher on the slope.

Although the Gebra Slide is positioned in front of a glacial trough with a higher sedimentary input, the sedimentation rates during both the present interglacial and the last glacial maximum - estimated as 0.24 and 3.4 cm/yr, respectively, based on sediment cores and seismic stratigraphy - are too low for significant build-ups of excess pore pressure to develop in the sedimentary column. The position of the main

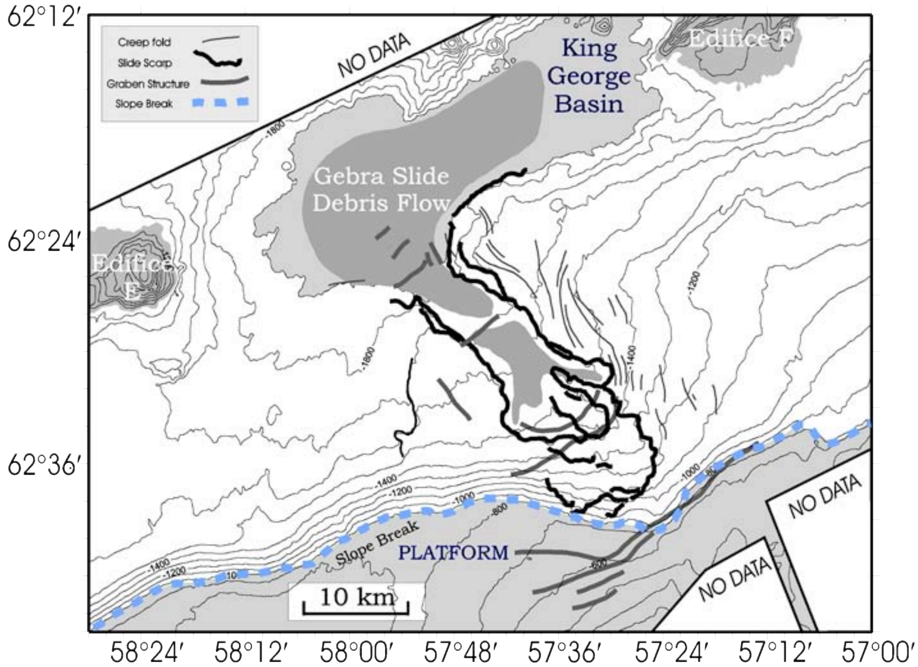

Figure 1. The Gebra Slide in the Central Bransfield Basin.

scarp on water depths of 1500 m is far below the maximum grounding depth of the Antarctic Peninsula ice sheet (about 1000 m), excluding a possible triggering by loading/unloading of an advancing/retreating ice cap as a possible cause. No deep faulting in the underlying basement is observed on the seismic profiles, which also rules out a purely tectonic control. On the other hand, triggering by an earthquake in the volcanically and seismically active Bransfield Basin should not be excluded. Therefore, we propose that only an interaction between all the above processes - in space and time - could have led to the triggering of the Gebra Slide.

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Shallow Drilling along the Antarctic Continental Margin: Feasibility, Technical Considerations and Current Plans

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For over three decades, scientists exploring the shallow shelves and seas along the margins of Antarctica have been consistently frustrated by their inability to penetrate through the over-compacted glacial diamictons encountered at shallow sub-bottom depths (within the upper 10 m) over these terranes. This is particularly frustrating because advanced high-resolution seismic reflection techniques clearly show in many areas (e.g. the Ross Sea and off Seymour Island) the presence of older successions of Neogene and even Paleogene sequences lying just beneath this thin veneer of diamictons. Until the means are developed to recover these sequences, a detailed history of the Antarctic ice sheets, which is an essential prerequisite to understanding Cenozoic palaeoclimates and future climate change on a global scale, will undoubtedly remain an elusive and unobtainable goal.

As evidenced by workshop reports, white papers, and symposia publications (e.g. Anderson et al., 1994, Cooper et al., 1994), the geoscience communities are in full agreement that the most practical way to solve this long-standing problem of obtaining the necessary cores from the Antarctic continental margins and seas is to install a shallow-water (< 1000 m), shallow penetration (50-150 m sub-seabed) rotary-drilling system as a widely-available, if not routinely used, tool on major research vessels operating in these waters.

In response to this need for the deployment of a shallow drilling system on United States Antarctic Program (USAP) vessels, the National Science Foundation's Antarctic Working Group on Geology and Geophysics (ANTWGGG) formed a committee (SHALDRIL - SHALlow DRILling) to evaluate the technical feasibility of such an undertaking. The committee retained a professional engineer, Mr. Leon Holloway with the Ocean Drilling Project, College Station, TX, to evaluate existing or proposed drilling systems and potential USAP platforms (e.g. RVIB Nathaniel B. Palmer) based on criteria provided by the committee.

The SHALDRIL committee defined criteria for site selection (water depth, depth of penetration, type of substrate, etc.) and identified likely areas of the Antarctic margin where shallow drilling would be possible and useful (e.g. prograding glaciomarine Cenozoic sequences, old (Mesozoic) marine sequences of the Weddell Sea and Quaternary carbonate deposits). Based upon these criteria, the engineer obtained detailed information from numerous operators of candidate drilling systems that might be utilised by U.S. investigators in the Antarctic. He also conducted a detailed cost and feasibility study on the emplacement of a moon pool on the RVIB Nathaniel B. Palmer and conducted a cost analysis for two hypothetical multi-leg drill plans. Five types of drilling rigs could be utilised for drilling and coring including a sea-floor coring system, portable mining-type coring systems with steel or polyethylene risers, and a geotechnical ship with a fixed derrick utilising a piggy-back coring system and a steel riser (Holloway, 1997, 1999).

The SHALDRIL committee is now focussing efforts on a multi-institutional effort to drill and core sites along the Antarctic Peninsula in early 2003.

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Glaciated Continental Margin Processes and Stratigraphy: Cenozoic of Antarctica and Neoproterozoic of Rodinia Compared

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The glacially-influenced Cenozoic continental margin of Antarctica shows a large-scale subsurface stratigraphy consisting of flat-lying "topsets" recording episodic aggradation of the continental shelf, that rest on seaward-dipping, wedge-shaped "foresets" formed by progradation of the continental slope. Ocean Drilling Program (ODP) Leg 178 (February-April 1998) drilled two sites (1097, 1103) through the outer Antarctic Peninsula Pacific shelf into strata no older than late Miocene or early Pliocene (< 4.6 Ma) (Barker et al., 1999). "Topset" stratigraphy comprises multiple units (up to 100 m thick) of deformation till recording episodes of ice expansion to the shelf edge and subglacial reworking of marine sediment. Till is interbedded with intervals of stratified and graded diamictites that contain *in situ* marine biofacies typical of proglacial marine settings recording ice retreat from the shelf. During ice expansion, shelf sediments are reworked and transported downslope by debris flows allowing the continental slope to prograde as "foresets". ODP Leg 188 (January-March 2000) drilled in Prydz Bay at the downstream end of the Lambert Graben which has served as the principle drainage outlet for the East Antarctic Ice Sheet during the Cenozoic (O'Brien et al., 2001). Site 1166 drilled the mid-continental shelf and recovered the transition, as yet undated, from pre-glacial to glacial conditions. The slope site (1167) in the Prydz Channel Trough Mouth Fan is characterised by debrites separated by thin (> 1 m) intervals of hemipelagic and contourite sedimentation. Cenozoic facies and overall stratigraphy of the Antarctic Peninsula and Prydz Bay continental margins are very similar and directly comparable with Neoproterozoic glaciated

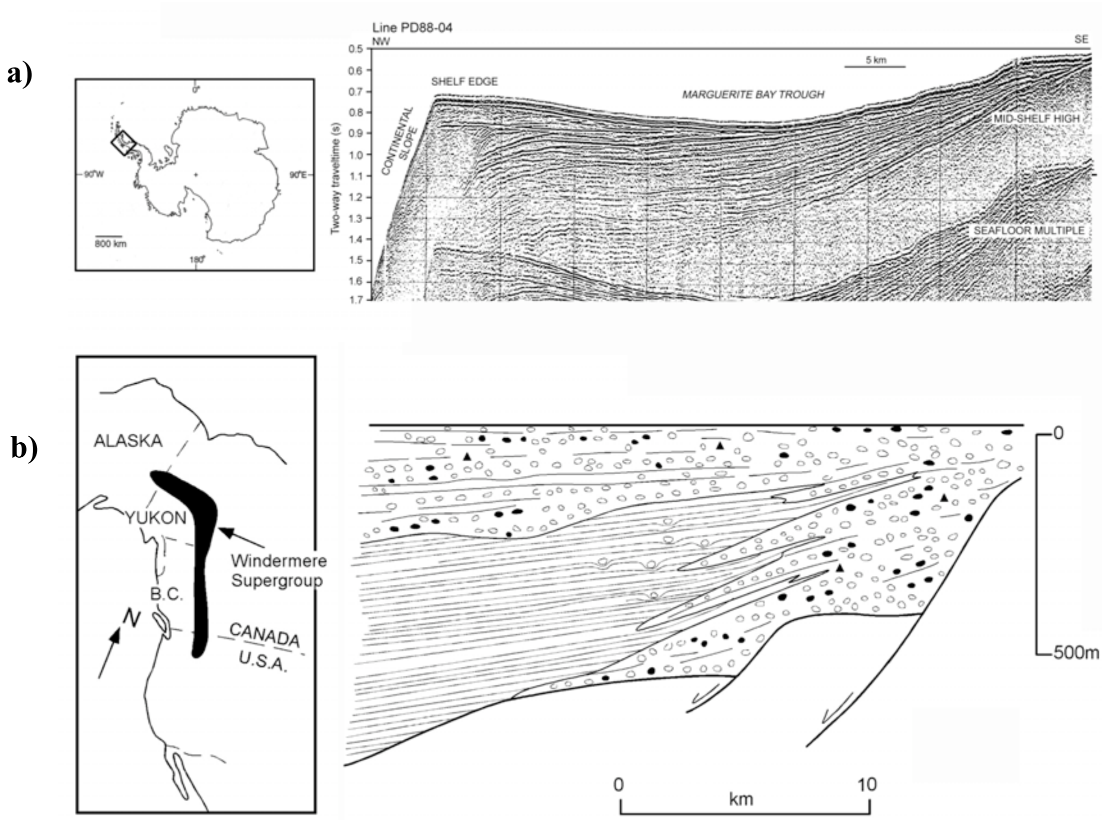

Figure 1. **a)** Representative acoustic stratigraphy of the outer Antarctic Peninsula Pacific continental margin: reproduced from Barker et al. (1998); in comparison with **b)**. Restored rift margin of Late Proterozoic Windermere Supergroup: reproduced from Eisbacher (1985). Note similar stratigraphy: flat-lying topsets record aggradation of the margin and are underlain by seaward-dipping foresets which record progradation of the margin.

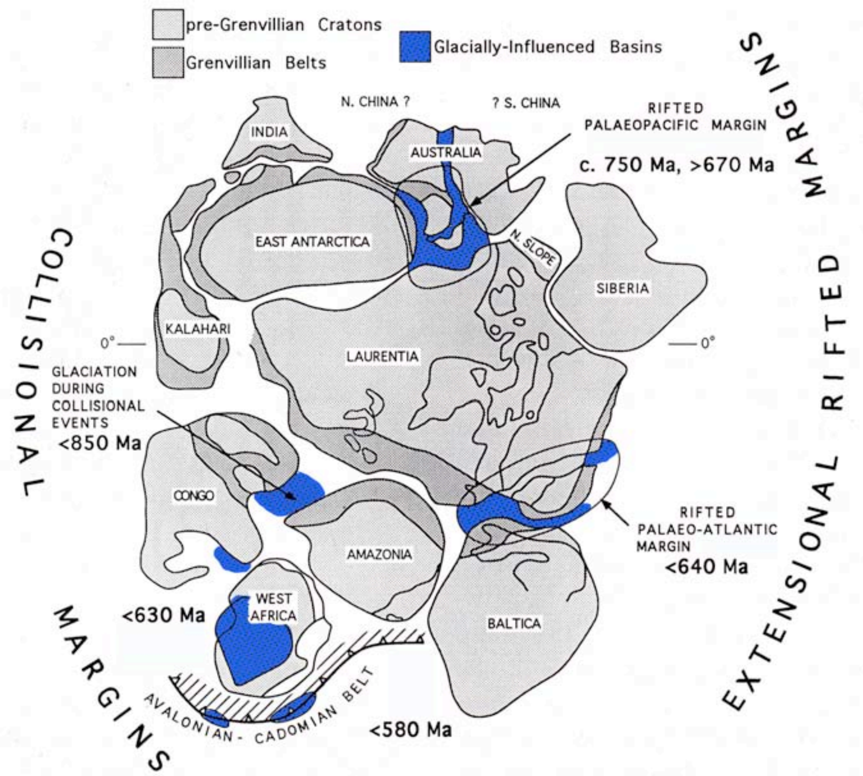

Figure 2. Plate tectonic setting and age of principle Late Proterozoic glacially-influenced strata. Late Proterozoic supercontinent is depicted according to Hoffman (1991): reproduced from Eyles (1993).

continental margins of Rodinia after 750 Ma now preserved in Australia and western North America (Figs. 1 and 2).

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Early Basin Evolution in the Atlantic/Indian Ocean Sector of Antarctica

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An accurate palaeogeographic reconstruction of the early Southern Ocean formed between South America, Africa and Antarctica requires a solid magnetic data base for identifying seafloor spreading anomalies. A good knowledge of the basin evolution will allow identifying areas where complete sequences of Mesozoic sediments are likely to exist. In order to close this gap the East Antarctic Margin Aeromagnetic and Gravity Experiment (EMAGE) began in 1996/97 and has been continued during the subsequent austral summers in 1998, 1999, 2000 and 2001. These surveys were supplemented by helicopter-based magnetic measurements in the austral season 1999/2000 to date the southernmost magnetic anomalies.

The results of five seasons show remarkably continuous seafloor spreading anomalies from 0º to 20º W along the margin of East Antarctica. In the investigated area the anomalies are parallel to the continental margin and show amplitudes up to 200 nT. The anomaly pattern indicates a surprisingly simple opening history compared to previously published geodynamic models in the area of the Explora Escarpment. The new magnetic data show that the earliest opening started in the Riiser-Larsen Sea at Chron M24, while South America was still attached to Antarctica. The final separation of East and West Gondwana was completed around Chron M13, when the rift system propagated approximately from 0º to the Astrid Ridge in a relative short period of time. The consequence of this age model is that the seaward dipping reflectors sequences of the Explora Wedge are not 180 Myr old but were created some 140 Ma. This is in excellent agreement with the Aptian/Albian age of black shales drilled within the ODP programme in that region. The magnetic anomalies are less well developed in the Lazarew Sea. The new geodynamic model is used to better constrain the palaeoceanographic evolution of this region since the Late Phanerozoic.

Preliminary Results of the TH99 Geological and Geophysical Survey in the Cooperation Sea and Prydz Bay Area

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Geophysical and geological surveys were carried out in the 1999-2000 austral summer season for the TH99 cruise aboard the R/V Hakurei-maru. The survey includes the abyssal basin and the continental rise area of the Cooperation Sea (CS) and Prydz Bay (PB), offshore of Mac Robertson Land and Princess Elizabeth Land, Antarctica (Figs. 1 and 2).

In the northern abyssal plain of the CS, a mantle-like sequence (G) appears at a depth of 10 seconds two-way travel time (TWT), approximately 13 kilometres. The sequence disappears south of 64ºS, in the southern part of the CS. These observations suggest the southern parts of the CS and PB are underlain by intermediate type crust that is characteristic of oceanic and continental material. The deep structure of most of the PB continental shelf is not clear due to the presence of strong seafloor multiples.

More than 7 kilometres of thick sedimentary sequences in the northwest area of PB are confirmed by the multi-channel seismic (MCS) survey. Very thick sedimentary sequences, interpreted as pre-rift, rift and drift sediment can be observed under thick pelagic sediment.

Geological samples, which were recovered in the CS and PB, offer important evidence on the recent history of drift sediments caused by iceberg floes.

Finally, palaeomagnetic analyses identified the presence of the Brunhes-Matuyama boundary (0.78 Ma) in two cores.

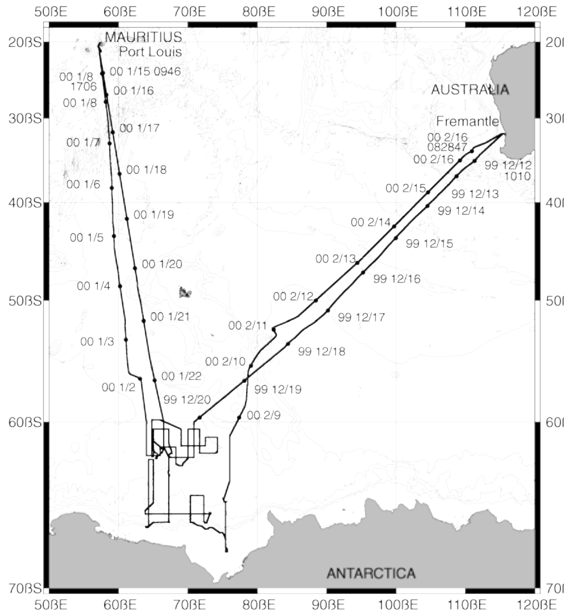

Figure 1. R/V Hakurei-maru track lines during the TH99 cruise.

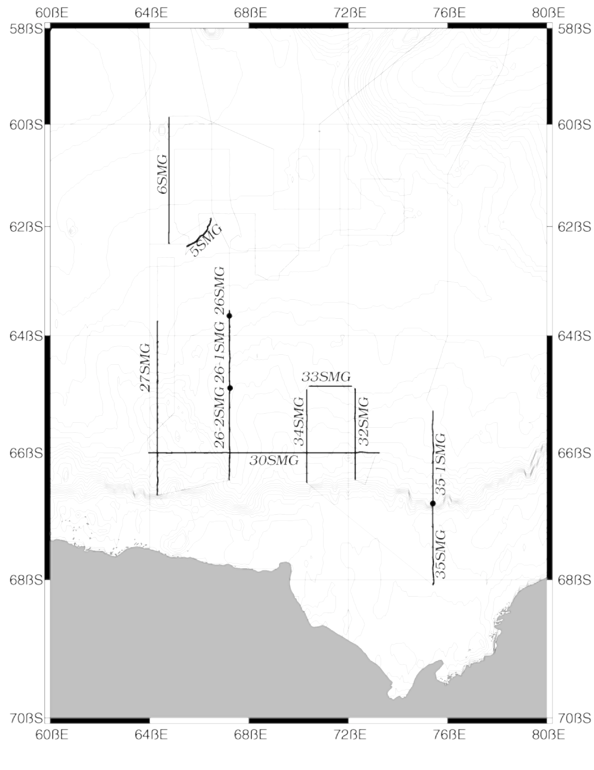

Figure 2. Multi-channel seismic survey lines collected during the TH99 cruise.

Sediment Geochemistry of Prydz Bay, ODP Leg 188: Documenting Variability of Export Production, Terrigenous Flux, and Terrigenous Provenance

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A transect of three cores on the continental slope (Site 1165), rise (Site 1167), and continental shelf (Site 1166) were drilled during ODP Leg 188 to Prydz Bay, Antarctica (O'Brien et al., 2001). A suite of sediment samples have been analysed at each site for a comprehensive group of major and trace elements (Si, Al, Ti, Fe, Mn, Mg, Na, K, P, Ba, Sr, Zr, Cr, V, Ni and Cu) by ICP-emission spectrometry. Ba and P, in particular, are being used to assess changes in export production. In addition, we are focusing on changes in provenance and terrigenous accumulation from the record of accumulation of refractory elements including Al, Ti, Zr, Cr, and Fe, and their relative ratios. The porewater distributions of some of these elements (e.g. Ba, P, and Fe) have also been studied and can be used in conjunction with shipboard porewater results to assess the effects of potential diagenetic modification of the primary geochemical signal. Combined with the palaeoproductivity aspects of the project, we aim to link changes in the chemical composition and the flux of terrigenous matter to weathering style and intensity, which in turn may be responding to climatic processes.

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Molluscan Oxygen Isotope Estimates of Seasonality and Cenozoic Antarctic Marine Temperatures

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Estimates of marine palaeotemperatures are critical to our understanding of the long-term evolution of the Antarctic cryosphere. Growth line sampling for oxygen isotope palaeothermometry has been performed on well preserved aragonitic and calcitic bivalve fragments from early Miocene (24 Ma) and early Oligocene (29 to 31 Ma) age marine sediments recovered from the McMurdo Sound region of the western Ross Sea.

The analysed fragments reported here represent splits of the molluscan shell material used for strontium isotope dating of the recently drilled CRP-2/2A and CRP-3 cores from the Victoria Land Basin, Antarctica (Lavelle, 2000). Information on shell type, preservation and taphonomy are presented in Lavelle (2000). Detailed growth increment sampling of individual pectinid and modiolid bivalve fragments proved impossible due to the small size of the available shell fragments (fragment weight averaged 2-5 mg of carbonate). Instead, the fragments were broken along growth lines at c.1 mm spacing to provide 1-4 samples from each specimen. Individual samples covered a shell span of 5-10 growth ridgelets in the pectinids and modiolids. The heated and crushed microsamples (weighing 40-500 µg) were analysed using a Micromass Multicarb preparation system attached to a PRISM mass spectrometer in the Godwin Laboratory, University of Cambridge. Results are reported to the international standard VPDB and the precision was better than +/- 0.08 per mil.

The "cold water" equations used to convert measured carbonate $\delta^{18}O$ to temperature are:

Aragonite (Grossman and Ku (1986), as modified by Barrera et al. (1994)):
$T(^{\circ}C) = 22.05 - 4.72\ (\delta^{18}O_{arag} - \delta^{18}O_{water})$.

Calcite (O'Neil et al. (1969) as published by Shackleton (1974)):
$T(^{\circ}C) = 16.9 - 4.38\ (\delta^{18}O_{calcite} - \delta^{18}O_{water}) + 0.10\ (\delta^{18}O_{calcite} - \delta^{18}O_{water})^2$.

As the $\delta^{18}O$ value of Miocene and Oligocene seawater is unknown, I have produced two palaeotemperature estimates for each sample. Both assume that Oligocene McMurdo

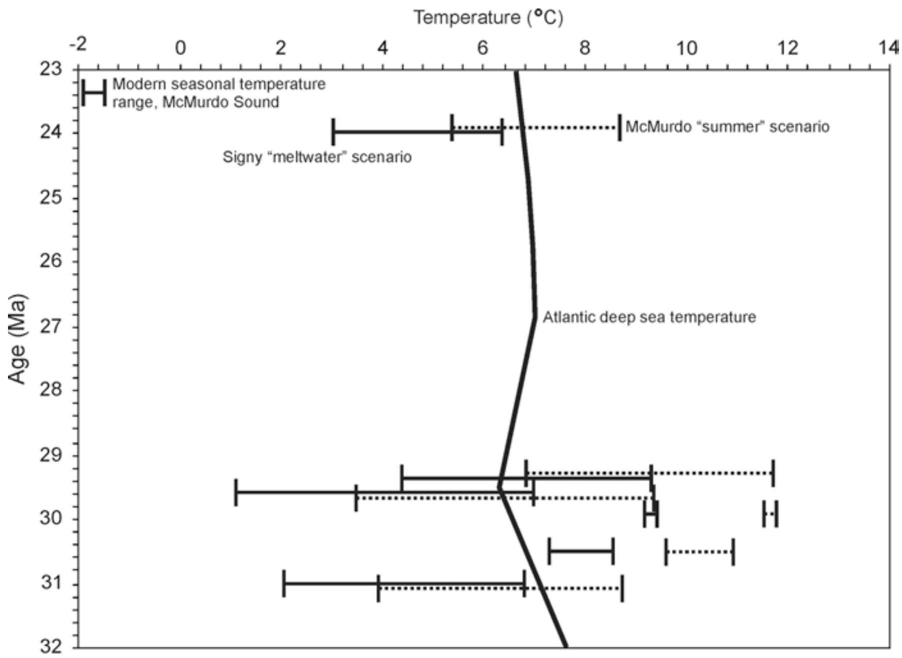

Figure 1. Marine palaeotemperature estimates vs. depositional age for shelf waters in the McMurdo Sound region during the early Oligocene and earliest Miocene. Atlantic deep-sea temperatures are from Lear et al. (2000).

Sound seawater was both warmer and more saline than the average conditions observed today (see palaeoenvironmental summary in Cape Roberts Science Team, 1999, 2000). The Signy meltwater scenario (SS) uses the measured mean modern value of -1.2‰ SMOW for a coastal high latitude site where seawater mixes with freshwater of highly negative isotopic composition (c. -35‰ SMOW) (Marshall et al., 1996). The McMurdo Sound summer scenario (MS) assumes more frigid conditions and a lowest isotopic value of -0.7‰ SMOW (Barrera et al., 1990).

Figure 1 shows the calculated palaeotemperature range for the samples analysed, plotted against depositional age. Early Miocene (24.0 Ma) benthic shallow marine temperatures (<100 mbsl) are 3.0 to 6.3°C (SS) and 5.4 to 8.7°C (MS). This compares to the modern McMurdo Sound shelf bottom water temperature range of -1.9 to -1.4°C. Early Oligocene palaeotemperatures vary between 1.1 to 9.3°C (SS) or 3.5 to 11.7°C (MS). Of particular note is the apparent warming between 31.0 Ma [2.0 to 6.7°C (SS); 3.9 to 8.7°C (MS)] and 30.5 Ma [7.3 to 8.5°C (SS); 9.6 to 10.9°C (MS)].

These palaeotemperature estimates are assumed to represent spring through late summer marine temperatures (the dominant period of Antarctic bivalve shell growth), and reflect a minimum estimate of the total seasonality range. Extensive sedimentological evidence of ice rafting suggests winter surface water temperatures may have been at or below freezing (Cape Roberts Science Team, 1999, 2000). The data are in broad agreement with deep Atlantic marine temperature estimates for the early Oligocene from Mg/Ca ratios in foraminifera (6 to 7°C), terrestrial palynology (7 to 10°C) and palaeobotany (mean annual temperature >5°C).

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Cenozoic Evolution of the Antarctic Continental Margin and Opening of Southern Ocean Seaways

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As Gondwana broke apart during the Middle to Late Jurassic through the Cretaceous, East Antarctica (EANT) was left with passive rifted margins. Only the North Victoria Land and Oates Land margins of EANT were tectonically active into the Cenozoic with transtension occurring as the South Tasman Rise slid past the EANT margin. By the end of the Cretaceous, the continental margin of Marie Byrd Land (MBL) of West Antarctica (WANT) had rifted as a new seafloor spreading centre separated the Campbell Plateau from MBL. To the north-east along the western margin of the Antarctic Peninsula, subduction of the Phoenix plate under WANT continued until about 4 Ma when the last remnant of what had originally been the Pacific-Phoenix ridge ceased spreading.

A complete circum-Antarctic seaway did not open until both the South Tasman Rise cleared the Oates Land Coast of EANT and Drake Passage opened between the southern tip of South America and the northern end of the Antarctic Peninsula (Figs. 1 and 2). Dated seafloor spreading anomalies and clear fracture zone lineations (Royer and Rollet, 1997; Marks et al., 1999) constrain the opening of a seaway between Australia and Antarctica to coincident with the Eocene-Oligocene boundary at 33.6 Ma. Timing of the opening of Drake Passage is more circumstantial because the exact motions of certain continental fragments are not known. Motion of Africa with respect to South America is well known for the Cenozoic (Müller et al., 1999) and motion of EANT with Africa is also known for the Cenozoic (Royer and Chang, 1997). If it can be assumed that there has been no Cenozoic motion of the Antarctic Peninsula with respect to EANT then tight constraints can be placed on the location of the Antarctic Peninsula with respect to the southern tip of South America for the critical period of Late Eocene to Late Oligocene. Even with the unconstrained motion of various high-standing crustal fragments in the Scotia Sea, a through-going, deep-water seaway had to have been open at Drake Passage prior to 25 Ma. With reasonable assumptions concerning motion of the crustal fragments in the western and central Scotia Sea, it is likely that Drake Passage or passage through Powell Basin was open to deep water circulation by 31±2 Ma.

While a deep-water circum Antarctic passageway existed from Early Oligocene, that did not by itself force a vigorous Antarctic Circumpolar Current. In fact, if Antarctica is isostatically adjusted for ice-loading, there may have been an oceanic passage that connected the Ross Sea and Weddell Sea embayments through what is now the Byrd subglacial basin. If higher sea level during the Cretaceous (+200 metres) is considered, the transpolar seaway may have been as much as 1000 metres deep but it would have had little or no driving force.

Initial collision of India with Eurasia at 55 Ma (Lee and Lawver, 1995) deflected the circum-equatorial circulation from 30°N of Africa to 45°S and began the Cenozoic chilling of the world's oceans. Opening of a circum-Antarctic

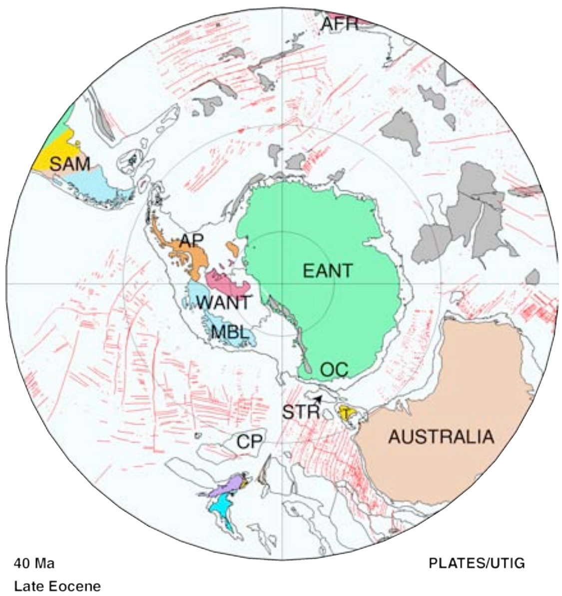

Figure 1. Late Eocene (40 Ma) reconstruction of the circum-Antarctic region using the University of Texas, Institute for Geophysics, PLATES database. Magnetic anomaly picks are shown in red. Magnetic anomaly isochrons are parallel to the magnetic anomaly picks while fracture zone lineations are shown in red (see frontispiece), orthogonal to the spreading centers. AFR=Africa, AP=Antarctic Peninsula, BR=Broken Ridge, CP=Campbell Plateau, EANT=East Antarctica, KP=Kerguelen Plateau, MBL=Marie Byrd Land, OC=Oates Coast, SAM=South America, STR=South Tasman Rise, T=Tasmania, WANT=West Antarctica.

passageway allowed the dramatic drop in $\delta^{18}O$ at the Eocene-Oligocene boundary (Zachos et al., 1996) but did not produce an accelerated chilling of the world's oceans until the next closure of an equatorial seaway, that of the Indonesian seaway at ~17 Ma when New Guinea/Australia initially collided with Southeast Asia. Final impact on the world's climate came when the Panamanian seaway was closed in the Pliocene, permitting the development the world's "oceanic heat conveyor belt" as shown by Gordon (1986).

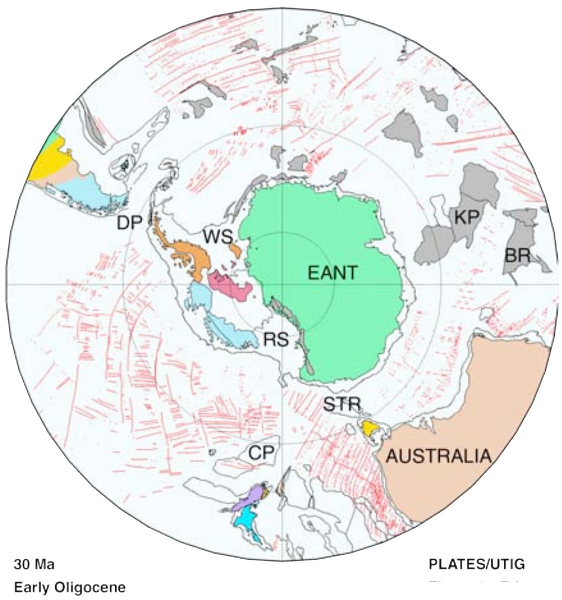

Figure 2. Late Oligocene (30 Ma) reconstruction of the circum Antarctic region using the University of Texas, Institute for Geophysics, PLATES database. Abbreviations and symbols as in Figure 1. DP=Drake Passage, RS=Ross Sea, WS=Weddell Sea.

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Cenozoic Seismic Stratigraphy and Sediment Drift Development in Cooperation Sea and Cosmonaut Sea (East Antarctic Margin from 40ºE to 80ºE)

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Deep-water part of Cooperation Sea (CpS) and Cosmonaut Sea (CsS) showing a thick (up to 2 km), well-developed Late Cenozoic (glacial-related) sedimentary cover are key regions to understanding the evolution of East Antarctic Ice sheet. Totally more than 20,000 km of MCS lines have been collected by different countries (Russia, Australia, Japan and Germany) in these regions and recent ODP drilling (Leg 188) provided a good geological groundwork for the interpretation of seismic data.

In CpS, the base of Late Cenozoic deposits is marked by a very prominent regional unconformity P_2, which displays a transition from the lower relatively homogenous part of section, with mostly irregular or continuous reflectors to the upper heterogeneous one where a variety of mostly well-stratified seismic facies are developed. This transition appears to reflect a dramatic change in the continental margin depositional environment resulted from first advance of grounded ice sheet at the shelf edge which transported large amounts of sediment to the margin. Earliest facies (above P_2) are characterised by submarine canyons and related channel/levee deposits as well as chaotic reflectors interpreted as debris flows.

Three major unconformities (P_3, P_4 and "A") can be identified above P_2 transition. The unconformity P_3 represents a foot of deposits containing abundant, current-controlled drift facies, including sediment waves and elongated ridges (detached drifts interpreted as modified levees) aligned mostly along the margins of deep and wide channels. The structure of drifts implies that they formed under the influence of strong, presumably westerly-flowing, bottom currents. The changes at level P_3 appear to have been related to initiation of the Antarctic Circumpolar Current after the opening of Drake Passage and vast Antarctic glaciation around the Oligocene/Miocene boundary (or slightly later). The most conspicuous sediment drifts are developed in the western part of CpS between 100 – 150 km wide Wilkins and Wild Canyons and consist of two parallel sub-latitudinal ridges. The area of central and eastern CpS shows less evidence of current influenced sedimentation, although narrow buried ridges, similar in shape and stratigraphic position to one from western CpS, occur above P_2.

Unconformity P_4 is another major interface, which marks a fading of current-controlled sedimentation. Detached drifts are not developed above P_4 although sediments waves (less distinctive than below P_4) are still observed. The upper part of the section (above P_4) is characterised (mostly in the eastern part of CpS) by at least two generations of well-developed channel/levee complexes trending north-east. On the upper slope they separated by an unconformity "A". The change from the older generation of channel/levee complexes to the younger one can be correlated with the beginning of the Prydz Channel formation and its trough mouth fan.

CsS continental slope and rise is characterised by narrow (20 - 40 km wide) deeply-incised linear canyons and well-developed elongated mounds between them. The upper (Late Cenozoic) part of CsS sedimentary cover differs noticeably from that of CpS, showing the dominance of downslope sedimentation, although poorly expressive sedimentary waves locally recognised here. The Cenozoic deposits in this region are underline by a distinct unconformity CsS-4, which is the top of thick and extensive in space wedge of preglacial unit pinching out oceanward. The unconformity CsS-4 is tentatively correlated with P_3 in CpS. Only regional unconformity (CsS-5) can be identified within the Late Cenozoic Section above CsS-4. It underlies canyons (almost unfilled by sediments) and well-developed levee deposits (drifts) which are as much as 1.5 km thick. CsS-5 is tentatively correlated with P_4 in CpS. In broad area within levee deposits BSR's are revealed accommodating between 2500 and 3500 m isobaths.

Hydrocarbon Gas Concentration and Isotopic Composition of Headspace Gases from Site 1165, ODP Leg 188, Prydz Bay, Antarctica

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One of the primary objectives of drilling Site 1165, situated on the continental rise offshore from Prydz Bay, Antarctica, was to obtain a proximal continental rise record of Antarctic glacial and interglacial periods for comparison with sites around Antarctica and with Northern Hemisphere ice sheets (Shipboard Scientific Party, 2001). Sediment from Site 1165 provides an early Miocene and younger record of variations in the supply of terrigenous sediment from East Antarctica and biogenic matter from ocean productivity, during the past 19-21 m.y. when floating ice intermittently passed over the site. Sediment at Site 1165 represents a history of long-term lower to upper Miocene transition from temperate to cold-climate glaciation with superimposed short-term glacier fluctuations since early Miocene time. Morphologically, Site 1165 targeted mixed sediment-drift, channel-levee sediments of the central Wilkins Drift, an elongate sediment body formed by the interaction of sediment supplied from the shelf and westward flowing currents on the continental rise.

A set of gas headspace samples were collected at Site 1165 for the analyses of carbon isotopic composition of sediment gases (methane, ethane, propane and carbon dioxide) with a focus on their relevance to gas hydrate formation. No gas hydrate was observed; however, understanding the isotopic composition of carbon sources and sinks is important in deciphering a possible carbon isotopic proxy measurement between recycled (glaciated) continental carbon and marine carbon sources. For example, continental carbon from eroded mature source rocks may record glacial advances, whereas primary (planktonic), marine carbon with a different carbon isotopic composition may record times of diminished or lack of glaciation. Thus, the possibility exists to link unified carbon isotopic records with glacial advances and retreats representing integrated events over large areas. Such proxy signals should be recorded in sediment organic matter (SOM), carbonate, dissolved inorganic carbon (DIC), and sediment gases derived from breakdown of SOM and DIC.

Dissolved hydrocarbon gases were analysed at Site 1165 by the headspace method. Methane contents are very low (>400 parts per million by volume (ppmv)) to 140 metres below seafloor (mbsf). Below 140 mbsf, methane increases rapidly reaching 20,000 to 40,000 ppmv at depths below 270 mbsf. These headspace measurements represent residual gases (about 8 millimolar) remaining in the porewater of cores after outgassing upon retrieval to the surface. Methane levels remain within a relatively uniform range (20,000 to 40,000 ppmv) down to 700 mbsf, and then increase again to the 40,000-80,000 ppmv range in the deepest part of Hole 1165C (700 to 980 mbsf). The linear dissolved sulfate gradient above 130 mbsf projects to 0-mM concentration at a depth of 147 mbsf, where the condition of sulfate-free sediments inevitably results in onset of methanogenesis and the presence of abundant methane in deeper cores. Ethane is present in gas samples deeper than 157 mbsf, and C1/C2 ratios are initially constant at 2000 down to 500 mbsf and then decrease regularly to a C1/C2 ratio of 400 at 700 mbsf. The decrease in C1/C2 ratio is normal for the observed geothermal gradient at this site (52ºC/km). Cores from within the gas hydrate stability zone, estimated to extend from the sea floor down to 425 mbsf, were examined immediately upon recovery, but no hydrates were observed.

Thus far, only the lower sections of Site 1165 have been measured for carbon isotopic composition. At the present time only a general statement is warranted. The heavy methane carbon isotopic composition suggests that the methane may have a thermogenic source. However, carbon isotopic composition from carbon dioxide is light and may indicate that the residual methane in the sample has been oxidised by bacteria resulting in a false thermogenic signature.

Ongoing analyses will help determine the nature of the relationship between headspace hydrocarbon gas and less volatile carbon sequestered in sediment, and if this information is useful in deciphering glacial history.

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Glacimarine Sedimentary Processes on a High-Latitude Neogene-Quaternary Sediment Drift: Geological Investigations on the Antarctic Peninsula Pacific Margin

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Sediment Drift 7 on the Pacific margin of the Antarctic Peninsula is the focus of the geophysical and geological investigations of the SEDANO (SEdiment Drifts of the ANtarctic Offshore) Project. This drift is included in one of four main glacial depositional systems developed since middle Miocene. Drift 7 is produced by the interaction of weak along-slope bottom water flows with sediment entrained from turbidity currents, biogenic settling, ice rafted debris (IRD) and turbid plumes. A total of 17 cores have been collected from Drift 7 and analysed for sedimentological, compositional and biostratigrafic characteristics (c. 1000 analyses). Cores show an alternation of differently coloured muddy sediments corresponding to alternation of glacial and interglacial cycles (Pudsey and Camerlenghi, 1998). Interglacials appear brownish, intensely bioturbated and contain microfossils and sparse IRD. Glacial sediments are generally barren, grey in colour and finely laminated, with local occurrence of bioturbation, IRD layers and mm-thick silty turbidites. X-ray investigations allow us to define a number of additional facies and to outline transitional zones. Grain-size analysis indicate 4 sediment types as follows: glacial mud, very fine grained with 1% of sand; hemipelagic mud, with a higher percentage of sand (5%); thin turbidites, with grain-size mode in the coarse silt; and IRD layers, with 18% of sand. Clay mineral analysis indicates two distinct assemblages: glacials are dominated by chlorite, whereas interglacials show a higher percentage of smectite and diagnostic presence of kaolinite. Magnetic susceptibility logs show a sequence of troughs and peaks that can be correlated between cores (Pudsey and Camerlenghi, 1998; Lucchi et al., in press). These logs together with the compositional and biostratigraphic results (see Villa et al., this volume), allow correlation up to 200 km and the identification of up to 3 glacial and interglacial cycles (Fig. 1).

On the basis of these data, we identified 5 settings characterised by different sedimentary processes operating during last glacial (unit B):

1) deep sea channel: the sedimentation is mostly influenced by turbidity currents. Decimetre-thick turbidites with gravel, erosive bases and reverse grading was found at 250 km from the continental slope;

2) gentle slope facing the channel: expanded glacial sequences are directly influenced by both turbidity currents (closely-spaced mm-thick silty horizons and lenses) and contouritic flows (laminated muddy sediments);

3) crest of the drift: the sedimentation is dominated by slow contour flows and turbid plumes (finely laminated muddy sediments);

4) distal part of the drift: the sedimentation is dominated by contour currents (laminated and bioturbated sediments) and occasionally by turbidity flows (mm-thick silty horizons and amalgamated layers in the most distal condensed sequences);

5) steep side of the drift: here the sedimentation is disturbed by local mass instability (sharp lithological boundaries) and sediment reworking possibly by the contour flows that deplete deposits from the fine fraction.

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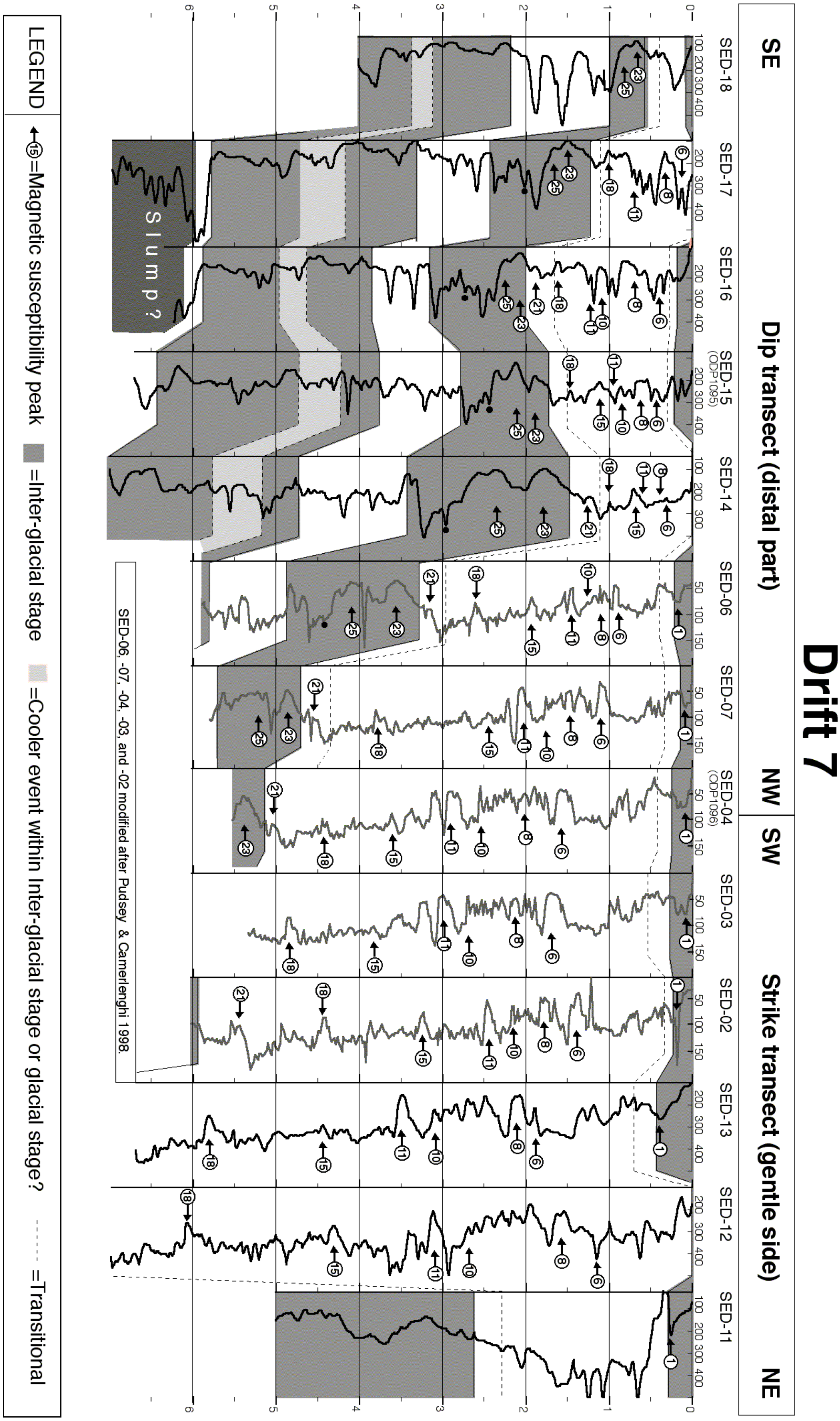

Figure 1. Core correlation on the gentle (NE) and distal (NW) sides of Drift 7.

Environmental Magnetic Record of the SEDANO Deep Sea Cores (Pacific Margin of the Antarctic Peninsula) and Interhemispheric Correlation of Late Pleistocene Climatic Events

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This paper reports on a high-resolution palaeomagnetic and rock magnetic analysis performed on three gravity cores (SED-02, SED-04, SED-06) recovered, during the SEDANO-1 cruise of RV OGS-Explora, on sediment Drift 7 (Rebesco et al., 1996) on the continental rise west of the Antarctic Peninsula (Fig. 1).

The cores, each about 6 metres long, consist of very fine grained sediments that span the time interval between the present-day and the last interglacial, with one (SED-06) extending to about 150 kyr. The cores were measured at one centimetre interval using a 2-G Enterprises DC SQUID cryogenic magnetometer at INGV in Rome. Relative palaeointensity curves were obtained and correlated with the reference curve SINT-200 of Guyodo and Valet (1996), thus improving the original age model of Pudsey and Camerlenghi (1998) and refining the previous estimates of sedimentation rates. The variations of rock magnetic properties downcore were used to improve correlation between cores, and to estimate variations in composition, concentration and grain size of magnetic minerals as semi-quantitative proxies of palaeoenvironmental and/or palaeoclimatic changes. The more pronounced rock magnetic variations were observed for the coercivity-dependent MDF_{NRM} parameter. Rock magnetic data indicated that coercivity variations in the SEDANO sediments reflect a disproportion in the mixture of two magnetic minerals: magnetite and pyrrhotite. Magnetite is present throughout the SEDANO cores, whereas the amount of pyrrhotite is reduced during interglacials and even suppressed in correspondence to characteristic decimetric finely laminated dark grey marker beds found in the last glacial of SED-02 and SED-04. We speculate that the variations in diagenetic processes of sulphides formation could reflect changes in the input of detrital organic matter controlled by past sea-ice extent on the Antarctic Peninsula Pacific margin. The improved age model, shows that the marked lows of the coercivity-dependent parameter MDF_{NRM}, corresponding to characteristic dark grey layers, are systematically time correlated to the Heinrich layers, deposited in the North Atlantic between 14 ky and 70 ky (Heinrich, 1988) (Fig. 2). With the present chronological uncertainties we cannot resolve possible time lags/leads in these interhemispheric climatic

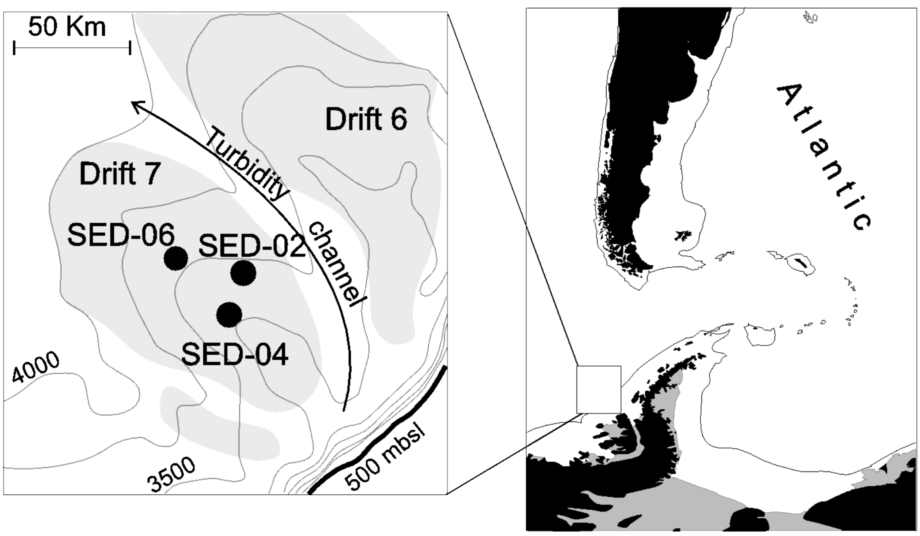

Figure 1. Location of the three SEDANO cores (SED-02, SED-04 and SED-06), collected on the continental rise of the Pacific margin of the Antarctic Peninsula (ca. Lat 67º20'S; Lon 77º20'W) on the gentle side of sediment Drift 7.

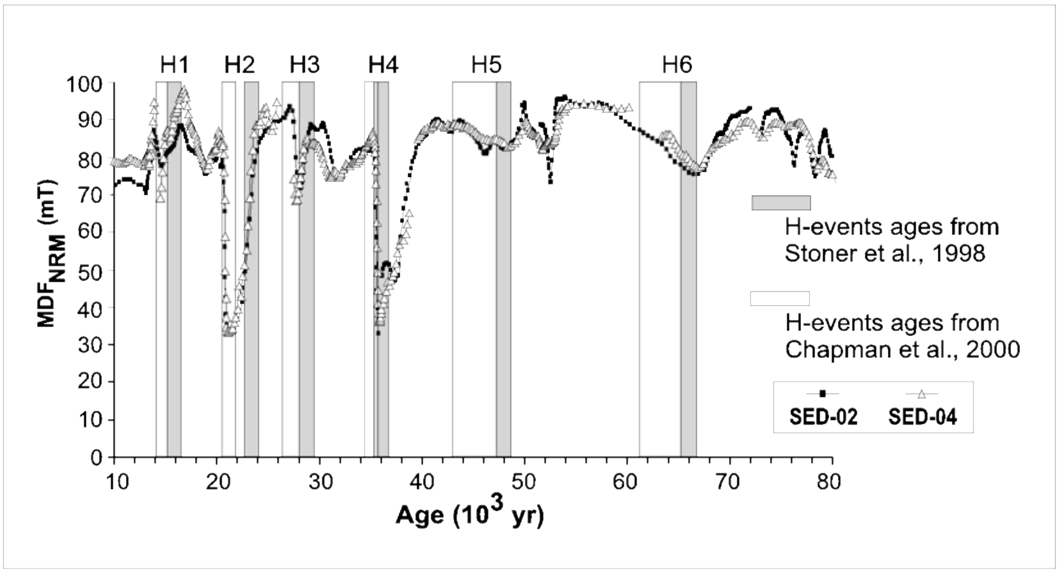

Figure 2. Chronostratigraphic variation of the MDF_{NRM} in SED-02 and SED-04 cores and correlation with the Heinrich events (H1-H6) from the north Atlantic. The H1-H6 ages are taken both from the "geomagnetic" chronostratigraphy developed for cores from the Labrador Sea by Stoner et al. (1998) and from the recent compilation of radiocarbon ages of north Atlantic H-layers by Chapman et al. (2000).

events. Nevertheless, the timing of the environmental magnetic signal in the SEDANO cores is close enough to that of the Heinrich events to suggest an interhemispheric consistent response to global climate changes during the last glaciation.

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Contourite Deposits in the Central Scotia Sea: Palaeoceanographic Implications

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Introduction

The Scotia Sea is a small ocean basin developed as results of the final processes of the continental fragmentation of Gondwana and the Late Paleogene separation of the Antarctic Peninsula from South America (Livermore et al., 1994; Barker, 1995). During the 2000-2001 austral summer season a sector of the central and southern Scotia Sea, north of the South Orkney Microcontinent was investigated using swath bathymetry, multichannel and high-resolution seismic profiles, together with magnetic field measurements. A segment of the sea floor was also mapped with the multibeam echo sounder fitted to the BIO HESPERIDES (Fig. 1). The oceanic seafloor according to the magnetic anomalies oriented E-W in the mapped area is about 13.6 to 20.2 Ma old (Chron C5C to C6), from north to south (Tectonic Map of the Scotia Sea, 1985).

The area investigated with swath bathymetry is located at the exit of a major morphologic gap in the South Scotia Ridge, northward of the entrance to Jane Basin. The bathymetry ranges between 2500 in the SE corner and more than 3500 m in the northern sector. The sea bottom is accidented, with wide valleys, incised channels, depressions and areas of very irregular physiography.

Contourite deposits

The swath bathymetry map reveals an irregular bottom relief and a variety of bedforms which are attributed to contourite deposits. Large drifts have an elongated and mounded morphology oriented in two predominant directions: N-S in the southern sector and NW-SE in the northern sector. These deposits are over 1 s (twt) thick in the centre of the drift and they have a wedge geometry with reflectors converging towards marginal zones of non-deposition (Fig. 2). Contourite waves fields are also well developed. Most sediment waves are slightly

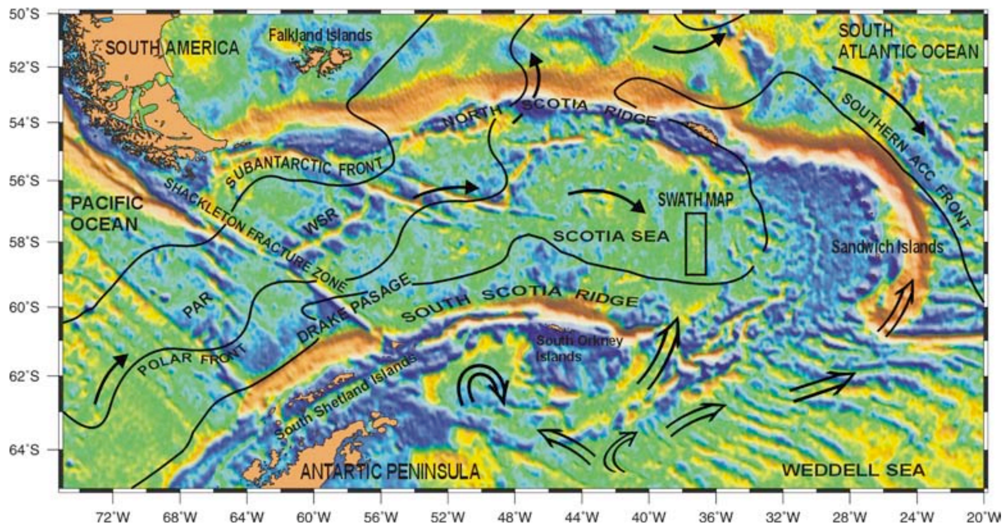

Figure 1. Simplified map from the GEOSAT gravimetric anomaly map recently released by the US Navy showing the distribution of the main oceanographic features. The ACC (arrows) and the WSBW (open arrows) flow directions are shown.

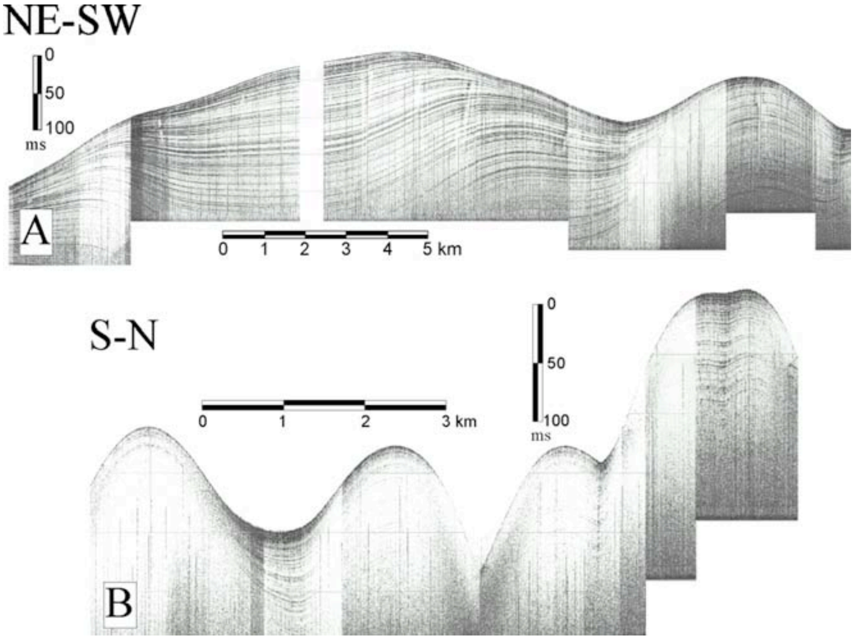

Figure 2. High-resolution seismic profiles showing representative contourite drift (A) and large-scale contourite wave (B) deposits in the central Scotia Sea.

asymmetrical and they migrated in the direction of the bottom current, either upslope or downslope, whereas the wave fields tend to be elongated in the direction of the current.

A contourite channel-levee fan occupies the central sector of the swath map. It is about 80 x 40 km and elongated in the downslope direction. Like turbidite fans, this system is developed from a main feeder channel and it is composed of several distributary channels and the associated levees.

The MCS profiles show strong basement reflections of the top of Layer 2 at a mean depth of 0.8 s twt beneath the sea floor, although locally the sedimentary cover of the igneous crust is absent. Four large amplitude, continuous reflectors can be recognised across most of the profiles. Seismic Unit I, at the top, is a rather thin sediment drape, some 0.5 s twt thick, which is attributed to the Quaternary. The other five units display high amplitude, discontinuous internal reflectors, characterised by wavy to subparallel internal configuration. Towards the base of each unit are also observed oblique and sigmoid configuration which downlap the reflector boundary. Unit III shows densely packed reflectors of marked wavy configuration, whereas the top and bottom boundary reflectors depict erosional character. This unit is of Late Miocene to Early Pliocene age and reveals a marked cyclic pattern of deposition of alternating high and low energy periods. The overall seismic character of these units exhibit active bottom currents, which resulted in the development of large contourite wave and drift deposits over the entire area.

Discussion and conclusions

The deposits in the central sector of the Scotia Sea result from the interplay between the northward flowing Weddell Sea Bottom Water (WSBW) and the eastward directed flow of the Antarctic Circumpolar Current (ACC). The initiation of the ACC following the opening of the Drake Passage is considered perhaps the most important event controlling the evolution of the Cenozoic climate and one crucial factor influencing the development of extensive Antarctic icesheets during the Miocene (Kennett, 1982; Barrett, 1996). More recently, however, it is contested if a deep circumpolar passageway alone is sufficient to produce a strong current and the subsequent permanent icesheets of the East Antarctic (Lawver and Gahagan, 1998).

In this presentation we show that the opening of seaways around Antarctica not only allowed the installation of a strong circumpolar flow, but also triggered a high production of Antarctic deep water. This water was swept northward from the Weddell Gyre into the South Atlantic and this flow could be the thermal motor influencing the late Cenozoic circulation patterns, the cooling of the oceans since the Early Oligocene and, as consequence, the chilling of the world' climate.

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Mineralogy and Geochemistry of Clay Fraction of Sediments of CRP-3 Core (Victoria Land Basin, Antarctica)

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In this work preliminary results on the chemical composition of the clay fractions in sediments of the CRP-3 core (Victoria Land Basin) are discussed. Twelve samples of clay fraction (<2 µm) were collected from different levels along the sequence. Mineralogical analyses were carried out through X-ray diffractometry to evaluate the relative abundance of clay minerals and smectite crystallinity, while chemical analyses on major, minor, trace elements and Rare Earth Elements (REE) were performed by X-ray fluorescence (XRF), neutron activation analyses (INAA) and inductively coupled plasma with *aqua regia* digestion (ICP-OES).

Sediment chemical composition can be used to identify sediment sources and the genetic processes, detrital or authigenic, of clay minerals, and to describe the geochemical conditions of depositional environments. In particular, REE can indicate the occurrence of hydrogenous, volcanic or hydrothermal episodes in the sedimentary sequences. The clay fraction of CRP-3 core consists of smectite, chlorite and illite. In the upper sedimentary sequence chlorite and illite are more abundant with respect to smectite, while in the lower part the clay fraction is almost exclusively smectite. The clay fraction from lowest levels, belonging to the basement, is mainly made up of kaolinite with variable amount of a mixed-layer phase (illite-smectite or kaolinite-smectite). Smectite is generally well crystallised and the crystallinity degree increases in the lower sedimentary sequence.

The elemental composition shows considerable variations along the core. Samples from upper levels are characterised by higher contents of SiO_2, Al_2O_3, K_2O, TiO_2, Ba and Rb, as these elements are related to the abundance of detrital minerals like chlorite and mica, and by lower Fe_2O_3, MnO and MgO. Transition metals are generally low or also below the detection limits, while Sr is quite variable. The levels in the central section show higher contents of Fe_2O_3 and MgO, because clay fraction is almost exclusively smectite with composition intermediate between beidellite and saponite. Also, a clear increase of transition metals like Sc, V, Cr, Co, Cu, Ni and Zn is observed, which may be attributed to some hydrothermal episodes, or to the alteration of femic minerals. Conversely, SiO_2, Al_2O_3, K_2O, TiO_2, P_2O_5, Ba, Rb and Y contents are generally lower then in upper levels, and the trend of Sr is rather uniform. Al_2O_3 and K_2O contents in the sedimentary part of the sequence show a good linear relation, suggesting a similar detrital source, while the trend of MnO is quite variable.

Lastly, the samples from the basement are characterised by high Al_2O_3 and P_2O_5 contents, probably related to the abundance of kaolinite/mixed-layers and apatite respectively, and Fe_2O_3, which may be attributed to presence of Fe oxides. MgO content is very low.

Shale-normalised REE distributions show very different patterns. The samples from upper levels display flat patterns similar to the North American shale ones, so indicating clay minerals are mostly detrital. Smectite-rich sediments are characterised by lower REE contents and the patterns show a light enrichment in heavy with respect to light REE. These features can reflect a volcanogenic influence, and smectites probably formed from the alteration of volcanic material (pyroxenes, glasses) and/or through precipitation from fluids of possible hydrothermal origin (Jeans et al., 2000). REE patterns do not show the negative Ce anomaly typical of sediments equilibrated with seawater, and this may indicate smectite precipitated under suboxic or anoxic pore-water conditions (Jeans et al., 2000).

These preliminary results highlight the clay fraction of the upper levels is likely to be of detrital origin, while smectite in the central part of the core is probably largely authigenic, as was suggested by previous TEM investigations (Setti et al., submitted).

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An Overview of the Italian National Antarctic Program

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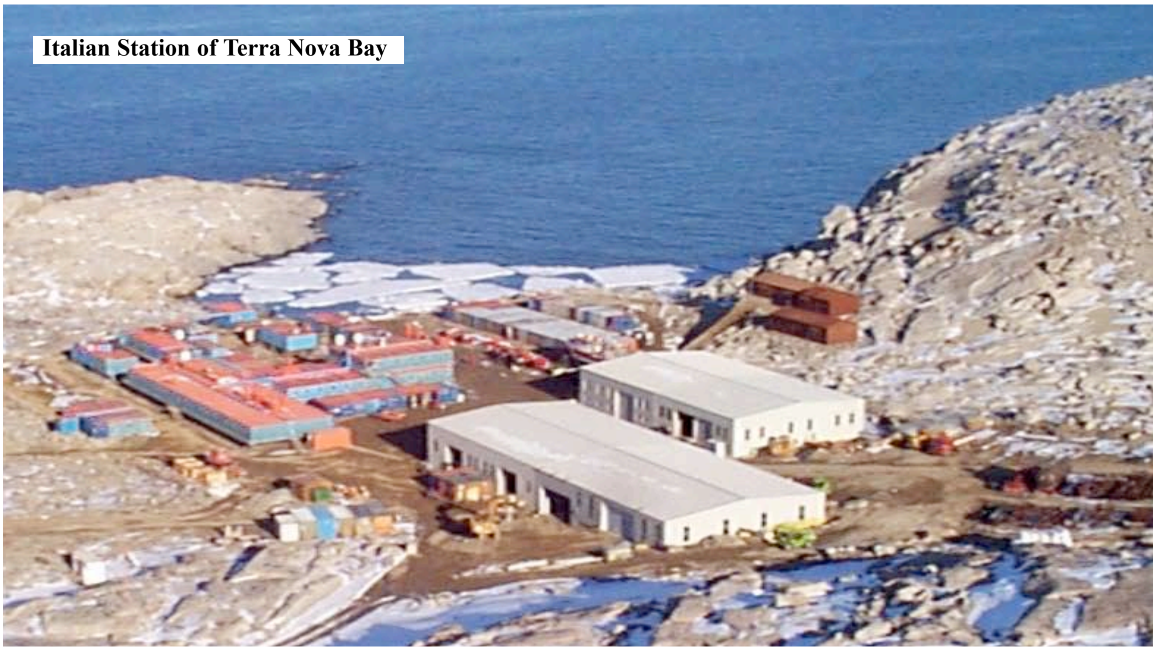
The Italian National Antarctic Program (PNRA) has started its operations in Antarctica in 1985. Since that year the Program has undertaken scientific expeditions every year and has opened a national Base in Terra Nova Bay (Northern Victoria Land) in the Ross Sea area that can host about a hundred persons. In fifteen years the Program has brought to the ice about 2500 people and has also started a joint venture with France aimed to build a new Base on the plateau at about 3800 m above the sea level and at 1600 km from South Pole: Concordia station. Other activities were undertaken in the Antarctic Oceans aboard on Oceanographic and Geophysical ships and also Airborne experiments were made.

Many scientific activities started during these years in accordance with SCAR strategy and several times in international co-operation. The science started at the beginning with a disciplinary approach: Earth Sciences, Atmosphere, Ocean Sciences, Cosmology and Astrophysics, Biology, Environmental studies and Technology. After the first years the focus was moved to five interdisciplinary sections; activities were then organised following an interdisciplinary structure in which the items were more consistent with the international approach: Geological Evolution of the Antarctic continent and the Southern Ocean, Global Change, Observatories and Geographical information, Environmental concerns and rules, and finally Robotics and Sensor Sciences. In 1999 the present organisation of the program started with what we call now the Scientific Sectors namely: Biology and Medicine, Geodesy and Observatories, Geology, Glaciology, Atmospheric Chemistry and Physics, Solar Terrestrial Relations and Astrophysics, Oceanography and marine ecology, Chemical Contamination, Geographical and Juridical Sciences.

Apart from the participation to national programs and bilateral activities, in the last five years some multidisciplinary projects based on multi-national participation on some converging interest programs were started. Among them the Cape Roberts Project (CRP), the International Trans-Antarctic Scientific Expedition (ITASE), the Airborne Polar Experiment (APE) and the European Project for Ice Coring in Antarctica (EPICA).

Many are the results gathered in the national system following the Italian entrance in Antarctic science; focusing only on the scientific results we can enumerate a large number of data reports, thematic maps, and scientific papers as well as new technologies and prototypes that have been built. About 45,000 km of seismic lines, thousands of biological and abiological samples were collected and a consistent historical data set in the Observatory system was realised.

An overview of the scientific activities and the results as well as on the operations and management strategies adopted during these fifteen years will be given here.



Late Quaternary East Antarctic Ice-Sheet Melting Event around the Lützow-Holm Bay and Mt. Riiser-Larsen Region

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The melting history of Antarctic ice-sheet during the Late Quaternary is a significant problem which has a bearing upon global sea-level changes and climatic changes through the formation of bottom and intermediate water.

Such history can be detectable using the oxygen isotopic composition of epipelagic organisms. The Sôya Coast in the Lützow-Holm Bay region (Fig. 1), east Dronning Maud Land, is located in the margin of East Antarctic ice sheet, where glacial advances and $\delta^{18}O$-depleted water from melting ice at deglacial events may affect the organisms lived in shallow-water. The beach deposits in the northernmost part of Sôya Coast are clearly divided stratigraphically into two marine sediment layers that contain *in situ* fossil shells of *Laternula elliptica*. The TAMS ^{14}C ages of fossil shells in the upper layer range from 4 to 5 ka without a reservoir correction, and those from the lower layer range from 32 to 46 ka (Miura et al., 1998a). Any marine layer and *in situ* fossil shells were not disturbed by ice sheet loading or scouring. Some fluvial sediments associated with the meltwater can be often observed under the Holocene marine beds or over the older marine beds (Fig. 2). The $\delta^{18}O$ (PDB) values of 24 fossils in the Pleistocene marine beds ranged from about 2.9 to 4.2 ‰, and 27 fossils in the Holocene beds from about 3.9 to 4.6 ‰, namely the variation of former is relatively wider than the latter one (Fig. 3) (Miura et al., 1998b, c).

In the Mt. Riiser-Larsen region (Fig. 1), Enderby Land, at an elevation of about 500 metres above sea level, the presence of a glacial trimline indicates the level of the former ice sheet surface (Ishikawa et al., 2000). Above this level, glacial erratic boulders were not seen, and the bedrock has no glacial polish or striations and is commonly deeply weathered (Zwartz et al., 1998). This melting event occurred at least after the last Interglacial on the basis of TL dating of calcite in the till deposits (Takada et al., 1998).

These facts lead us to the following conclusions: (1) the EAIS had possibly retreated from the northern Sôya Coast prior to the LGM, (2) there was more $\delta^{18}O$-depleted meltwater in the northern part of Sôya Coast during the last interstadial (30-46 ka) than in the Postglacial age, (3) the relatively strong fluvial process probably caused by the ice melting event might have occurred in the Lützow-Holm Bay region around 30-46 ka.

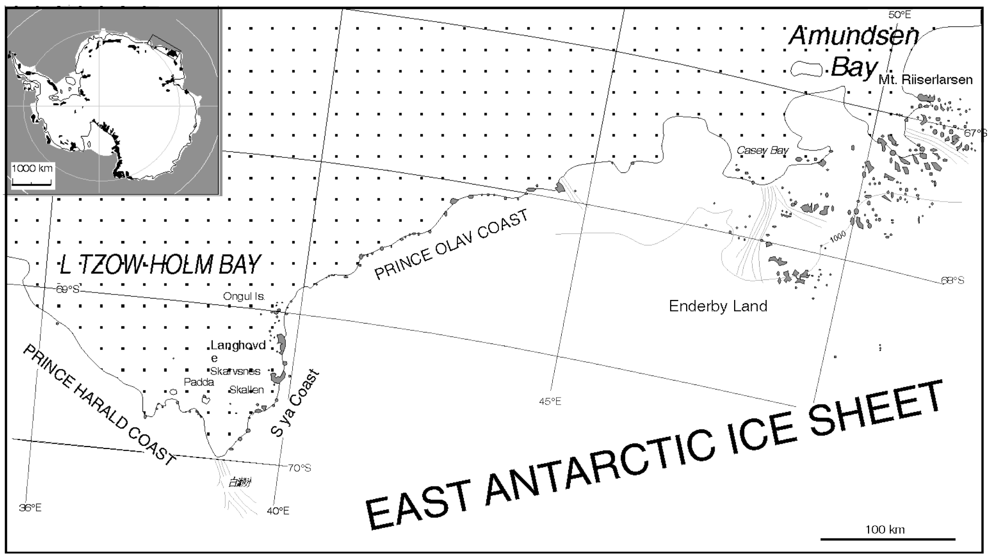

Figure 1. Index map.

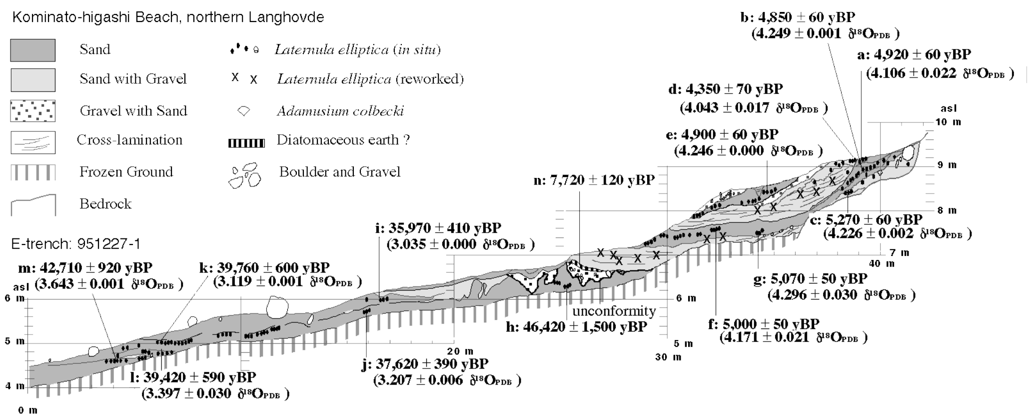

Figure 2. Profiles of the E-trench and AMS ^{14}C ages with $\delta^{13}C$ correction and oxygen isotope ratio ($\delta^{18}O$ PDP‰) of fossil shells, at Kominato-Higashi Beach, northern Langhovde.

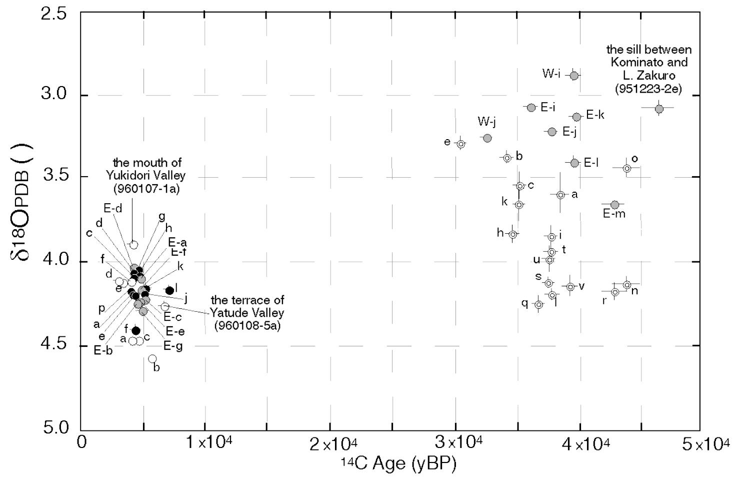

Figure 3. Oxygen isotopic ratio ($\delta^{18}O$ PDP‰) of *in situ* fossil shells obtained from beach deposits in the Sôya Coast region, plotted against AMS^{14}C ages (yBP) calibrated by ^{13}C.

Nakada et al. (2000) have examined the sea-level variations at eight sites along the coast of Antarctica to investigate the melting history of Antarctic ice sheet complexes. From these calculations, two features are derived: (1) the meltwater occurred at 30-35 ka, and (2) a relatively stable period of about 30-12 ka is required. These features are well consistent with our geological and geochemical field data.

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Oceanographic Changes in the Southern Pacific Ocean, during the Last Deglacial Time, as Recorded by Planktic Foraminifers and Oxygen Isotopes

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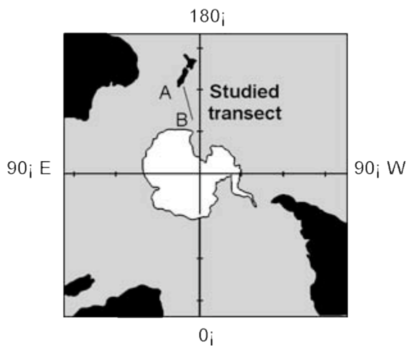
The Southern Ocean is a key area for understanding global hydrologic condition and climatic changes through past glacial and interglacial cycle. Although this area has an important role in the world oceanic circulation and plays a decisive part in the climatic changes, the palaeoceanographic evolution during the last deglacial time is still poorly known.

In this study, we present results of micropalaeontological and geochemical analysis of two deep-sea cores, collected in correspondence of the present day position of the Polar Front (PF). In particular, core 157 was collected in the Antarctic Polar Front Zone, whereas core 17 was collected just south of the summer southernmost position of the PF (Fig. 1). Position of the cores are so ideally located for detailed study about the position of the PF and to analyse the eventually variations of primary production, during the last 14 ky. Strong fluctuations of the biological and geochemical proxies show higher productivity conditions during colder periods in both cores, although the two sites record two different hydrologic regimes. Qualitative and quantitative foraminiferal assemblage distributions suggest that only the northern core records the southward shift of the Polar Front, whereas the southern site, core 17, has been south of the PF during the whole investigated time interval. The two sedimentary sequences contain very different benthic and planktic foraminiferal assemblages. In core 17, the planktic microfauna is almost monospecific (*N. pachyderma* left-coiling), whereas core 157 has a more diversified microfauna with higher abundance of *G. bulloides* and *G. inflata*. During the last deglaciation, the abundance of *G. bulloides* in core 157 indicates cold and productive waters, whereas the increase of *G. inflata* during the Holocene suggests a homogeneous water column with reduced biological productivity. This palaeoenvironmental interpretation appears in agreement with the coeval decrease in abundance of number of planktic foraminifera. A possible oceanographic history could imply that from the deglacial to the Holocene, site 157 experienced the retreat of the PF from North to South. In fact, in present-day conditions, hydrologic structures, such as the PF and the Southern Boundary, are characterised by stratified water with downwelling of surface water at the Southern edge and by deep vertical mixing just north of the fronts. Furthermore, the fronts are generally considered areas with high productivity and the southward displacement of the PF during this time interval would explain the inferred decrease of productivity. On the contrary, during the last 14 ka, the site 17 has been always south of the PF, and it recorded only minor environmental changes.



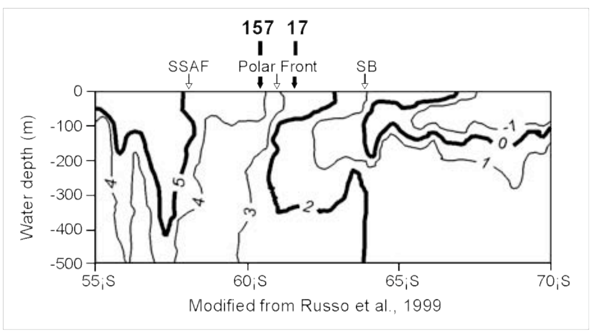


Figure 1. North-South section of the study area and core locations. The variation of position of the main hydrological features in the summer season, as documented by Russo et al. (1999), are shown. NSAF, Northern Sub-Antarctic Front; SSAF, Southern Sub-Antarctic Front; PF, Polar Front; SB, Southern Boundary of the Antarctic Circumpolar Current (ACC).

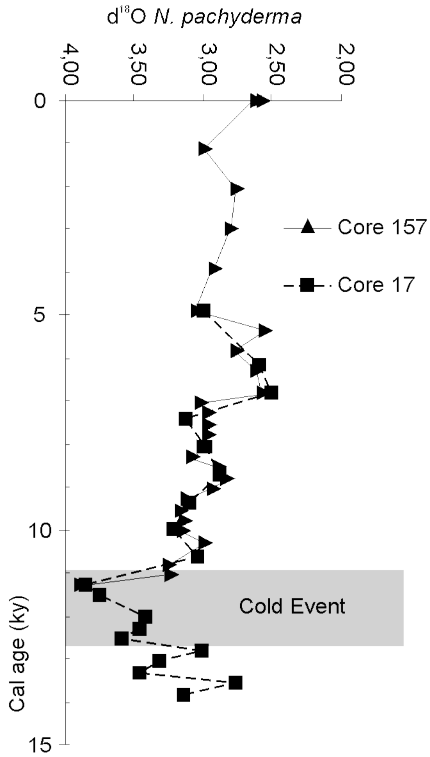


Figure 2. Comparison of the planktic foraminiferal $\delta^{18}O$ of the two cores versus calibrated years. The cold event is indicated by grey rectangle.

The oxygen isotope record documents a cooling interval, which occurred between 12.5 cal ky and 11.0 cal ky (Fig. 2). The time control, although not yet refined, could suggests that this event corresponds to the Younger Dryas chronozone defined in the Northern Europe. This implies that the climate changes recorded at this latitude still show some synchronicity with the Northern Hemisphere variations.

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Orbitally-Induced Oscillations in the East Antarctic Ice Sheet: Direct Evidence from Antarctic Margin Drilling

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Oxygen isotope records from deep-sea sediment cores imply that continental ice volume and global temperatures during latest Eocene to Miocene (34 to 15 Myr) time were influenced by high-latitude, 400-kyr, 100-kyr and 40-kyr, astronomical cycles. In this poster, we present the first direct evidence of orbital control on cycles of glacial advance and retreat of the Ross Sea margin of the East Antarctic Ice Sheet (EAIS) within that time period.

The evidence comes from the upper 1200 m of pre-Pliocene sediment recovered by Cape Roberts Project (CRP) drilling off the Victoria Land coast of Antarctica between 1997-1999. The CRP drillcore comprises 52-unconformity-bound glacimarine sequences spanning c. 33 to 17-myr. The sequences have been recognised on the basis of the cyclical vertical arrangements of their constituent lithofacies, which are enclosed by erosion surfaces produced during the grounding of the advancing ice margin onto the seafloor. The thickest of these sequences (e.g. >50 m) have also been identified as laterally continuous units in seismic reflection profiles. Each sequence represents deposition in a range of offshore shelf to coastal, glacimarine sedimentary environments during oscillations in the ice margin across the Western Ross Sea shelf, and coeval fluctuations in water depth.

Here we investigate the duration and periodicity of sedimentary cycles over representative portions of the CRP record for which robust age data are available. Such data are provided by a combination of $^{40}Ar/^{39}Ar$ geochronology of volcanic ash beds, microfossil biostratigraphy, $^{87}Sr/^{86}Sr$ analyses of molluscs and magnetostratigraphy. Previously cored cyclic sequences from the Antarctic margin have lacked the chronological precision needed to determine their frequency.

Time series analysis of closely-spaced grain-size data spanning sequences 9-11, CRP-2/2A and sequences 1-7, CRP-3, suggest that individual sequences had durations of similar length to Milankovitch frequencies, probably 41-kyr, but possibly as low as 100-kyr. Higher frequency periodic components at 23-kyr (orbital precession) and 15-10-kyr (sub-orbital) are recognised at the intrasequence-scale. The sub-orbital periodicities may represent climatic cycles, akin to the ice rafting episodes described in the North Atlantic Ocean during the Quaternary.

Our results suggest that this ancient Antarctic ice sheet, which existed when planetary temperature was 3˚C warmer than today, had a fundamentally different style of behaviour from the modern ice sheet, oscillating with the same orbital frequencies as the northern hemisphere ice sheets during the last 2.5 million years.

Neogene Climatic Transitions in East Antarctica: Evidence from Leg 188 Drilling

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The largest post-Paleogene transition in ODP Leg 188 cores is a major change in sedimentation in the middle Miocene in Site 1165 (Fig. 1, 307.8 mbsf, 13-14 Ma.). The proportion of siliceous, biogenic sediment increases at the expense of terrigenous silt and clay, the proportion of ice-rafted pebbles and sand grains increases, total clay increases, there is less plagioclase in the clay-sized fraction, and glauconite first appears. Overall sedimentation rates fall more steeply from the mid Miocene onwards. On adjacent seismic sections, the mid Miocene change also marks renewed channel incision and a reduction in sediment wave formation on the Wild Drift flank.

The changes at Site 1165 indicate a reduction in the input of detritus from the continent relative to biogenic input. Detrital glauconite is an indicator of a sedimentary source; in this case most likely the sedimentary basins of the adjacent continental shelf. Plagioclase is most likely derived from the basement of East Antarctica so the change in clay size fraction mineralogy reflects a relative increase in erosion of shelf sediments. At the same time, on the continental rise, vigorous, west-flowing, downslope currents slackened.

The next major change in sedimentation is marked by the development of the Prydz Channel Fan. Before fan building, the Lambert Glacier prograded a nearly linear shelf edge across Prydz Bay (Fig. 1, Cooper et al., this volume), but thereafter the shelf edge was convex. In the late Miocene to early Pliocene, the main ice flow was deflected westward, cutting Prydz Channel and building the large fan that fills canyons and buries older drifts and channels. The change in ice flow probably indicates an increase in the proportion of ice flowing into Prydz Bay from the south-east, deflecting the Lambert Glacier westward.

The age estimate for initial fan growth is based on ties to Sites 739 and 1165 of a surface at the base of the trough mouth fan mapped as surface A by Mizukoshi et al. (1986). It can be followed onto the shelf and is bracketed by mid Miocene and early Pliocene horizons in Site 739. In Site 1165, Horizon A could be represented as a short hiatus at 67 mbsf between Chrons C3An.2n and C3r, corresponding to

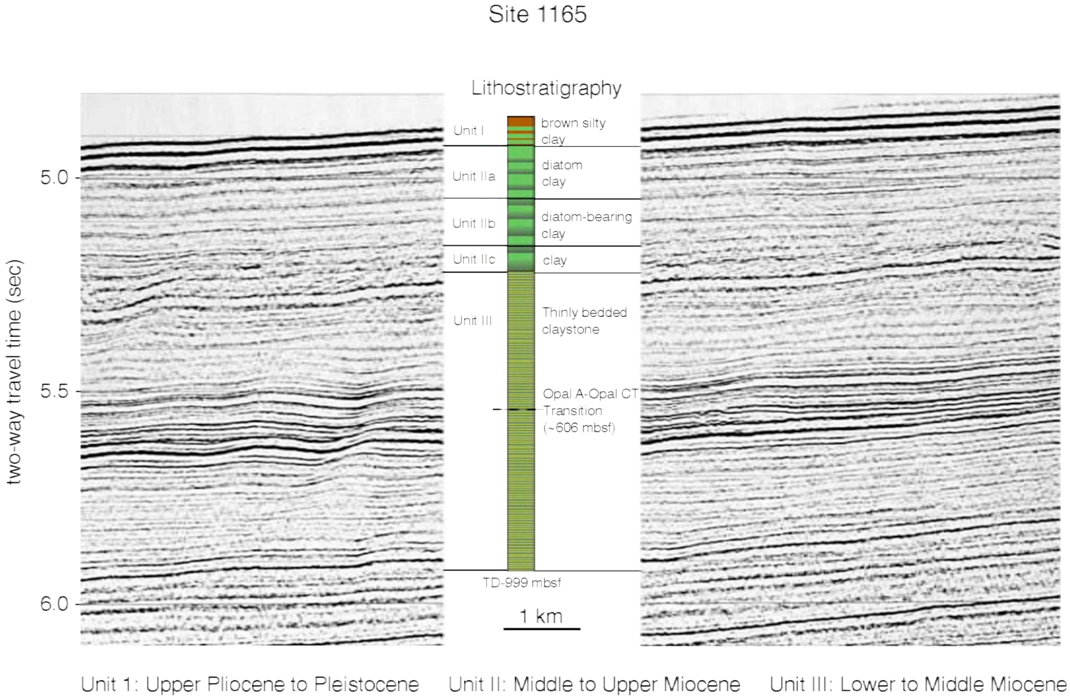

Figure 1. Site 1165 and East-West seismic section.

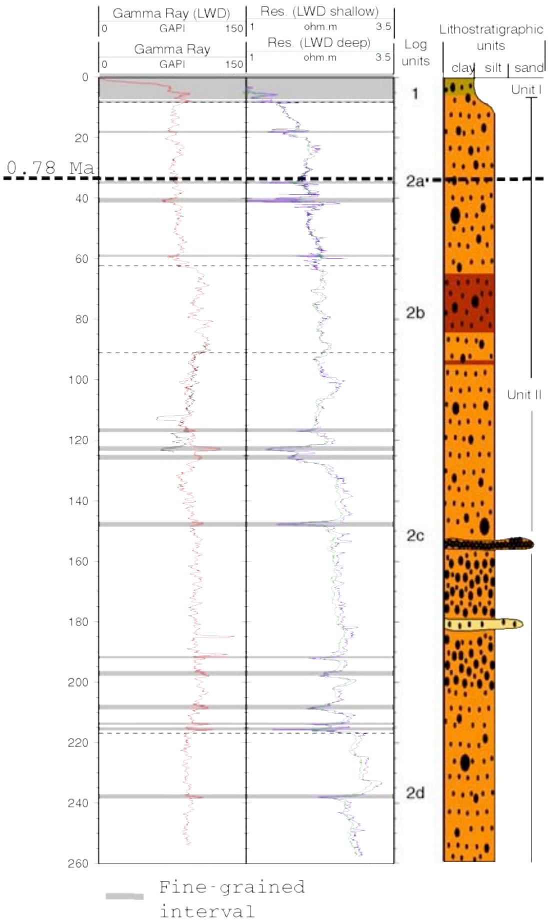

Figure 2. Geophysical log data, Site 1167.

about 5.9 Ma (late Miocene, Messinian).

The next major transition in Antarctic climate history involves the Prydz Channel Fan. Most of the fan comprises debris flows derived from the grounding line of the Lambert Glacier when it reached the shelf edge. Interbedded with these units are hemipelagic muds deposited when the ice had retreated from the shelf edge (Fig. 2). Site 1167 palaeomagnetic measurements identified the presence of a magnetic polarity reversal at 32 mbsf, interpreted with nannoplanton records to be the Brunhes-Matuyama boundary (780 ka.). This means that the bulk (>95%) of the Prydz Channel Fan was deposited prior to the middle Pleistocene. There have been only 4 debris flow intervals since the Brunhes-Matuyama boundary, which suggests that extreme advances of the East Antarctic Ice sheet occurred mostly before the mid Pleistocene climate transition.

The series of Neogene transitions indicated by Leg 188 drilling can be interpreted as thresholds reached on an overall, progressive cooling trend that changed the state of the East Antarctic Ice Sheet causing it to be progressively less geologically active:

- The mid Miocene event represents the expansion of ice onto the shelf and reduction in meltwater and ice erosional capacity caused by cooling of a temperate ice mass.
- The late Miocene-early Pliocene initiation of a shelf-crossing ice stream and trough mouth fan resulted from the increase in the importance of coastal ice input into south-east Prydz Bay as cooler temperatures reduced vapour transport (i.e. less snow) to the interior.
- The mid Pleistocene reduction of to shelf edge advances by the Lambert Glacier reflected a further reduction in vapour transport to the East Antarctica interior caused by further cooling.

However, superimposed on these changes are significant warmer episodes. Further evidence is needed to decide which specific palaeoenvironmental events caused these transitions in the state of the East Antarctic Ice Sheet.

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Australian Antarctic and Southern Ocean Profiling Project: Major new Antarctic Seismic Surveys

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In the 2000/01 Antarctic season, the Australian Antarctic and Southern Ocean Profiling Project acquired major new geophysical data sets to define the morphology and geology of the Antarctic continental margin. The main component of these data sets is more than 10,500 km of deep-seismic data and 3400 km of high-speed seismic data along a series of margin transects (up to 500 km in total length) that extend from below the shelf break into the deep ocean basins. In many areas, these transects provide our first look at the continental margin that evolved with the separation of India-Antarctica and Australia-Antarctica in the Cretaceous and Cenozoic.

The deep-seismic data were acquired from the 2-D seismic survey vessel Geo Arctic from January-April, 2001. The data were acquired from a 3600 m streamer with a 3660 cu in airgun array source, and were recorded 36-fold with a record length of 16 seconds. Gravity, magnetic, bathymetric and sonobuoy data were also recorded on this survey. The high-speed seismic data were acquired from the survey vessel Polar Duke, from January-March, 2001. These data were acquired from a 300 m streamer with a 370 cu in airgun array source, and were recorded 4-fold. Bathymetry data were also recorded on this survey.

While the surveys covered about 5500 km (~30%) of the margin of Antarctica and sampled a wide range of geological styles, the data can be divided into discrete sets that reflect the spreading history of the margin, as follows:

India-Australia separation: From 45ºE to approximately 95ºE, the margin was formed by the separation of India and Antarctica, probably commencing in the Early Cretaceous (although seafloor magnetic spreading anomalies have not been positively identified in this region). Eight long lines and several shorter lines were acquired in the Enderby Basin, southwest of Kerguelen Plateau, while a further five lines were acquired from southeast of the Kerguelen Plateau to the Bruce Rise. The oceanic basement types in this sector are highly variable, probably reflecting different spreading episodes. On several lines, deep structures in the oceanic crust showed a strong resemblance the Early Cretaceous crust of the Argo and Cuvier Abyssal Plains off northwest Australia, suggesting contemporaneous spreading.

Australia-Antarctic normal separation: From 95ºE to 136ºE, 14 transects were collected over the normal-rifted margin formed by the separation of Australia and Antarctica in the Late Cretaceous. This segment was particularly characterised by the complex transition from continental to oceanic crust in deep water, and shows strong similarities with the conjugate southern Australian margin. When combined with equivalent transects acquired on the Australian margin, there will be a unique opportunity for modelling the evolution of a passive, non-volcanic continental margin.

Australia-Antarctica strike-slip separation: East of Terre Adélie (142ºE to 160ºE), three short deep-seismic lines and several high-speed seismic lines were acquired over the strike slip margin between Australia and Antarctica that formed in the Late Cretaceous and Cenozoic. These lines were largely curtailed by expanding sea ice late in the season, and give only a limited view of the geological evolution of this sector.

Sedimentary section: This part of the margin of East Antarctica also shows large variations in the Cenozoic sedimentary section. Some parts of the margin (e.g. Princess Elizabeth Trough, Mac. Robertson Land and Bruce Rise) have erosional upper slopes where older Cenozoic and possibly Mesozoic sediments crop out. Prograding upper slopes are common; however, equally common are slopes underlain by parallel reflectors that are continuous with sediments on the shelf. Large turbidite fans and sediment drifts are present, and some lines display the first evidence for large-scale mass movement on the East Antarctic margin. Bottom Simulating Reflectors are common.

Opportunities for Antarctic geoscience: The data acquired on the Antarctic margin by these surveys comprise by far the largest high-quality seismic data set ever recorded off Antarctica. The data provide unique opportunities for studies of, for example: the early separation of India and Antarctica and Australia and Antarctica; models of evolution of conjugate, non-volcanic passive continental margins; reconstructions of the greater Indian Ocean; and an enhanced understanding of Antarctica and its role in the global climate system.

Global Dynamics of the Antarctic Ice Sheet

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The large-scale dynamic behaviour of the Antarctic ice sheet is studied with a simple axi-symmetrical ice-sheet model. The model is based on a consideration of the total mass budget of the ice sheet, in which the mechanics are highly parameterised. This is in contrast to earlier studies with simple models, in which the mechanics are central and the mass budget is not the controlling factor (e.g. Weertman, 1974). The ice-sheet has a parabolic profile resting on a bed that slopes linearly downwards from the centre of the ice sheet into the ocean. The mean ice velocity at the grounding line is assumed to be proportional to the water depth. The snow accumulation rate increases linearly with the distance to the centre. Setting the total mass budget to zero yields a quadratic equation for the steady-state ice sheet radius R.

After choosing model parameters by matching the model to the presently observed state of the ice sheet, the mass gain (total accumulation A) and mass loss (flux of ice across the grounding line F) can be studied. Figure 1 shows how these quantities vary with R. When R increases both the accumulation and the flux at the grounding line increase, but at a different rate. At the intersection of the curves the ice sheet is in equilibrium: the gain equals the loss. The intersect in Figure 1 (reference state) is for an ice-sheet radius that is close to the present value (R=1918 km). It can be seen that this state is stable, because, for increasing R, the accumulation increases less rapidly than the flux across the grounding line.

Analysis of the equilibrium states sheds light on the sensitivity of the ice-sheet radius to changes in sea level (S) and precipitation with respect to the present state (P_{rel}). It turns out that a 100 m drop in sea level leads to a 240 km increase in R. Similarly, for a 10 % increase in the snow accumulation R increases by about 40 km.

The model can also be used to study transient behaviour of the ice sheet. The change in ice-sheet volume in time simply equals A-F. The characteristic e-folding time scale is found to be about 3500 years, which is in good agreement with the results of more sophisticated numerical models. It is interesting to force the model with a sea-level and accumulation history over the past few hundred thousands of years. This yields insight in the behaviour of the Antarctic ice sheet through two full glacial cycles.

The forcing functions are shown in Figure 2 (upper panel). The sea-level curve was adopted from Imbrie et al. (1984). It is based on oxygen isotope ratios from deep-sea sediments (a proxy for total ice volume on earth) and, for the later part, elevated beaches and coral reefs

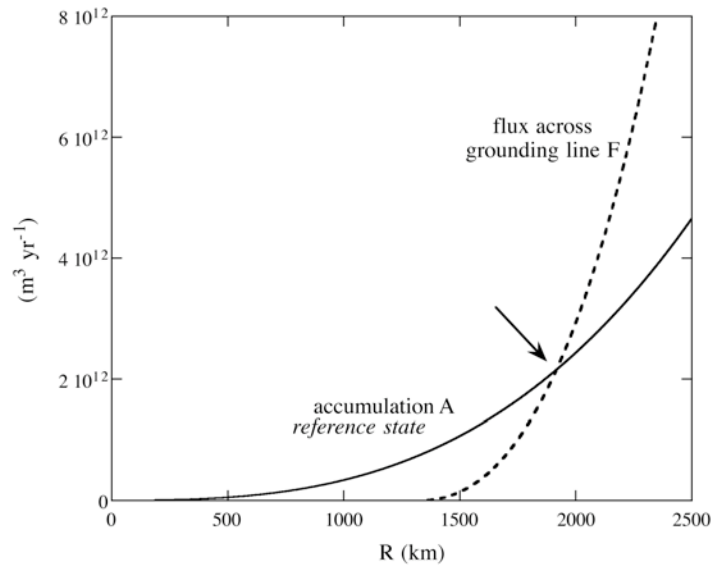

Figure 1. The components of the mass budget in dependence of the ice-sheet radius R. The reference state corresponds to the present-day area of the Antarctic ice sheet.

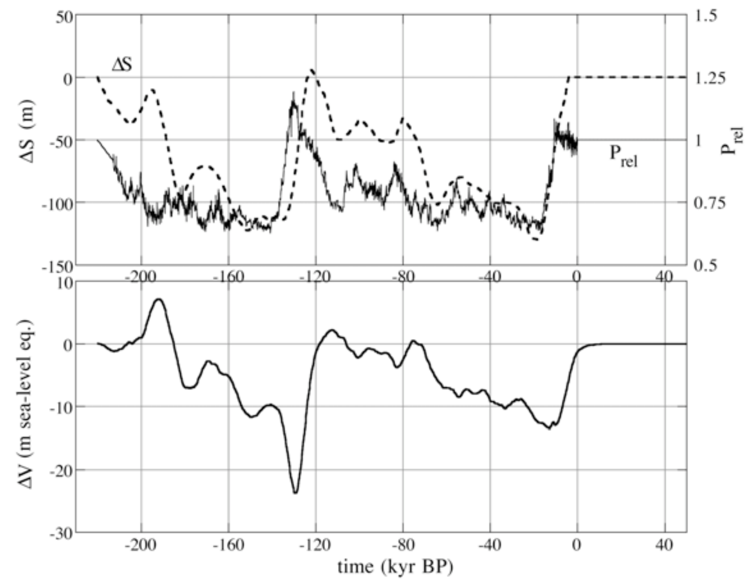

Figure 2. The response of the ice-sheet volume to forcing over the last two glacial cycles. The upper panel shows the forcing functions: the accumulation rate P_{rel} and the sea-level perturbation ΔS (dashed). The lower panel shows the resulting ice volume expressed as m of sea-level equivalent.

dated with radiocarbon. It is clear that there is a considerable uncertainty in this curve, notable for the period 50 to 230 kyr BP. The accumulation is related to the temperature signal from the Vostok ice core (Petit et al., 1999). It is generally accepted that the accumulation on the Antarctic ice sheet is smaller in colder climates, but it is hard to get reliable figures from the ice cores drilled in various places. Here a simple exponential relation between the Vostok temperature proxy and the accumulation rate is used, which implies that the accumulation rate would be 40% smaller for a 10ºK temperature drop and 28% larger for a 5ºK temperature increase.

The response of the model ice sheet to these forcings is shown in Figure 2 (lower panel). The difference in the ice-sheet volume between the Last Glacial Maximum (LGM) and the present state corresponds to 12 m of sea-level equivalent (but only about two thirds of this translates into actual sea-level change because part of the ice lost was below sea level).

The model suggests that at present the Antarctic ice sheet is still loosing mass, although the rate of retreat has slowed down quickly during the last 1000 years. The rate of change of ice volume at the present time represents a sea-level equivalent of 36 mm per century. Taking into account that part of the ice lost was below sea level than yields a value of about 24 mm per century for the Antarctic contribution to sea-level rise. If the climatic conditions would remain constant the model predicts a 1 m sea-level rise until the ice sheet has reached a steady state.

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Modelling the Climate and Glacial History of Antarctica: Progress and Challenges

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Climate models, in conjunction with ice sheet models, are powerful tools in the study of the past history of Antarctica. Most fundamentally, these models serve as a test of our understanding of the basic processes involved in the climate and glaciation of Antarctica, and how these have changed through time. Using modelling in conjunction with geology (data) is at its essence an iterative process in which the modellers want the geologic data to evaluate how well (or poorly) their models are working, while the geologists want the models to guide them in their interpretations and to suggest future data needs. Previous Global Climate Model (GCM) modelling of past Antarctic climates helped consolidate our understanding of key processes responsible for the presence or absence of Antarctic glaciation, but was severely restricted due to model (and data) limitations. Over the past few years tremendous advances have taken place in our ability to simulate Earth climate in general, and of more importance for this community, the climate at high southern latitudes. For the first time, polar meteorologists are saying that current GCMs can adequately (though not perfectly) simulate high latitude climates. The new generation GCMs can also be run at higher resolution, which both improves the overall simulated climate and also allows a better discrimination at the regional and local level. For palaeoclimate studies this higher resolution is, however, much more demanding of geology and palaeoceanography because locally-detailed reconstructions over a wide geographic area must be made both to provide model boundary conditions such as topography, surface/vegetation type, etc. and to validate the model results. This also means that strict geologic time controls are needed so that boundary conditions and forcings match up properly. Results from these new studies will also have major implications for climate on all scales, including global, because the climate of Antarctica plays a major role in modulating climates over the entire Earth, primarily because of its ability to act as a refrigerator. The effects of this refrigeration may propagate directly through the atmosphere (as a consequence of interactions with the polar vortex) but are probably more important by affecting ocean circulation and sea ice.

Late Neogene to Holocene Sedimentation on the Prydz Bay Continental Shelf and Slope, ODP Sites 1166 and 1167, East Antarctica

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The Prydz Bay continental shelf and slope are key areas for the investigation of sediment transfer from the East Antarctic Ice Sheet to the deep sea. Excavation of the Prydz Channel by fast-flowing ice since the late Miocene/early Pliocene supplied sediment to the shelf break, which was redeposited on the upper slope. The late Neogene to Holocene sediments recovered at Sites 1166 in eastern Prydz Bay and Site 1167 on the Prydz Channel trough mouth fan provide an important record of sediment transfer and glacial-interglacial dynamics (O'Brien et al., 2001). Lithofacies analysis, laser particle-size measurements and compositional data are used to characterise the depositional environments and sediment sources, and to reconstruct the ice-sheet dynamics since 4-5 Ma.

The Neogene section (above 135.41 mbsf) of site 1166 is dominated by clast-rich sediments with a glacial origin. The dominant lithofacies in the upper 94 m of the hole is gravel-rich diamicton (Dg), which is structureless, massive and has a medium sand mode. Below 94 mbsf sediments contain less gravel-sized clasts and diamictons locally display stratification. In a short interval of upper Pliocene sediments (112-117 mbsf) finer-grained facies occur in repetitive sequences of gravel-poor, muddy diamicton (Dm), greenisch grey muds (M-1) and greyish brown muds (M-2). The muddy diamicton facies (Dm) generally has a bi-modal grain-size distribution with a medium sand mode and a clay mode. The greenish grey mud (M-1) overlies facies Dm and contains few diatoms and dispersed sand- and granule-sized clasts. The greyish brown muds (facies M-2) are structureless and massive, and overlie facies M-1 with flame-like contacts. Both mudstone facies have grain-size distributions with coarse clay to fine silt modes. The gravel-rich diamictons are interpreted as deposited by grounded ice or in an ice-proximal depositional environment. The stratified diamictons probably originated in a glaciomarine depositional environment with current reworking, perhaps underneath an ice-shelf. The interval between 112 and 117 mbsf likely represents glacial-interglacial cyclicity in an ice-

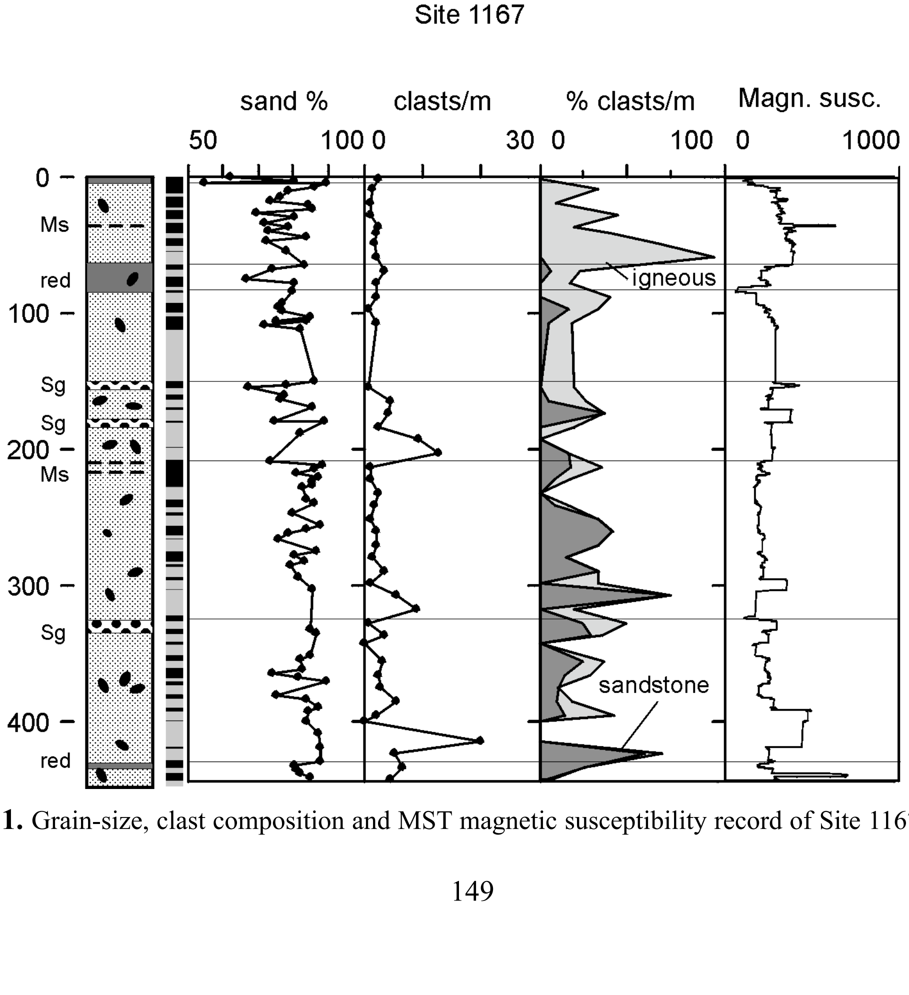

Figure 1. Grain-size, clast composition and MST magnetic susceptibility record of Site 1167.

distal setting more similar to the present-day.

The sediments at site 1167 are generally poorly sorted and gravel-rich. Four lithofacies are distinguished. Clast-poor diamicton (D) is the dominant lithofacies with similar matrix (<2 mm) grain-size distributions as the diamictons from site 1166. Some of the diamictons have a reddish overprint and low values in the low-field magnetic susceptibility. In a few places the clast-poor diamictons are interbedded with sandy mud with dispersed clasts (M), thinly bedded mud with silt laminae (Ms), or poorly sorted coarse sand and granule beds (Sg). Facies Ms has a bi-modal grain-size distribution with fine silt and clay modes. Facies Sg is structureless and locally contains dispersed cm-sized mud clasts. Because of the similarities in grain-size and composition the most likely sources of the gravel-rich materials are glacial sediments eroded from the continental shelf. Facies D represents down-slope transport as debris flows of glacial sediments when the grounding line of the Lambert Glacier-Amery Ice Shelf system reached the shelf break. Facies Sg may indicate meltwater release at the grounding line and remobilization of bedload-gravel and sand on the upper slope through grain-flows. In contrast, the thinly bedded mud with silt laminae generally lacks sand or gravel, and most likely represents deposition by contour currents in a more ice-distal environment.

The stratigraphic distribution of the lithofacies at sites 1166 and 1167 suggests that ice repeatedly advanced and retreated in the last 4-5 m.y. The most significant glacial retreat preserved at site 1166 took place in the late Pliocene. Both glacier mass balance and sea level fluctuations may have caused the repetitive facies associations. Based on the lithofacies distribution and the compositional data the stratigraphy of Site 1167 can be subdivided into seven units. A major break in the stratigraphy occurs at ca. 217 mbsf. The sand % of the sediments decreases upsection and igneous rock clasts become more important, whereas sandstone clasts decrease in abundance. The sediments at this boundary were assigned an early to mid-Pleistocene age based on nannofossils. The shift in composition of the sediments either indicates a change in flow pattern of the Lambert Glacier or a change in the position of the grounding line caused by sea level fluctuations. Analysis of the facies associations at Site 1167 suggests that several advances and retreats of the grounding line occurred since the sediments at the bottom of the hole were deposited (probably in the early Pleistocene).

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Modelling of Antarctic Ice-Sheet Initiation in the Early Oligocene Using a Coupled GCM and Dynamic Ice-Sheet Model

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Introduction

High resolution stable isotope data indicate that dramatic cooling and growth of a continental ice sheet on Antarctica to nearly 50% of its present volume occurred within a brief 300 ky period beginning at ~33.7 Ma (Zachos et al., 1996). Rapid ice-sheet growth may be triggered as a slowly descending meteorological snowline intersects regions of high topography (e.g. Abe-Ouchi and Blatter, 1993). Milankovitch orbital variations with periodicities of 10^4 to 10^5 years may also play an important role. In this study, a global climate model (GCM) is coupled to a dynamic ice sheet model of Antarctica, to investigate these mechanisms in the context of gradually decreasing atmospheric CO_2 in the early Oligocene (DeConto and Pollard, this volume). Our first goals are (i) to estimate the critical CO_2 level at which significant Antarctic ice can first grow, and (ii) to ascertain whether nascent ice sheets, initiated on high Antarctic topography during an orbital interval of cold southern summers, can survive subsequent intervals of warm southern summers.

Models and Simulations

The GCM used here, GENESIS version 2, produces reasonably realistic present-day mass balances on Greenland and Antarctica (Thompson and Pollard, 1997), using a simple 50-m mixed-layer ocean with diffusive ocean heat transport. The stored monthly climate is interpolated from the 3.75º GCM grid to the finer 1x1° topography of the 3-D ice-sheet model using constant lapse-rate corrections, to calculate the surface mass balance. A standard 3-D dynamic ice-sheet model is used that includes ice thermodynamics and bedrock depression but neglects ice shelves (e.g. Huybrechts, 1993; Ritz et al., 1997).

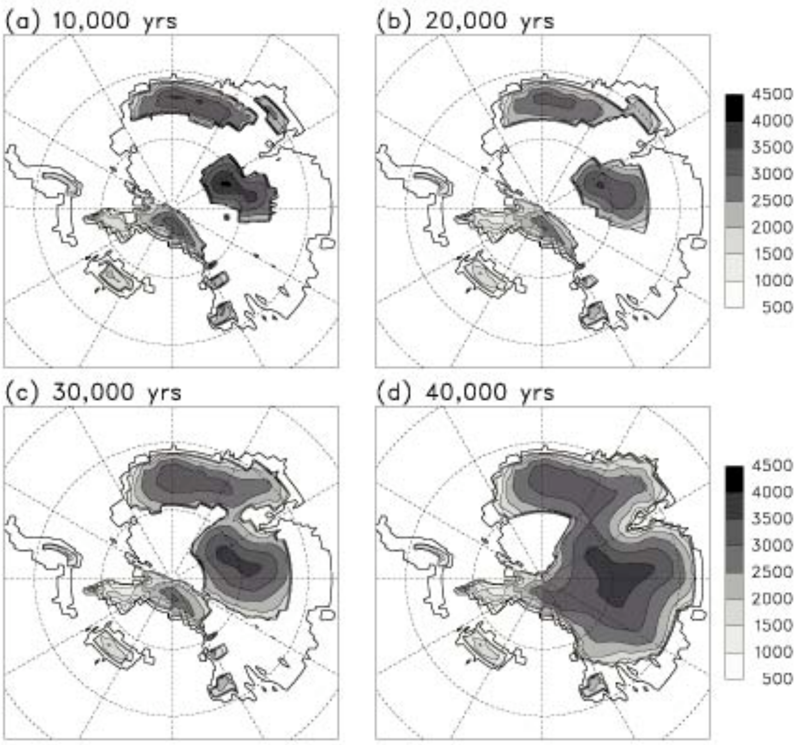

Figure 1. Ice surface elevations (m) at various times during a 40,000-year coupled simulation with varying orbital parameters. (a) after 10,000 years; (b) after 20,000 years; (c) after 30,000 years; (d) after 40,000 years.

A preliminary series of experiments has been performed with early Oligocene boundary conditions and various CO_2 values ranging from 0.5 to 8 times pre-industrial atmospheric levels (PAL), all with an orbital configuration that yields cold southern summers, to find the critical CO_2 value at which significant ice can first accumulate on Antarctica. This was found to be between 2x and 4x PAL, i.e. 560 to 1120 ppmv.

One 40,000-year long asynchronously coupled experiment has been completed to date using 2x PAL CO_2, and starting with no ice and a cold southern summer orbit. A generic sequence of orbital variations is assumed, and the 40,000-year duration spans two complete precessional cycles and one obliquity cycle, with slowly decreasing eccentricity. Ice-sheet extents and elevations are shown in Figure 1 at several times during the 40,000-year run. Small ice caps first grow on regions of high topography (Fig. 1a), and fluctuate but do not vanish during subsequent warm summers (Fig. 1b). By the end of the run, they have coalesced into a single ice sheet with a volume comparable to todays, and the margin is calving into the ocean around much of the eastern coastline.

These results show that the critical CO_2 level for significant ice growth is at or slightly above 2x PAL (560 ppmv), and well below 4x PAL. With this CO_2 level and a favourable orbit, ice caps can initiate on high Antarctic topography, and grow rapidly enough to survive subsequent more hostile orbital intervals. This CO_2 level is consistent with estimates for the earliest Oligocene (e.g. Berner, 1994).

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A Temperate Glacial Sequence Stratigraphic Model Applied to Antarctic Oligocene and Miocene (CRP) Successions

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Temperate glaciated continental shelves are by their nature complex basins in that they not only have typical low-latitude siliciclastic processes acting to produce a sedimentary record and depositional architecture, but they also have the consequences of glacial action superimposed. As an extreme end-member of glacimarine environments these shelves typically occur at mid-latitudes with active tectonism and very dynamic climatic systems, or at the extreme limit of large ice sheets as they expand into lower latitudes, or occur at higher latitudes during a major global climatic transition. Compared with non-glacial successions, base level is not necessarily sea-level, and changes in relative sea-level include glacial isostatic forcing. Furthermore, facies changes may occur simply by a glacial advance and retreat independent of other external forcings. Glacial systems tracts related to glacial advance and retreat signatures have been developed for Alaskan examples of these systems (Powell and Cooper, accepted) and include: glacial advance (GAST), maximum (GMaST), retreat (GRST) and minimum (GMiST) systems tracts and glacial erosion surfaces (GES) or their equivalent conformities.

Oligocene and Miocene sections from three Cape Roberts Project (CRP) drill cores at 77˚S, Antarctica, include: outer shelf to inner shelf to nearshore to shoreface, deltaic, grounding-line fan, ice proximal, ice marginal, and subglacial depositional systems (Powell et al., 1998, Powell et al., in press, Powell et al., submitted). They represent repeated glacial fluctuations across the drill sites. Sediment accumulation rates through the Oligocene and Miocene appear to have been very high and facies associations indicate high volumes of glacial meltwater indicative of "warm" glacial regimes.

Using the Alaskan models, glacial parasequence motifs have been evaluated for this Antarctic glacial record. They include facies reflecting grounding line movements and they vary from inner to outer shelf settings. Ideal motifs start in GMiST of a condensed section (dark mudstone, winnowed lags, coquinas varying areally) above which lie progradational deposits of paralic systems dominated by deltaic and siliciclastic shelf systems. Glacial isostatic depression with advance increases relative sea level and accumulation of bergstone mudstones ensues. Next in the GAST are glacimarine laminites including thin debrites, turbidites, cyclopsams and cyclopels and perhaps iceberg-rafted varvites in fan to sheet geometries. Above these are grounding-line deposystems dominated by diamictic debrites, coarse-grained, poorly- to well-sorted breccias and conglomerates, and poorly sorted sandstones. Grounding-line deposystems commonly have the geometry of banks or wedges/fans if they occur at the shelf-slope break. The upper-most sediments preserved may exhibit soft-sediment deformation due to glacial over-riding, below the GES and subglacial till representing the GMaST. However, tills may be absent because of patchy preservation in these types of glacial systems. GRST occurs immediately above the till and is similar to an inverted GAST, but the GRST is more likely preserved because it occurs above the GES. Grounding-line deposystems of the GRST have similar facies to those of the GAST but occur in a retrogradational stacking of bank and fan forms. However, thickness and geometry of GRST vary with rate of grounding-line retreat. The bergstone mudstones or diamictites of GRST transition through paraglacial mudstones into a condensed section comprising the next GMiST.

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Biostratigraphy of the East Antarctic Margin, 45-160ºE

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The East Antarctic margin, especially in the Prydz Bay region, is emerging as a fruitful source of data on Antarctic Phanerozoic biostratigraphy and palaeoenvironment. Sediments older than late Cretaceous are terrestrial; late Cretaceous and early Tertiary include both marine and terrestrial, but Neogene sediments are marine. Neogene sections are *in situ*, or have moved little under glacio-tectonic influence.

In situ Permian sediments in the Prince Charles Mountains (PCM) have a total thickness of about 1875 m, and consist of Late Kungurian and younger conglomerate (alluvial fan deposits of the Radok Conglomerate) and Bainmedart Coal Measures (with six members that are 'high-energy, braided stream fluvial channel deposits alternating with widespread, low-energy, flood basin and forest mire environments' (McLoughlin et al., 1997). The section post-dates the Gondwanan glaciation and is the source of reworking to the Prydz Bay region via the Lambert Graben system (e.g. Kemp, 1972). Glossopterid plant macrofossils and well-preserved wood (*Australoxylon*) are features. Floras in palynological residues are very similar to those in other southern Gondwanan localities but lack typical *Dulhuntyispora*-complex elements, generally are poorly preserved, and of low diversity.

The PCM Triassic sequence is terrestrial, *in situ*, and appears to lack only the Rhaetian. It is incorporated in the Flagstone Bench Formation, divided into three members with a total thickness of over 850 m. The section lacks coals but palynomorphs indicate sporadic seasonal wetness. Macrofossils include *Lepidopteris* and possibly *Dicroidium*. Spores and pollen are diverse and include corystosperms, peltapserms, lycophytes, conifers, ferns, algal cysts. Later Triassic floras are dominated by corystosperms, conifers, and other gymnosperms or ferns, and show markedly reduced influence of lycophytes and bryophytes. Animal fossils, other than possible arthropod cuticle, are unrecorded from the section.

The Permian-Triassic transition marked by a dramatic change from abundant water in the Permian to sporadic seasonal moisture in the Triassic. During the Late Permian-Triassic, the region was part of Gondwana with Australia immediately to its north. Also, for this time scale, the region was in high southern latitudes. The affinity of the floras during the Gondwana phase is clearly with Australian equivalents, any differences reflecting local environmental variation.

Jurassic and Early Cretaceous sediments are not known in outcrop but Mac. Robertson Shelf has yielded a good, but incomplete, palynological record from material that is close to *in situ* from sections that have slumped into modern sediments without causing mixing of ages (Truswell et al., 1999). All are non-marine and deposited in structures formed during the early phase of rifting of the continental margin, prior to India's northward movement. Domack et al. (1980) recovered Early Cretaceous farther east and Truswell (1983) documented recycled material of this and younger ages from many locations. Holocene and Late Pleistocene sections have yielded reworked Paleocene and Eocene marine foraminifera and *Inoceramus* prisms, the latter suggesting some Late Cretaceous marine influence (Quilty et al., 2000).

ODP drilling in the Prydz Bay area has recovered undated terrestrial redbeds, Early and Late Cretaceous terrestrial, and Late Eocene and younger marginal marine and marine sediments. Time gaps dominate the section and further drilling is imperative.

Miocene, Pliocene and Quaternary marine sections, with diverse and abundant fossils, occur around the margins of Prydz Bay and promise major contributions to resolution of contentious palaeoclimate issues (Quilty, 1996). They include important marine vertebrate faunas.

There are reports of older acritarchs (requiring re-examination) (Iltchenko, 1972), and undated, but probably Palaeozoic, red sandstone, common in modern sediment around the eastern half of the region.

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Vegetation History and Climate from the Early Oligocene to Early Miocene, Cape Roberts, Ross Sea Region, Antarctica

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Terrestrial palynomorphs from the Cape Roberts Project drillholes (Raine, 1998; Askin and Raine, 2000; Cape Roberts Science Team, 2000) record early Oligocene (and possibly late Eocene) to early Miocene vegetation history and climate for the Victoria Land Basin, Ross Sea region of Antarctica. In the youngest part of the Cape Roberts succession, early Miocene-late Oligocene assemblages (in CRP-1 and upper CRP-2/2A) reflect low diversity mossy tundra vegetation, with few dwarf woody plants (one or more species of *Nothofagus* and podocarp conifers) in more protected locations. Mean summer temperatures for this sparse periglacial vegetation were likely at least 1-2ºC but probably less than 7ºC, similar to temperatures today in islands near the Antarctic Convergence.

Milder conditions existed through much of the early Oligocene (represented in lower CRP-2/2A and above 410 mbsf in CRP-3), reflected by more diverse palynomorph assemblages. Vegetation probably included low scrub or closed forest of *Nothofagus*, plus podocarpaceous conifers, few other angiosperms and cryptogams (mainly mosses), growing in cold temperate-periglacial conditions, and likely similar to extant Magellanic *Nothofagus* woodland. Summer daily mean temperatures may have been in the 10-12ºC range at sea level.

The lower part of the CRP-3 Cenozoic section, below 410 mbsf, is a coarse sandy section that is essentially barren of palynomorphs. This unfossiliferous section probably encompasses the Eocene-Oligocene boundary. Rich spore and pollen assemblages, like those recovered from middle-late Eocene McMurdo Sound erratics (Askin, 2000) were not encountered in Cape Roberts cores. However, in the lower part of CRP-3, at 781.36 mbsf, a sparse but relatively high diversity assemblage contains *Casuarina*-type pollen, unknown in the higher CRP sequence. In New Zealand, following a major vegetational change in response to cooling at the end of the Kaiatan Stage (late Eocene, 35.5 Ma), *Casuarina* became much less abundant. A similar but more extreme vegetation response must have occurred after deposition of the parent strata of the Eocene McMurdo erratics, but prior to deposition of the upper part of the CRP-3 core, resulting in the loss of most ferns, some previously important podocarpaceous conifers, the previously diverse Proteaceae, the *brassii* group of *Nothofagus*, and other angiosperms. The basal CRP-3 Cenozoic sediments may pre-date this event, or the palynomorphs may be redeposited.

The CRP record attests to drastic reduction of the previously rich Eocene Antarctic flora, and a slow decline through the Oligocene. However, the Oligocene to early Miocene palynomorph record is also notable in that it includes various first appearances of taxa, either by evolution within the region during deteriorating climatic conditions or by immigration. Some of these taxa are characteristic of the Sirius Group tundra vegetation (Askin and Markgraf, 1986). Many of these taxa are now characteristic of alpine-subalpine environments in New Zealand and elsewhere, including the Subantarctic Islands. This CRP record provides possible evidence for Antarctic origins of some elements of the extant southern alpine flora (e.g. the cushion plant *Colobanthus*, and the triggerplant family Stylidiaceae).

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Miocene Rhythmic Sedimentation in the Wild Drift, Antarctica (ODP Site 188-1165)

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ODP Site 1165 is situated in a water depth of 3357 m on the continental rise in front of the outlet of the Lambert glacier-Amery Ice Shelf system that today drains about 22% of East Antarctica (Shipboard Scientific Party, 2001). The site cored a 999-m lower Miocene-Holocene section into an elongate sediment body (Wild Drift) formed by the interaction of westward-flowing currents with the sediment supplied from the shelf. Throughout the hole, from early to at least late Miocene time, there is a regular repetition of two basic facies: 1) greenish grey bioturbated diatom bearing mud with foraminifera and dispersed clasts and lonestones (IRD) and 2) dark grey almost barren laminated mud. The greenish grey facies is almost devoid of primary structures, whereas the dark grey one contains silt lamina (in the lower part of the hole), colour (ligth/dark) banding (in the upper part of the hole), and a number of lightening-upward intervals (without any evident grain-size variation). The dark grey facies is interpreted as contouritic sediment deposited during maximum ice advances whereas the greenish facies indicates hemipelagic deposition under warmer climate conditions. The lower boundary of the dark grey facies is mostly sharp, whereas its upper boundary is generally transitional to the greenish grey one. General upward trends include: overall increasing occurrence of IRD, biogenic content and bioturbation, and decreasing average sedimentation rate and silt lamina occurrence. The alternation of the two facies and the variation in their relative thickness result in a complex rhythmic sedimentation with cycles at different scales (ranging from centimetres to hundreds of metres) nested together. Analysis of colour photo-spectrometer data reveals that the cycles are best described by the ratio of the average reflectivity in the green colour band (550 to 600 nm) to the average reflectivity of all bands (400 to 700 nm). The 2 to 5 cm spaced colour reflectance measurements thus provide high-resolution data sets for quantitative analyses of the observed cyclicities.

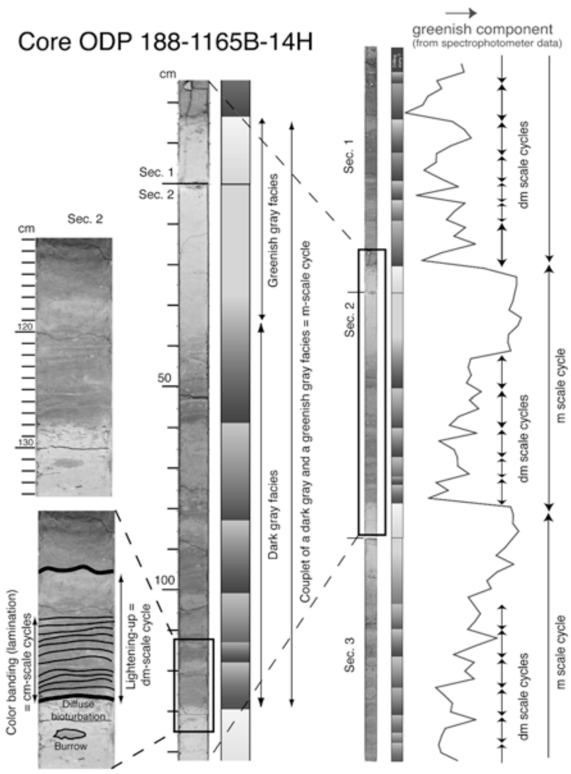

Figure 1. Composite diagram showing an example of cycles at different scale nested together in the colour record from Core 1165-14H. The cm-scale cycles are marked by colour banding and lamination (see the interpreted black and white photo in the left bottom). Such cycles are included within dm-scale cycles characterised by lightening-up intervals. In turn, these cycles are included within dark grey facies (see the black and white photo in the centre and the synthetic interpretation on its right). Finally m-scale cycles are constituted by a couplet of dark grey and greenish grey facies. The dm- and m-scale cycles are precisely recorded by colour photo-spectrometer data (see the ratio of the reflectivity in the green colour band versus the average reflectivity on the right side of the diagram). Moreover, larger scale (tens to hundreds of m) cycles (not shown here) are produced by the variation in ratio between the thickness of the two facies.

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Environmental Magnetism of the Pliocene-Pleistocene Section of Site 1165 (Wild Drift, East Antarctica)

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Wild Drift is located on the continental rise offshore Prydz Bay and recovered almost 1000 m of hemipelagic and terrigenous sediments of early Miocene to Pleistocene age with only a few minor disconformities (< 2 m.y.). The deposits are interpreted as the result of contour current activity resulting from the activity of large Antarctic deepwater masses. The primary objective of this study is to decipher the late Cenozoic environmental history of East Antarctica as part of a multiparameter interdisciplinary study. We analysed a set of 500 samples taken at ~10 k.y. resolution from the hemipelagic Plio-Pleistocene section at Site 1165 (0-50 mbsf) (Shipboard Scientific Party, 2001). The data set provides a 5 m.y.-long record of environmental change and ice-sheet history with the opportunity to link the histories of the Antarctic Ice sheet and the distal-ocean-current and climate systems.

As part of this project we investigated the sources of magnetic remanence and magnetic susceptibility variations by characterising rock magnetic properties. Variations in grain-size, mineralogy, and concentration of magnetic grains reflect pre- and post-depositional environmental changes, yielding clues to fluctuations in climate and depositional environment.

Concentration-dependent parameters (susceptibility, ARM, and IRM) co-vary and show, together with concentration-independent ratios (ARM/IRM, ARM/k, S-ratio) very distinct variations with time. From the beginning of the record at about 5 Ma throughout the early Pliocene the concentration of magnetic material varies very little, while the magnetic mineralogy and the magnetic grain-size (S-ratio, and ARM/k and ARM/IRM ratios) shows various large and small-scale cycles. At the beginning of the late Pliocene (34 mbsf) the magnetic grain-size exhibits a dramatic decrease, and stays in general lower above this depth, while the natural gamma radiation (proxy for clay mineral concentration/composition) increases and the concentration of the coarse grained magnetic fraction decreases. Another significant change occurred at around 3.33 Ma (30-28.5 mbsf) where the magnetic concentrations of both coarse and fine grained material drop to very low values and the magnetic properties are carried by a high-coercivity component. The clay mineralogy is not effected by this event. In the top 28 mbsf the magnetic mineralogy stays extremely constant (S-ratios around 0.97), while the concentration and the size of magnetic minerals display three major cycles (peaks at 23.4, 13.2, and 2.8 mbsf). These cycles are parallel to the main features of the natural gamma ray curve.

Rock magnetic measurements of the Plio-Pleistocene strata from the Wild Drift record a significant shift from fine-grained magnetic material with a relatively constant magnetic concentration and a magnetic mineralogy with a notable high-coercivity component to coarser-grained magnetic material with cyclic changes of the magnetic concentration and a lower high-coercivity component at the onset of the late Pliocene (34 mbsf). This shift coincides with an increase in the natural gamma radiation record. Above this event, a 1.5-m thick zone with very low magnetic concentrations is followed by three major cycles of the magnetic mineral concentration. The investigated sediments display an exciting record of magnetic property changes that will be used together with several non-magnetic data for a self-consistent and unique interpretation of environmental change of the Plio-Pleistocene section of Site 1165.

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A Geophysical Atlas of East Antarctica Between 40º West and 40º East – An Integrative Approach

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During the last two decades several international institutions and expeditions, including Russian and German ones, have collected geophysical data along the passive continental margin of East Antarctica. The aim of these expeditions was to improve our understanding of the main geological structures and their relation to the amalgamation and subsequent break-up of Gondwanaland. Especially marine and terrestrial geophysical data sets are of vital importance for the development and refinement of geodynamic models of the continental break-up. Until now, the processing and interpretation of the several seismic and potential field data sets in the region between 40ºW and 40ºE has been performed mainly on a national level. Due to a co-operation agreement between Russian institutions (PMGRE, VNIIO) and the AWI, the exchange of geophysical data is now substantially improved.

This gives us the opportunity to develop an atlas that assembles an almost complete set of geophysical research field data in the area along the continental margin of the Weddell Sea, Riiser-Larsen Sea, Lazarev Sea and Cosmonaut Sea. More than 56,000 km multi-channel seismic (MCS) data, 86,000 km aeromagnetic data, marine gravimetric and aero-gravimetric data of more than twenty expeditions will be compiled, readjusted, mapped and interpreted. In a first step we performed a joint compilation of MCS data of the Mesozoic ocean basins of East Antarctica with the main focus on the Weddell Sea. Here, the results on sedimentary structures in the Mesozoic ocean basins and new insights into the early opening of the South Atlantic will be included.

The Environmental Magnetic Record of Cenozoic Climate Change in the Victoria Land Basin, Antarctica

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About 1800 m of Early Miocene to Late Eocene glaciomarine sediments was recovered from the Victoria Land Basin (VLB) of the Ross Sea, Antarctica, in the CIROS-1 drill hole (1986) and in three holes associated with the Cape Roberts Drilling Project (1997-1999). The VLB sequences were studied with the aim of understanding Antarctic Cenozoic climate change and the processes that led to development of a permanently glaciated continent. We used an environmental magnetic approach, with multiple rock magnetic analyses on samples taken at an average spacing of 0.5-1 m (Sagnotti et al., 1998a, b, in press; Verosub et al., 2000). We recognise variation in the concentration, grain-size and composition of the magnetic minerals in the VLB sequences, on time scales of tens of thousands of years to a few million years, which allowed us to define a distinct rock magnetic zonation for each of the VLB cores. Magnetite is the main magnetic mineral and its delivery to the VLB appears to be controlled by climatic changes of regional significance. In Figure 1, the stratigraphic trend of the anhysteretic remanent magnetisation (an artificial remanence produced in an alternating field of 100 mT and a direct field of 0.1 mT) is shown as a direct proxy for magnetite concentration in the three CRP cores. Prior to the onset of activity associated with the McMurdo Volcanic Group, which is recognised at about 270 mbsf in CRP-2/2A, we relate intervals of low magnetite concentrations to periods of widespread glaciation on the continent and intervals of high magnetite concentrations to episodes of relatively warmer climate. Using this framework, climatic deterioration began in the middle to late Eocene, with repeated climatic alternations preceding a marked increase in glaciation at the Eocene/Oligocene boundary, as pointed out by integrated rock magnetic and clay mineralogy data in the lower half of CIROS-1 (Sagnotti et al., 1998a). A sharp change in magnetite concentration is also present at about 627 mbsf in CRP-3 (Sagnotti et al., 2001) and is correlated to the base of Chron C13n (i.e. near the Eocene/Oligocene boundary) (Florindo et al., submitted). Our data also indicate that there may

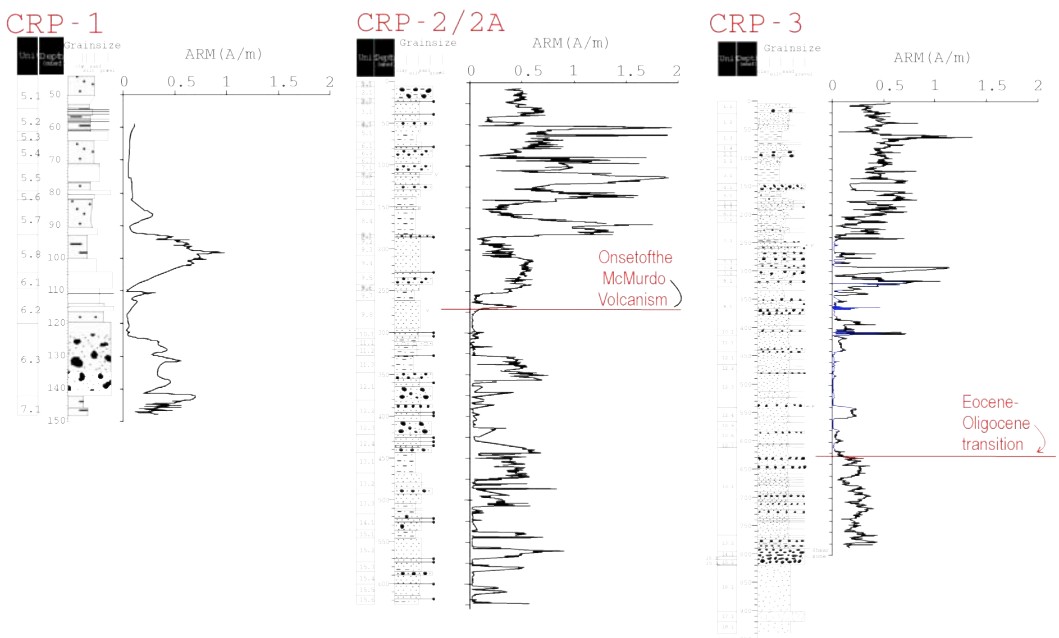

Figure 1. Stratigraphic variation of the anhysteretic remanent magnetisation in the three CRP cores.

have been significant fluctuations in the extent of glaciation during the Late Oligocene and Early Miocene (Sagnotti et al., 1998b; Verosub et al., 2000). However, starting from the uppermost Late Oligocene, the rock magnetic signal is also affected by development of local McMurdo Group volcanism (Verosub et al., 2000) and the climatic signature is less obvious for sediments younger than about 24.2 Ma.

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Clast Data from CRP Cores (Victoria Land Basin): Implications on the Uplift History of the Transantarctic Mountains

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The international Cape Roberts Project drilled three holes (CRP-1, 2/2A, 3), distributed along a SE-NW trending traverse at 16-8 km from Cape Roberts in the McMurdo Sound (southern Ross Sea, Antarctica). The 3 holes comprehensively recovered an almost continuous c. 1600 m thick section of Cenozoic glaciomarine sediments at the western margin of the Victoria Land Basin (Fig. 1). At the deepest (939 metres below the sea floor, mbsf) borehole (CRP-3), the Cenozoic sediments were found to rest unconformably on Devonian age arenites of the Beacon Supergroup, indicating a total post-Jurassic offset of the CRP block of c. 3000 m with respect to the adjacent Transantarctic Mountains block south of Mackay Glacier.

Clasts (granule- to boulder-grade) are a significant component throughout most of the recovered sediments, which range in lithology from diamictite/sandstone/argillite alternated sequences to conglomerate-bearing sandstone units (confined to the section below 200 mbsf in CRP-3). During all three field drilling seasons, petrological investigations on the coarser-grade clast fractions were focused on the preliminary petrographical characterisation of the main lithologies and their distribution and abundance throughout the core (Cape Roberts Science Team, 1998, 1999, 2000). Subsequent laboratory analysis were then carried out in order to refine the initial report dataset and highlight some preliminary interpretations about provenance and meaning of detected distribution patterns (Talarico and Sandroni, 1998; Smellie et al., 1999; Talarico et al., 2000; Brink et al., 2000; Sandroni and Talarico, submitted).

Similarly to previous drillholes (MSSTS-1, CIROS-1) in the McMurdo Sound, CRP clast lithologies were found to closely reflect the lithological composition of the major onshore geological units (granitoid and metamorphic basement, Beacon Sandstone, Ferrar dolerite, Kirkpatrick basalt, McMurdo Volcanics), thus providing a sound indication of a local provenance. A number of evidence lines based on modal and petrological investigations on granitoid basement clasts (mainly biotite±hornblende, foliated or undeformed monzogranites and ubiquitously distributed) consistently support a supply from areas of the Transantartic Mountain block located to the west and south-west of the drillsites. Nevertheless, the scattered occurrence of rare phyllites, apparently confined to the lower part of the CRP-3 section (below 200 mbsf), might provide some hints for a distant (>200 km) provenance from the south (Skelton Glacier-Koettlitz Glacier region).

The overall distribution patterns for coarse clasts in the three CRP drillholes provide a clear evidence of an evolving provenance which can be at least partly related to the uplift/erosion history of the on shore TAM blocks west and south of the drillsites. Several erosion phases can be distinguished and a major compositional discontinuity identified at c. 307 mbsf in CRP-2/2A, with granitoid-dominated clasts (plus McMurdo Volcanic Group clasts) above and mainly Ferrar Group lithologies (dolerite, basalt) below. The tectonic meaning of this and other petrological discontinuities detected in CRP cores will be discussed in order to assess their bearing in providing further constrains on the timing and style (gradual, short-lived rapid?) uplift history of the Transantarctic Mountains in Southern Victoria Land.

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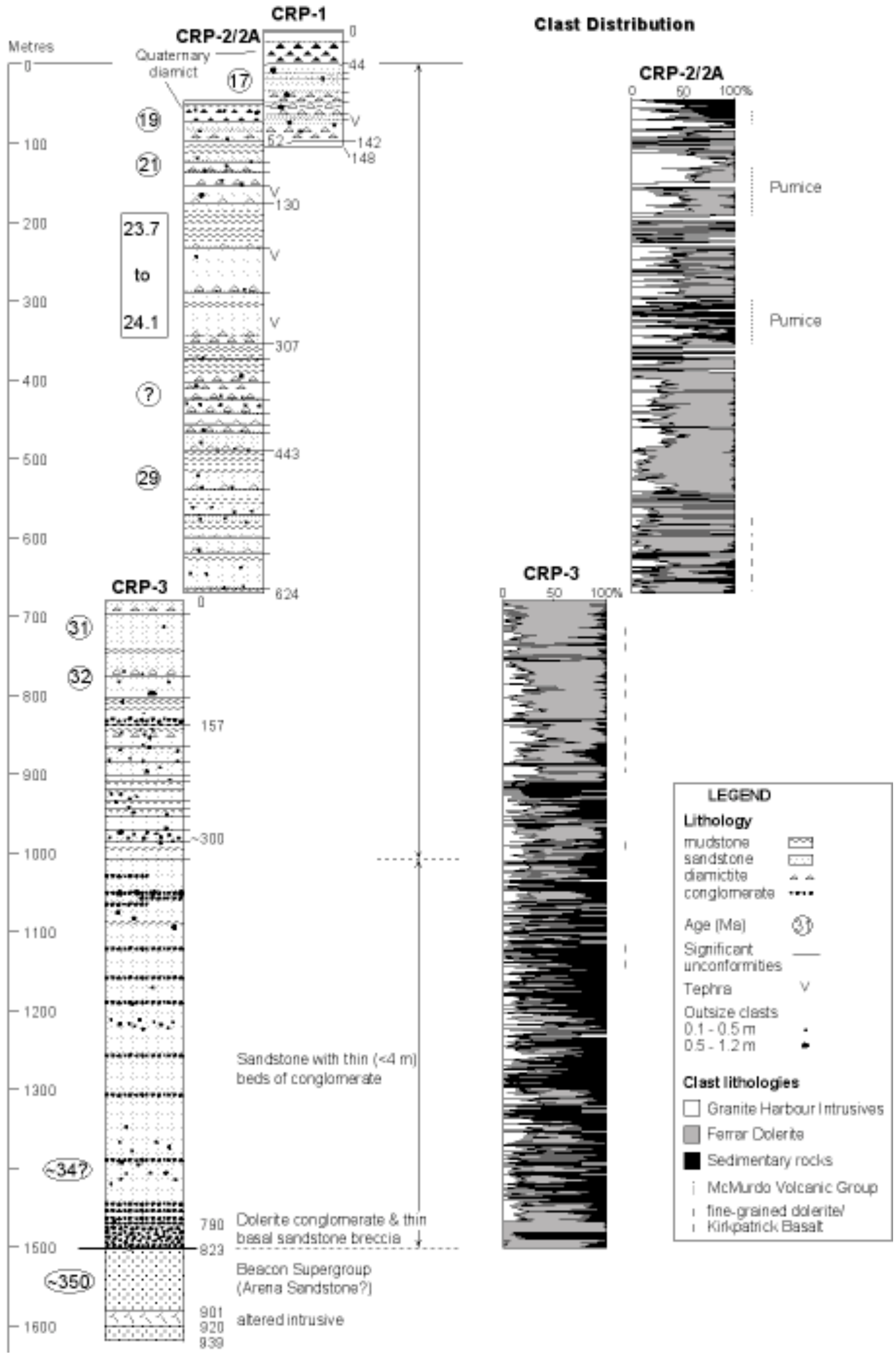

Figure 1. Relative proportion of major clast types plotted against depth; volcanic rocks are showed only where their abundance is significative. Stratigraphical columns after Cape Roberts Science Team (2000). Erosion phase 1 (c. 825-790 mbsf, CRP-3); phase 2 (c. 790-175 mbsf, CRP-3); phase 3 (c. 175-80 mbsf, CRP-3); phase 4 (c. 80-0 mbsf, CRP-3; c. 625-575 mbsf, CRP-2/2A); phase 5 (c. 575-440 mbsf, CRP-2/2A); phase 6 (c. 440-307 mbsf, CRP-2/2A); phase 7 (c. 307-250 mbsf, CRP-2/2A); phase 8 (c. 250-185 mbsf, CRP-2/2A); phase 9 (c. 185-150 mbsf, CRP-2/2A); phase 10 (c. 150-27 mbsf, CRP-2/2A; c. 147-44 mbsf, CRP-1).

Diatom Assemblages and Taphonomy in Antarctic Diamictons Provide Constraints for Modeling Past Marine Ice Sheet Configurations and Processes

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High seasonal diatom production along the Antarctic continental margin results in rapid accumulation of diatomaceous sediments. This has been the dominant pattern since early Oligocene time. Periodic ice sheet expansion across the continental shelves, especially during the late Neogene, has resulted in erosion, transport, and redeposition of massive volumes of marine and glacigenic sediment across the outer continental shelf, and these repeated glacial erosion/transport/mixing events, have resulted in complex shelf facies. We are using diatom fossils and geochemical signatures to distinguish between sedimentary packets formed under different glacial conditions and derived from distinct provenance envelopes.

High-resolution seismic surveying across the continental shelf is an effective method of mapping the geometry of submarine-glacial facies. The general stratigraphy of the Ross Sea floor is well established through detailed seismic studies, including high-resolution seismic data acquisition, multibeam images of large geomorphic features, and deep-tow side-scan sonar records of smaller bedforms (Shipp et al., 1999; Wellner et al., 2000). These show clear evidence of the distinctive “footprints” of former grounded ice. Sediment core stratigraphic and textural descriptions (Domack et al., 1999) have provided a general framework view of the upper few meters of sediment on the Ross Sea floor. Typical stratigraphy is a diamicton overlain by transitional sediments, capped by Holocene diatomaceous mud.

Interpreting the complex stratigraphy, especially temporally, is hampered by poor constraints on marine ice sheet basal processes. Understanding the various mechanisms acting on the bed, given differing glacial regimes, is critical to developing realistic ice sheet models. There are many outstanding questions. Some of the key questions pertain to ice stream behaviour. Are fast-moving ice streams, which are wet-based and temporally variable, more or less effective agents of mass erosion than slow-moving ice that experiences basal freezing? How effective is ice streaming at comminuting sedimentary particles - can diatoms be translated great distances beneath an active ice stream without sustaining severe breakage?

Our long-term goals are to address these questions in detail. A first step is to determine objective criteria for distinguishing between sub-ice sheet tills, sub-ice stream tills, and glacial-marine sediments. Diatoms provide an excellent means of analysing the degree of mixing of strata of different ages, and, consequently, may be useful in inferring transport distances. Furthermore, their physical taphonomy (degree of fragmentation/comminution) provides a useful (if qualitative) gauge of physical mixing. We are using recycled diatoms as tracers of glacial mixing and physical degradation, as recorded in core samples from the Ross Sea, and from beneath the Ross Ice Shelf and the Ross Sector of the grounded West Antarctic Ice Sheet. In a related project, in collaboration with Neil Iverson (Iowa State University), objective and reproducible criteria are being generated for diatom fragmentation by normal load and shearing, via quantitative analysis of diatoms subjected to controlled load and shear in a large ring-shear device, designed to mimic conditions beneath the WAIS (Iverson et al., 1997, 1998). These results, when available, will greatly aid in distinguishing glaciogenesis of marine diamictons.

To date, we have analysed nine short cores from the central Ross Sea, including the Challenger Basin and the Pennell Bank, with respect to diatom composition, the preservation of diatom valves, and the bulk chemistry, including major and trace elements. Diatom analysis shows a distinctly different pattern of deposition on the Pennell Bank and in the Challenger Basin of the central Ross Sea. The Pennell Bank diatom assemblage shows well-preserved, presumably locally derived sediment of mid and upper Miocene age in a matrix mixed with Pleistocene-age diatoms. Shipp et al. (1999) suggested that the Pennell Bank was a pinning point during the last glacial maximum. The abundance of Tertiarty diatoms, but the relative lack of stratigraphic mixing of diatoms tends to support that view. The sediments of the

Challenger Basin, in a trough interpreted to be a palaeo-ice stream, contain diatom assemblages indicative of intense mixing, with diatoms derived from upper Oligocene, lower Miocene, middle Miocene, upper Miocene, Pliocene, and Quaternary strata. The Challenger Basin diamictons compare favorably with sediments recovered from beneath current ice streams (Scherer et al., 1998; Scherer, 1991), whereas, texturally, Pennell Bank sediments more closely resemble those of Crary Ice Rise (Scherer et al., 1988) and Ross Ice Shelf Project Site J-9 cores (Harwood et al., 1989). Bulk chemistry shows little apparent variation between different units and between cores. An exception is the Holocene diamaceous mud where the concentration of biogenic tracers such as Barium is increased, and the concentration of detrital tracers, such as Zirconium, is low.

These observations are leading to better constraints on modern and past marine ice sheet processes, which will lead to an understanding of their corresponding sedimentary facies, and will, consequently, greatly aid in the palaeoenvironmental interpretation of drill core material from the Antarctic continental shelf.

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Numerical Modelling of the Eurasian Ice Sheet and Implications for ANTOSTRAT Ice Sheet Reconstructions

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Recent advances in our understanding of the former dynamics of the Antarctic Ice Sheet in the Cenozoic have been based largely on geological evidence. Because of this the ice sheet histories have been qualitative. Numerical ice sheet modelling allows geological evidence to be coupled with ice sheet dynamics to produce quantitative scenarios for former ice sheet behaviour. Such models have been used successfully in the ESF-QUEEN programme to develop time-dependent reconstructions for the Eurasian ice sheet during the last glaciation. Here, details of QUEEN modelling activities are presented with suggestions to how this modelling procedure may be applied to the Antarctic Ice Sheet.

Results from a numerical ice-sheet model were matched with geological evidence detailing the extent and timing of the Late Weichselian ice sheet in the Eurasian Arctic, through simple adjustments in the model's environmental inputs (Siegert et al., 1999; Siegert and Marsiat, in press). From this, the numerical model indicates the spatial and temporal variation in (1) subglacial sediment transport and deposition (2) rates of iceberg calving and (3) rates of supraglacial melting and runoff, required to form and decay the ice sheet. The ice sheet is characterised by a series of ice streams occupying bathymetric troughs in the Barents Sea and west of Norway, which act as centres for glacial sediment build-up and iceberg production. The model indicates that significant volumes of sediment are deposited over the Bear Island Trough fan (3000 km^3 in 12,000 years), Franz Victoria Trough fan (500 km^3 in 8000 years) and a series of smaller fans west of Norway (which combine to yield 4000 km^3 in 12,000 years). The Norwegian Channel fan was developed for only 4000 years during which time 400 km^3 of sediment was deposited. The ice-sheet experiences two major iceberg calving events where the rate of iceberg calving is increased by ~50% at 15,000 and 12,500 years ago. The marine portions of the ice sheet decay after 15,000 years ago, resulting in several embayments at the mouths of bathymetric troughs. A second pulse of enhanced iceberg calving at 12,500 years ago caused further decay of the marine ice sheet and forced the ice margin back to the shorelines of island archipelagos in the northern Barents Sea. Ice loss through surface melting was restricted mostly to the southern margin of the ice sheet. The total volume of ice lost through surface run-off is an order of magnitude less than that released by iceberg calving.

The modelling strategy designed for the Eurasian ice sheet will be applied over the next three years to the Antarctic ice sheet (involving M. Hambrey, D. Sugden, T. Payne, N. Hulton and J. Taylor). Specifically, work will be focussed on the Lambert-Amery system, utilising the wealth of recently acquired geological information from (1) offshore drill-core data and seismic stratigraphy from adjacent Prydz Bay (where the glacial record extends back to at least earliest Oligocene time), and (2) onshore stratigraphic and sedimentological data spanning the interval late Oligocene-Quaternary from the Prince Charles Mountains (Hambrey and McKelvey, 2000). These data, supplemented by geomorphic data, will yield a record of the role of ice-sheet erosion in landscape evolution. The value of the Lambert system is that ice has flowed through a conduit that may have existed since Permian time and, thus, the sedimentary successions are likely to record ice-sheet scale changes. This geological evidence provides input parameters to a numerical ice-sheet model, which will determine the conditions required to make the ice sheet conform to observed geological sequences, and to determine the scale and plausibility of fluctuations of the ice sheet and associated climates at critical stages in its evolution. Our modelling will also allow us to test whether or not dynamic behaviour in the Lambert system requires or causes dynamic ice-sheet change in other regions of East Antarctica. In this way we will be able to locate the most likely regions of the EAIS susceptible to stable glacierisation over Cenozoic time, and those other regions in which more dynamic ice-sheet behaviour is appropriate.

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Cenozoic Glacial History Preserved on King George Island (Antarctic Peninsula)

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A major reinvestigation of Cenozoic glacial rocks on King George Island (Antarctic Peninsula; Fig. 1) was undertaken by the British Antarctic Survey in the 1990's. The rocks studied include the oldest glacial sedimentary deposits in the region, and possibly the oldest in West Antarctica. They are particularly interesting as they contain glacially-transported rock fragments derived from East Antarctic sources, situated about 3000 km away from King George Island. The investigation sought to understand the depositional history, timing and climatic implications of the rock formations (Smellie et al., 1998; Troedson and Riding, submitted; Troedson and Smellie, submitted). Key results include confirmation that glaciations occurred at 30-26 and about 22 million years ago (Polonez Cove and Melville glaciations, respectively), and a third which is currently undated (Legru Glaciation). The Polonez Cove Formation includes the Magda Nunatak sequence, previously interpreted as evidence for Eocene glaciation (about 50 Ma).

The revised Polonez Cove Formation includes a basal unit laid down in contact with ice (Fig. 2a). The basal material overlies an uneven, glacier-modified surface, locally broken-up, deeply fractured and injected by fine matrix from the overlying unit. The clast source was predominantly local, but with persistent material with no obvious local source (i.e. none within the Antarctic Peninsula). Overlying sedimentary units are all shallow marine. They are dominated by basaltic clasts well suited to $^{40}Ar/^{39}Ar$ dating. Shelly fossils have also been used for Sr-isotopic dating. Although the ages obtained from the two isotopic systems are close, they do not agree in detail. The younger Cape Melville Formation (CMF) comprises a basal unit deposited proximal to marine-based grounded ice and overlain by a variety of shelf sediments and rare airfall volcanic beds (Fig. 2b). Exotic clasts are similar to those encountered in the older Polonez Cove Formation. The results of isotopic dating of the CMF (Sr isotopes; $^{40}Ar/^{39}Ar$) are consistent. The Vauréal Peak Formation is the youngest glacial unit preserved on the island (Legru Glaciation). It is a boulder clay deposit derived entirely from lithologies found on King George Island, and it is commonly draped spectacularly over subvertical rock faces. Although currently thought to be 26-29 Ma in age, our dating work indicates an age younger than 23-25 Ma, and it is probably much younger (< 10 Ma?).

All the glacial sequences on King George Island were formed as a result of deposition from, or close to, locally-sourced glaciers. The Polonez Cove and Melville glaciers were grounded below sea level, whereas the Legru glacier was probably terrestrial. The presence of far-travelled exotic clasts in the basal Polonez Cove Formation ice-contact deposits is as a result of secondary incorpora-

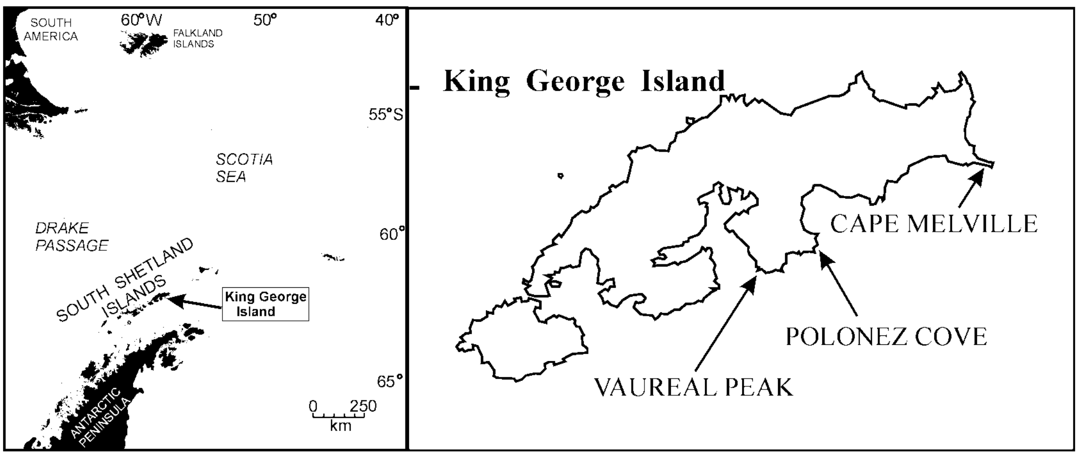
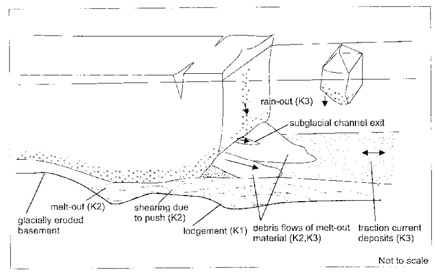
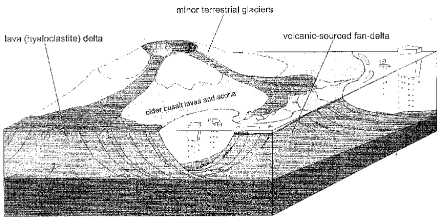


Figure 1. Location of King George Island.

a. Polonez Cove Formation



Basal glacigenic beds



Volcanic interbeds

b. Cape Melville Formation

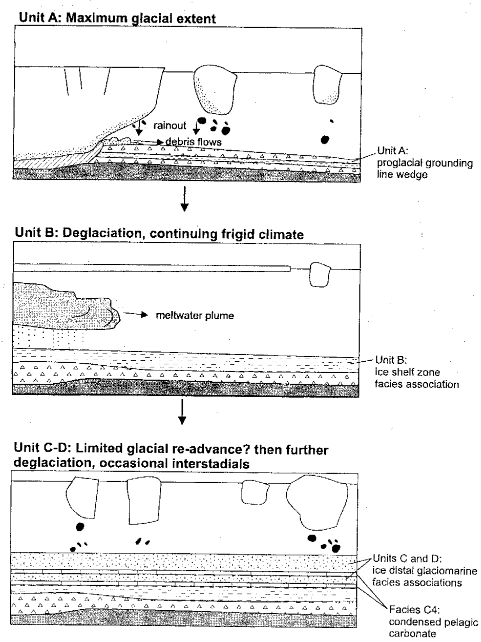


Figure 2. Depositional Palaeoenvironments.

tion of glacially rafted debris into the bedload of glaciers local to the northern Antarctic Peninsula region. There is no convincing evidence for the extremely far-travelled ice stream rooted in the East Antarctic Ice Sheet postulated by previous workers. The sediments generally do not closely resemble meltwater-dominated glacial-marine deposits in modern temperate settings, and an association with polythermal ice in a sub-polar to polar environment is suggested. The older glacial formations also provide evidence which can be used to infer other, much more areally extensive ice sheets, which were probably situated in East Antarctica, and also for a clockwise-flowing oceanic current system in the Weddell Sea, which still exists today.

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Implications of Microtextures of Quartz Grains for Eocene/Oligocene Glaciation in Prydz Bay, ODP Site 1166

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The Antarctic ice sheet and the ocean surrounding it are key components in the global climate regime through the Cenozoic to the present (Barker et al., 1998). ODP Leg 188 drilled Site 1166 on the Prydz Bay continental shelf to document onset and fluctuations of East-Antarctic glaciation. This site recovered upper Pliocene-Holocene diamictons and diatomaceous claystones directly above upper Eocene-lower Oligocene diatomaceous claystones with interbedded sand and lonestones (O'Brien et al., 2001). Lonestones suggest that the sediments were deposited during transition from pre-glacial to glacial conditions. Below these are fluvio-deltaic sands. Carbonaceous siltstone and mudstone lie below the deltaic sediment and contain Late Cretaceous (Turonian) palynomorphs.

We will show the results the SEM-microtexture study of quartz grains at Site 1166 to characterise onset of glaciation and preglacial sediments by their diagnostic microtextures of sand grains in fraction between 0.250 and 0.6 mm (Fig. 1). From each sample 20-30 grains were analysed and counted by using SEM-EDS and FESEM at the Institute of Electron Optics at the University of Oulu. A range of microtextures including angular to rounded outlines, surface reliefs, and mechanical textures such as concoidal fractures, cresentic gougles, edge and surface abrasion was used to determine the environmental history of these grain comparatively with the study of Mahaney et al. (1996). Angular outlines, edge abrasion as well as arcuate to straight steps are the most frequent in glacial deposits. Frequency of large breakage blocks ranges in wide spectrum (10-40%) in diamictons as the fluvio-deltaic sands preceding the upper Eocene-lower Oligocene claystones show constant values around 20%. The highest frequency of grains with rounded outlines is present in the fluvio-deltaic sands. The carbonaceous mudstones, however, have preserved high surface relief grains with angular outlines possible due to the high amount of fine-grained material provided and minor reworking.

The preliminary results show that microtextural analysis of quartz grains may well be used in verifying for some critical periods of ice-sheet evolution such as the transitions from

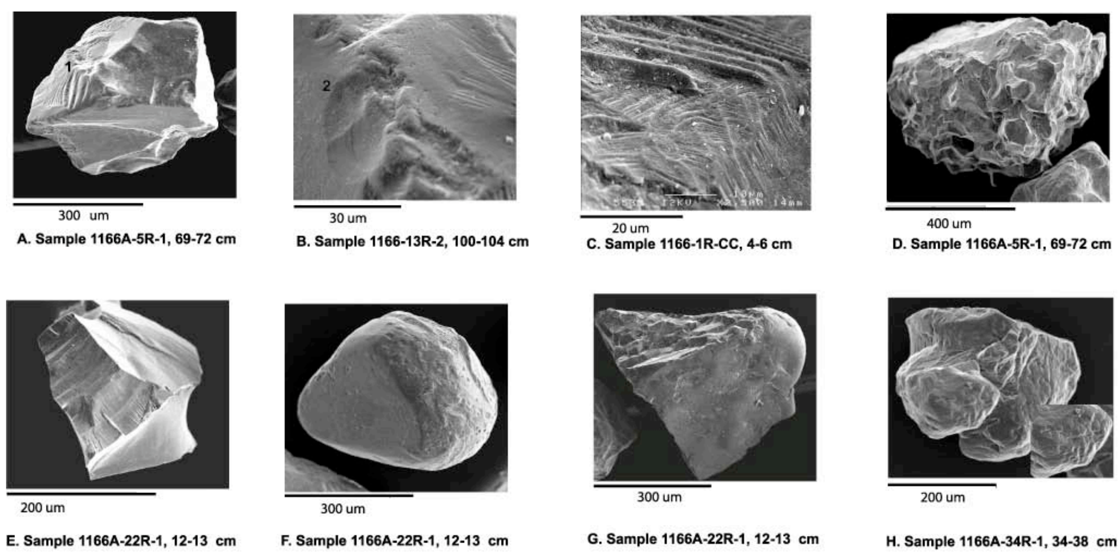

Figure 1. Selected SEM micrographs of grains from Site 1166 showing typical morphological, mechanical and chemical textures. **a)** Angular outline and straight grooves (1), **b)** Edge abrasion and conchoidal fractures (2), **c)** Straight and arguate steps, **d)** Angular outline and high relief, typically preserved in clay-rich intervals, **e)** Sub-parallel linear fractures and fractured plates, **f)** Rounded outline and surface abrasion, **g)** Rounded outline with later imbricated blocks, **h)** Chemically weathered surfaces.

East Antarctic preglacial to glacial conditions on the continental shelf. SEM photomicrographic and EDS data can provide representative information on general palaeoenvironmental reconstructions.

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Geology of Northern Offshore of Antarctic Peninsula

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MITI/JNOC had conducted twenty geological (dredge and gravity coring) and geophysical (gravity, magnetic, multi channel seismic) survey cruises in offshore Antarctica during 1980-1999 (e.g. Tanahashi et al., 1999). Four survey cruises, TH87, 88, 96 and 97, have accomplished in northern offshore of Antarctic Peninsula and Scotia Sea area (Fig. 1).

The geological framework of the area is controlled by the development of a triple junction among the Antarctic, Scotia and (former) Phoenix plates. Scotia Basin has a 1.0 to 1.5 s thick, well stratified, little deformed sedimentary sequences on the distinct oceanic basement which spread during Late Oligocene to the Early Miocene. Late Miocene andesitic island arc volcanism along the South Shetland Trench was suggested from the K-Ar dating on the dredge sample from the small ridge in the south of Elephant Island. Shackleton Fracture Zone (SFZ), which developed as a transform fault during the spreading of Scotia Basin, bounds Scotia and former Phoenix plates now. Sedimentary sequences in Scotia Basin folded in neighbour of SFZ and no intense folding away from it. Even the seafloor is mostly flat, subbottom sequences of the basin inclined westerly to SFZ. Upper sequences in the eastern part have been eroded somewhere (Fig. 2b). It suggests the eastern part of the basin is uplifting after the sedimentation of current inclining sequences during the reorganisation of plates in the area with the rifting of Bransfield Basin. There is a characteristic anticline in the southern margin of Scotia Basin in the foot of the South Scotia Ridge. It may suggest a transpressional movement of the boundary between Scotia and Antarctic plates.

Two types of bottom simulating seismic phenomena are well developed in this area. One is developed along the South Shetland inner trench slope (Fig. 2a). The BSR in the area has been analysed in detail by Tinivella et al. (1998) and is interpreted as the boundary between upper gas hydrate cemented layer and lower hydrate free layer whose top has a thin free gas

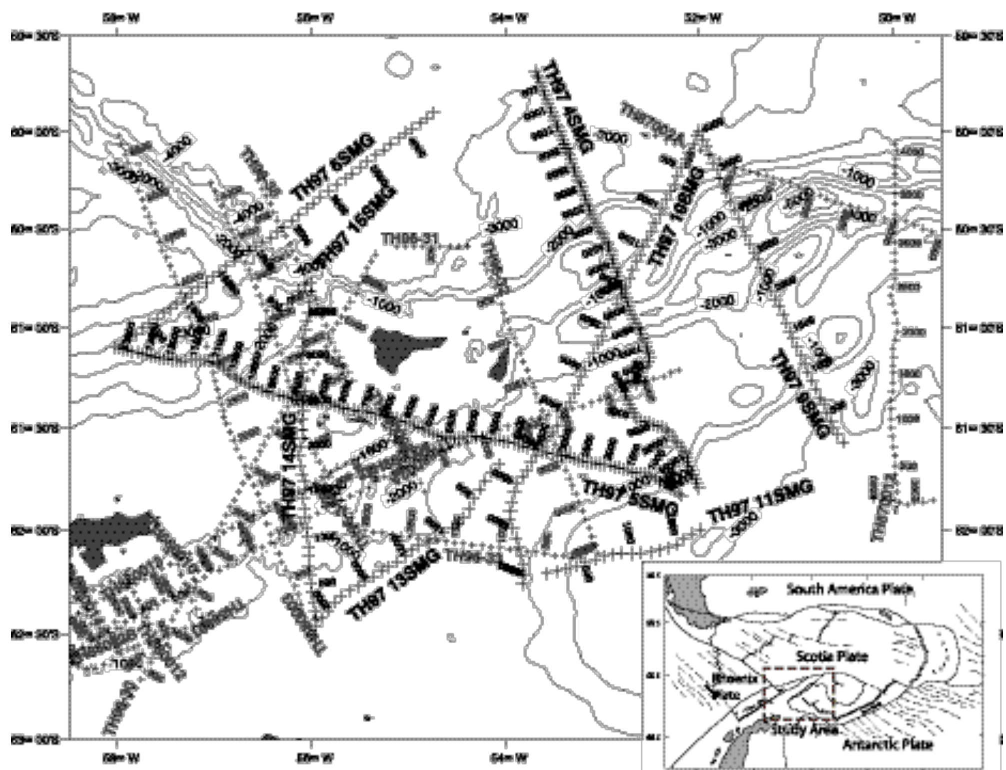

Figure 1. Seismic survey lines which were carried out during TH87, 88, 96 and 97 in northern offshore of Antarctic Peninsula.

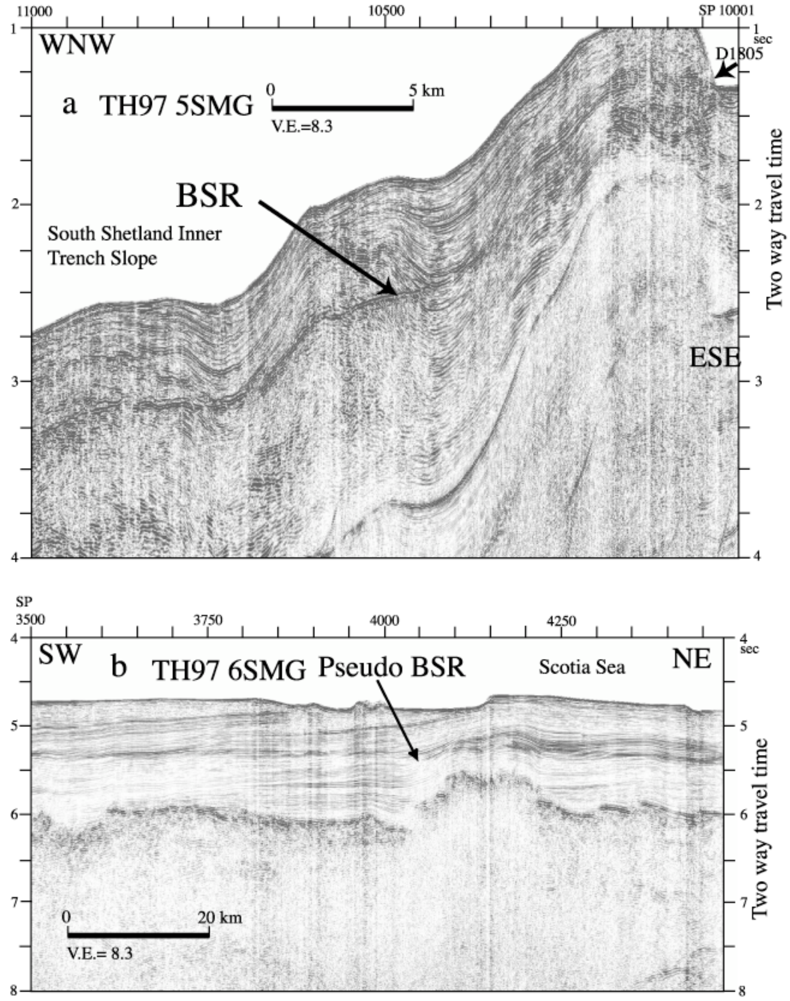

Figure 2. Two types of BSR in northern offshore of Antarctic Peninsula; a) is a typical BSR which is interpreted a boundary between upper gas hydrate bearing and lower hydrate free sediments; b) is a pseudo BSR, which is not a true reflector but a boundary between upper intense and lower weaker sedimentary reflectors.

layer. The other is developed in the southwestern part of the Scotia Basin (Fig. 2b). It is not a reflection but a boundary where the reflection amplitude changes from upper high to lower low, abruptly. It may be correlated to the phase boundaries of silica minerals, as suggested by Lodolo and Camerlenghi (2000) for the phenomena observed in sediment drift off the western Antarctic Peninsula margin.

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East Antarctic Marine Environments and Climatic Conditions in the last 30 Millions Years as Inferred from Macropalaeontological Data (Cape Roberts Project)

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Drilling at Cape Roberts (77.006ºS and 163.719ºE: Ross Sea, Victoria Land Basin, Antarctica) provided a number of macroinvertebrate fossils previously undocumented not only in the study area but in the whole of Antarctica (Jonkers and Taviani, 1998; Taviani et al., 1998, 2000; Taviani and Beu, in press). Such noteworthy palaeontological documentation for the Cenozoic of Antarctica sheds light on some crucial time intervals, i.e. the middle Pleistocene (CRP-1), early Miocene (CRP-1, CRP-2/2A) and Oligocene (CRP-2/A, CRP-3). The importance of the CRP palaeontological yield is obvious when one considers the number of macrofossiliferous horizons recorded in CRP-1 (31 horizons), CRP-2/2A (324 horizons) and CRP-3 (235 horizons) drillholes; sites previously drilled in the Ross Sea region were considerably less productive of macrofossils: Deep Sea Drilling Project Site 270 (40 horizons: Dell and Fleming, 1975) and CIROS-1 (15 horizons: Beu and Dell, 1989). Oligocene macrofaunal assemblages documented in CRP-2/2A represent the most diverse palaeontological documentation for this epoch in East Antarctica (Taviani et al., 2000), ranking second only to King George island, Antarctic Peninsula (Gazdzicki and Pugaczewska, 1984).

The palaeontological information gained through the three holes drilled at Cape Roberts in 1997, 1998 and 1999, proves to be of great value to understand (1) the transition from greenhouse to icehouse climatic conditions in Antarctica and (2) the evolution of polar biota.

Concerning the first issue, data from CRP drill cores clearly indicate that time intervals containing macrofossils in the early Miocene of CRP-1 and CRP-2/2A were characterised by cool climatic conditions, but definitely milder than true polar ones (Jonkers and Taviani, 1998; Taviani and Zahn, 1998; Taviani et al., 2000). The first unequivocal documentation of severe climatic conditions, comparable to those characterising Antarctica today, is the middle Pleistocene macrofauna hosted in the carbonate-unit of CRP-1 (Taviani and Claps, 1998; Taviani et al., 1998). The late and early Oligocene macrofaunal record of CRP-2/2A and CRP-3 also indicates conditions in the Ross Sea that, at that time, were warmer than present as suggested, among other, by the presence of non-polar bivalves, such as modiolid mussels in the late Oligocene sediments (Taviani et al., 2000; Taviani and Beu, in press).

Regarding the second issue, i.e. the evolution of polar biota, CRP drill cores suggest that the Oligocene-Miocene faunal stocks share many taxonomic (supraspecific) similarities with non-polar Tertiary faunas from the southern hemisphere, especially New Zealand (Beu and Maxwell, 1990). Combining drill evidence

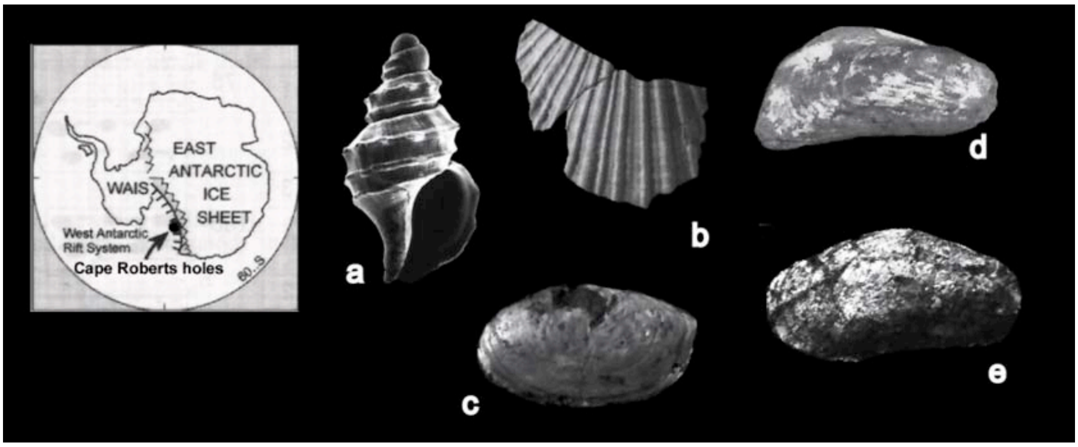

Figure 1. Selected macrofossils extracted from CRP drill cores are as follow: a) *Prosipho*, CRP-1 (middle Pleistocene); b) *Chlamys* sp., CRP-1 (early Miocene); c) *Yoldia* (*Aequiyoldia*) sp., CRP-2A (late Oligocene); d) ?*Modiolus* sp.1, CRP-2A (early Oligocene); e) ?*Modiolus* sp.2, CRP-3 (early Oligocene-?late Eocene).

in the Ross Sea with outcrop data in the Dry Valleys and the Antarctic Peninsula (e.g. Jonkers, 1998), it appears that the onset of true (modern) Antarctic biota took place sometimes between the late Pliocene and the middle Pleistocene. In fact, 1 million-year-old macro-faunal assemblages from the carbonate unit in CRP-1 are composed by extant taxa inhabiting the present Ross Sea (Dell, 1990). This record represents the oldest documentation of fully marine polar fauna thus far in Antarctica (Taviani et al., 1998).

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Late Pleistocene – Holocene Marine Diatom Record from the Palmer Deep, Antarctic Peninsula (ODP Leg 178, Site 1098)

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Late Pleistocene to Holocene climate variability in the Antarctic Peninsula is described using the marine diatom record of a 45-m advanced piston core recovered from ODP Leg 178, Site 1098 (Palmer Deep) (Shipboard Scientific Party, 1999). Multivariate statistical analyses are used to identify diatom community assemblages and total diatom abundance is calculated to provide a proxy for palaeo-productivity. Five diatom community assemblages are identified, which we are able to correlate to the distinct climate zones identified in the Palmer Deep by Domack et al. (2001):

- >13.2 kyr BP. Glacial ice present over the Palmer Deep site during the regional Last Glacial Maximum; diatoms absent.
- 13.2 – 11.0 kyr BP. Glacial ice retreats with climatic warming during a "deglaciation phase"; *Thalassiosira antarctica* assemblage deposited.
- 11.0 – 9.0 kyr BP. Seasonally open water present with diatom blooms occurring during a cooler "climatic reversal"; *Rhizosolenia* assemblage deposited.
- 9.0 – 3.7 kyr BP. Extensive periods of seasonally open water associated with a warm "climatic optimum"; *Fragilariopsis kerguelensis* assemblage deposited.
- < 3.7 kyr BP. Increased sea-ice cover and duration associated with climatic cooling during the Late Holocene "Neoglacial"; *Cocconeis* assemblage deposited.

Sediment laminations characterised by *Corethron criophilum* were deposited in the climatic optimum / Neoglacial transition, 4.4 – 1.8 kyr BP. We hypothesize that the laminations formed rapidly during short-lived (inter-annual) bloom events with high settling rates, or were deposited over longer time periods.

Total diatom abundance (measured as valves / gram dry sediment) at Site 1098 supports our findings. Diatoms valves are absent at the base of the 45-m long record, when glacial ice covered the Palmer Deep site during the regional Last Glacial Maximum (LGM). Well-preserved valves, in quantifiable abundance, are deposited after glacial ice retreat. Valve abundance (i.e. palaeo-productivity) fluctuates in tandem with the different diatom assemblages and transitions from cool to warm climate phases. Maximum palaeo-productivity occurs during the mid Holocene climatic optimum; the lowest period of diatom palaeo-productivity (since the post-glacial period) occurs during the last 500 years.

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Stable Isotopic Records of Pleistocene Climate Variability in the Prydz Bay Region, from ODP Site 1167

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We have constructed an isotopic record from foraminifers and sedimentary organic matter recovered at ODP Site 1167 (Fig. 1). The record shows gradual cooling, glacial/interglacial cycling, and sedimentation events that have occurred since the latest Pliocene/early Pleistocene in the Prydz Bay region of eastern Antarctica. Foraminifers have rarely been recovered in close proximity to the Antarctic continent and past ice margins where fluctuations in the size of the Ice Sheet and the associated isotopic signal should be most clear. Hence, the isotopic record from this location allows us to examine past glacial activity in the Prydz Bay region as well as long-standing questions about the stability of the East Antarctic Ice Sheet (e.g. Webb et al., 1984; Stroeven and Prentice, 1997) since the latest Pliocene.

Oxygen and carbon isotopes measured on the planktonic foraminiferal species *Neogloboquadrina pachyderma sinistral (s)* show a dynamic history of Quaternary climate change in the region (Fig. 2). Oxygen isotopic ratios ($^{18}O/^{16}O$) show a gradual ~2‰ increase from the bottom to the top of the section reflecting the long-term cooling trend over this time. In the upper 50 m, fluctuations of roughly 0.5 to 1‰ amplitude may indicate the preservation of glacial/interglacial cycling (Fig. 3). Carbon isotopic ratios ($^{13}C/^{12}C$) increase by over 4‰ from the bottom to top of the section. There is a notable $\delta^{13}C$ increase of ~1.5‰ in the upper 40 m of the core with a marked increase of over 1‰ in the uppermost 10 m. These changes reflect variability in upper water column nutrient concentrations and/or air-sea exchange of CO_2 accompanying glacial/interglacial transitions (Charles et al., 1993). In general, both carbon and oxygen isotopic ratios appear to be more variable below ~210 mbsf. Particularly large and abrupt changes in carbon and oxygen isotopic values at the base of the section and between 370 and 360 mbsf suggest important climate events in the latest Pliocene-early Pleistocene.

The oxygen isotopic record is well correlated with natural gamma logs collected at Site 1167 through logging while drilling (Shipboard Scientific Party, 2001; Fig. 3). The relationship between these two proxies demonstrates a connection between sedimentation on the slope and isotopic signature which are both, in turn, related to climate. Hence, fluctuations in natural gamma and isotopic values may record a number of distinct debris flow events, which correspond to glacial/interglacial cycles. Analyses of total organic carbon (TOC) and carbon isotopic values of sedimentary organic matter are fairly uniform over the course of the record, although sharp changes occur in thin hemipelagic clay intervals at ~215 mbsf and smaller changes occur in the uppermost part of the section. These changes are related to shifts in sediment sources, which are influenced by climate. Higher resolution isotopic analyses of *N. pachyderma* should make correlation with recognised Marine Isotopic Stages possible in the upper 50-110 m of section and provide better age control for Site 1167.

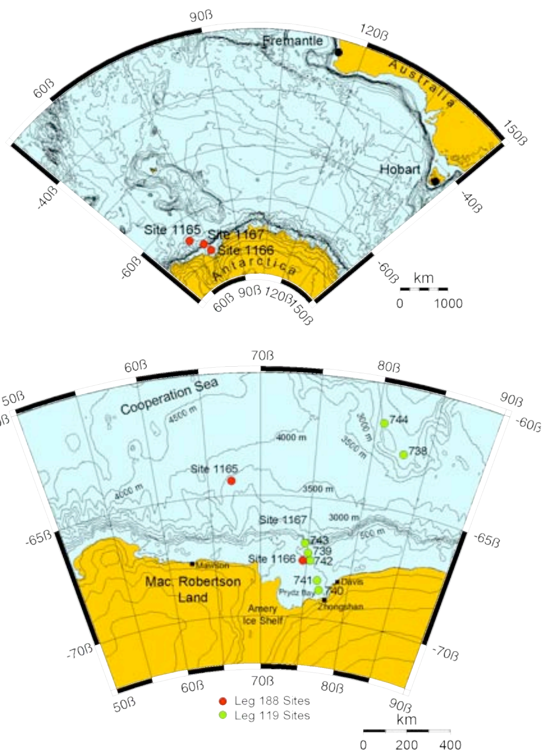

Figure 1. Regional and local maps of drilling sites from ODP Legs 119 and 188 in the Prydz Bay and Kerguelen Plateau regions (from Cooper and O'Brien, ODP Leg 188 prospectus).

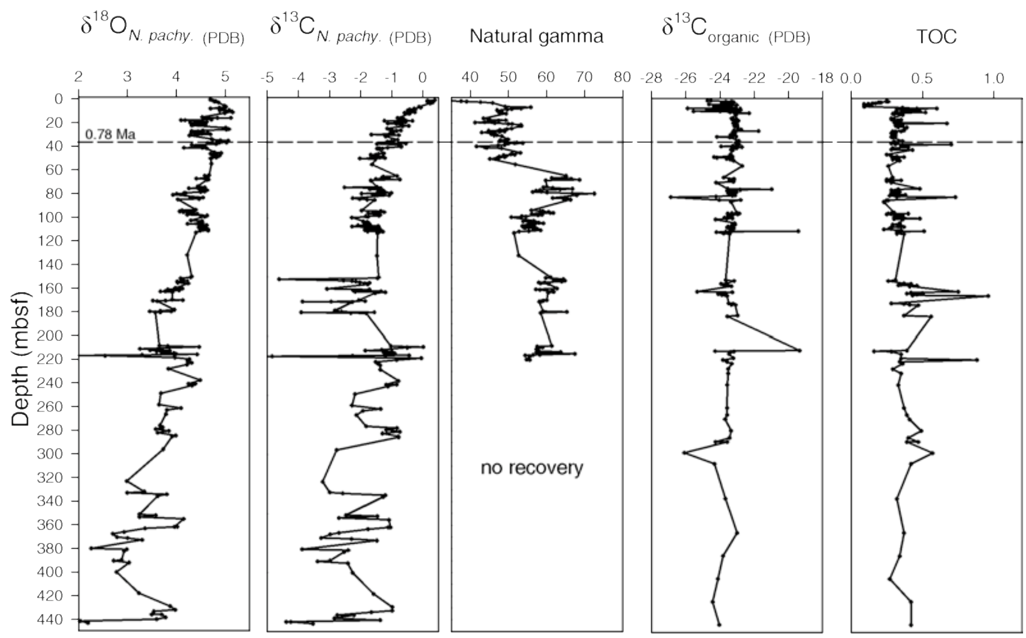

Figure 2. Plots of Site 1167 proxies: Carbon and oxygen isotopic values from *N. pachyderma*; natural gamma values; and carbon isotopic values and Total Organic Carbon (TOC) from sedimentary organic matter.

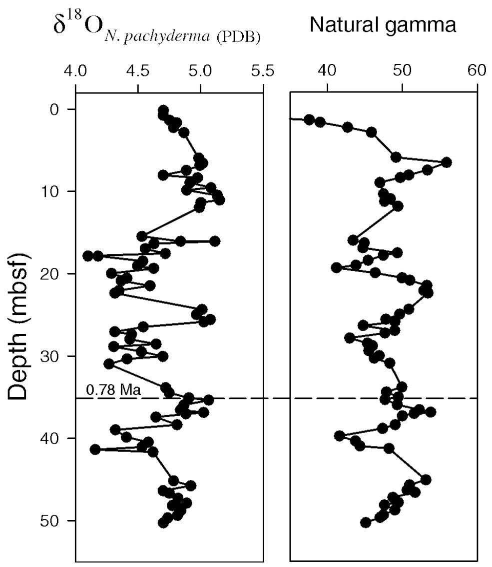

Figure 3. Plots of oxygen isotopic values and natural gamma from the upper 50 m of Site 1167. Note the correlation between these two records and the periodic fluctuations typical of glacial/interglacial transitions.

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Palynology of Cenozoic and Mesozoic Sequences on the East Antarctic Continental Margin - A Review

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Here we review sequences that have recently been examined palynologically during Leg 188 drilling in Prydz Bay, (Macphail and Truswell, 2000) and identify correlative sections within the region.

Cenozoic sequences

Site 1166 provides a key for understanding the stratigraphy of Prydz Bay and adjacent regions. Relatively abundant palynomorphs were recovered from the interval 145.5 m to 267.18 m, allowing an age of Mid to Late Eocene to be determined. Spores, pollen and dinocysts are abundant in most sampled cores; age control is provided primarily by the dinocysts, with reinforcing from a limited number of spore and pollen species.

Broad age control rests on the overall aspect of the dinocyst assemblage. Represented here is the 'Transantarctic Flora' - an assemblage of dinocysts first identified in erratics in McMurdo Sound, but known now from sites on the Antarctic Peninsula, in the Ross and Weddell seas, and in the South Atlantic. In much of Antarctica, the flora is distinguished by the species *Arachnodinium antarcticum*. Curiously, this species does not appear to be present at any of the east Antarctic sites. Generally, the flora is dominated by species of *Deflandrea* - originally described from the McMurdo erratics as *D. antarcticum*. The dominant species in Prydz Bay is similar to, but not identical with, *D. antarcticum*, and is referred to here by the manuscript name of *D. prydzensis*. Comparison with assemblages from relatively well-dated sequences in south-eastern Australia has enabled firmer age controls to be established on the Antarctic material. New work on Tasman Rise sequences provides an added geographic link between Australia and high latitude regions. Key age determining species include *Tritonites spinosus*, a minute form that appears in the latest Middle Eocene in the Gippsland Basin and South Tasman Rise; *Vozzhenikovia* sp.cf. *Gippslandia extensa*, with a Late Eocene range; and *Corrudinium* sp.cf. *incompositum* from the Late Eocene. Pollen species supporting these age determinations include some forms that are rare in the Antarctic material.

All pollen floras are dominated by pollen of the Southern Beech, *Nothofagus*, (present in frequencies of 41 - 57%) with lesser amounts of gymnosperms. Spores of cryptogams - ferns, mosses and liverworts - are rare. These abundances of spore and pollen species suggest that the source vegetation was a floristically impoverished gymnosperm - *Nothofagus* rainforest or scrubby rainforest, with a high degree of deciduousness, rather than tall tree communities.

Correlative sequences were identified within Site 742, drilled on Leg 119, but palynological examination of the units cored was much less detailed. From the Mac Robertson Shelf, shallow coring has indicated sedimentary sequences of comparable age and depositional environment at the seaward end of Iceberg Alley, and in samples from the wall of the Neilsen Basin, further east. Age determination there was strengthened by the presence of *Tritonites pandus*, which first appears in southern Australian basins in the late Middle Eocene (Quilty et al., 1999).

Mesozoic sequences

In Site 1166, all core-catcher samples below 267.18 m yielded relatively sparse palynofloras representing Late Cretaceous time. Dinoflagellate cysts are relatively rare. A provisional age determination of Turonian - ?Santonian rests largely on age diagnostic spores and gymnosperm pollen abundances, with some of these known only as manuscript species in the Gippsland and Bass Basins of southeastern Australia. Apart from the occurrence of the gymnosperm pollen *Phyllocladidites mawsonii*, age determination relies on the presence of undescribed species of *Coptospora*, *Dilwynites*, *Gleicheniidites*, and *Laevigatosporites*. Two rare dinocysts accord with this determination.

The pollen suite appears to have been produced by a vegetation dominated by conifers, perhaps widely spaced, in accord with low light angles found at high latitudes. A diverse fernland may have formed the understorey, with fern-dominated heath in open areas.

Sites drilled during Leg 119 yielded two sequences dated palynologically as Late Cretaceous. At Site 742, one interval yielded a sparse Late Cretaceous palynoflora that may be correlative of the Turonian - ?Santonian section encountered in Site 1166. At Site 741, the deepest unit cored yielded fairly diverse, fern-dominated spores and pollen corrrelating well with Australian Albian sequences.

On the Mac Robertson Shelf, the Neilsen Basin provided a remarkable suite of palynomorph assemblages that are apparently recycled, but are close to their source sediments, and relatively unmixed (Truswell et al., 1999). These suites, which are terrestrial in origin, range in age from late Middle Jurassic to Early Cretaceous, and are correlated with zonal sequences from the Perth Basin of Western Australia.

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Biostratigraphic Characterisation and Quaternary Microfossil Palaeoecology during Glacial-Interglacial Deposition on Sediment Drifts West of the Antarctic Peninsula: Results from SEDANO Project

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The SEDANO (SEdiment Drifts of the ANtarctic Offshore) Project recovered 19 gravity cores on the sediment drifts from the Pacific continental margin of the Antarctic Peninsula (Pudsey and Camerlenghi, 1998). Fifteen cores have been sampled for an integrated biostratigraphic-palaeoecological study based on calcareous nannofossils, planktic and benthic foraminifer and diatoms occurrence, framed in a depositional process reconstruction. Glacial and interglacial cycles are characterised by barren grey laminated, and brown bioturbated hemipelagic sediments, respectively. Sedimentological and compositional investigations pointed out distinctive differences in between the finer glacials and the relatively coarser interglacials. Glacial sediments are inferred to be produced by deposition from SW-flowing bottom current fed by the suspended load of turbidite flows and turbidity plumes, whereas interglacials are inferred to be produced mainly by hemipelagic fallout and ice-rafted debries (IRD). Up to six units have been recognised on the basis of these characteristics, and labelled from A to G (Lucchi et al., this volume).

Refinements of the unit boundaries were drawn by means of the microfossil distribution (Fig. 1). Analyses from both intervals allowed us to make comparisons between the microfossil occurrence in the glacial and interglacial cycles.

Peaks of diatom occurrence well correlate with the interglacial units and indicate high productivity and an open-ocean type of assemblage.

The presence of the diatom *Thalassiosira lentiginosa* in every core, from the base to the top, and the absence of *Actinocyclus ingens* infer an age younger than 650 ky; a more detailed age assignment was possible on the basis of the presence, in unit C, of the calcareous nannofossil *Emiliania huxley*. The abundance pattern of the latter suggests for Unit C an age range between 270 ky (First Occurrence) and 70 ky (acme beginning). A foraminiferal assemblage, made up of the sinistral coiling form of *Neogloboquadrina pachyderma* and few benthics, occurs as the nannofossil assemblage only in the interglacial Unit C.

On the basis of sedimentological and micropalaeontological evidences the interglacial Unit C is correlated to Oxygen Isotope Stage 5, thus dating the unit boundaries at 127 ky and 70 ky.

Calcareous microfossils are present in most of the cores examined and their discontinuous occurrence may indicate key environmental relationships. Tentative correlation of their occurrence to temperature tolerance, ice-free sea surface water (interglacial), nutrient availability, and factors limiting primary productivity are discussed.

Correlation of microfossil occurrence with clay mineral analyses added information on the palaeoecology and palaeoproductivity of the microfossil occurrence. Clay analyses indicate different distribution of smectite and chlorite, the first dominating during interglacial, and the second during glacial; traces of kaolinite occur in interglacial units.

Correlation of microfossil occurrence with magnetic susceptibility data helped to constrain the age assignment.

The present study contributes to a future map reconstruction of the distribution of the studied organisms in the late Quaternary Southern Ocean.

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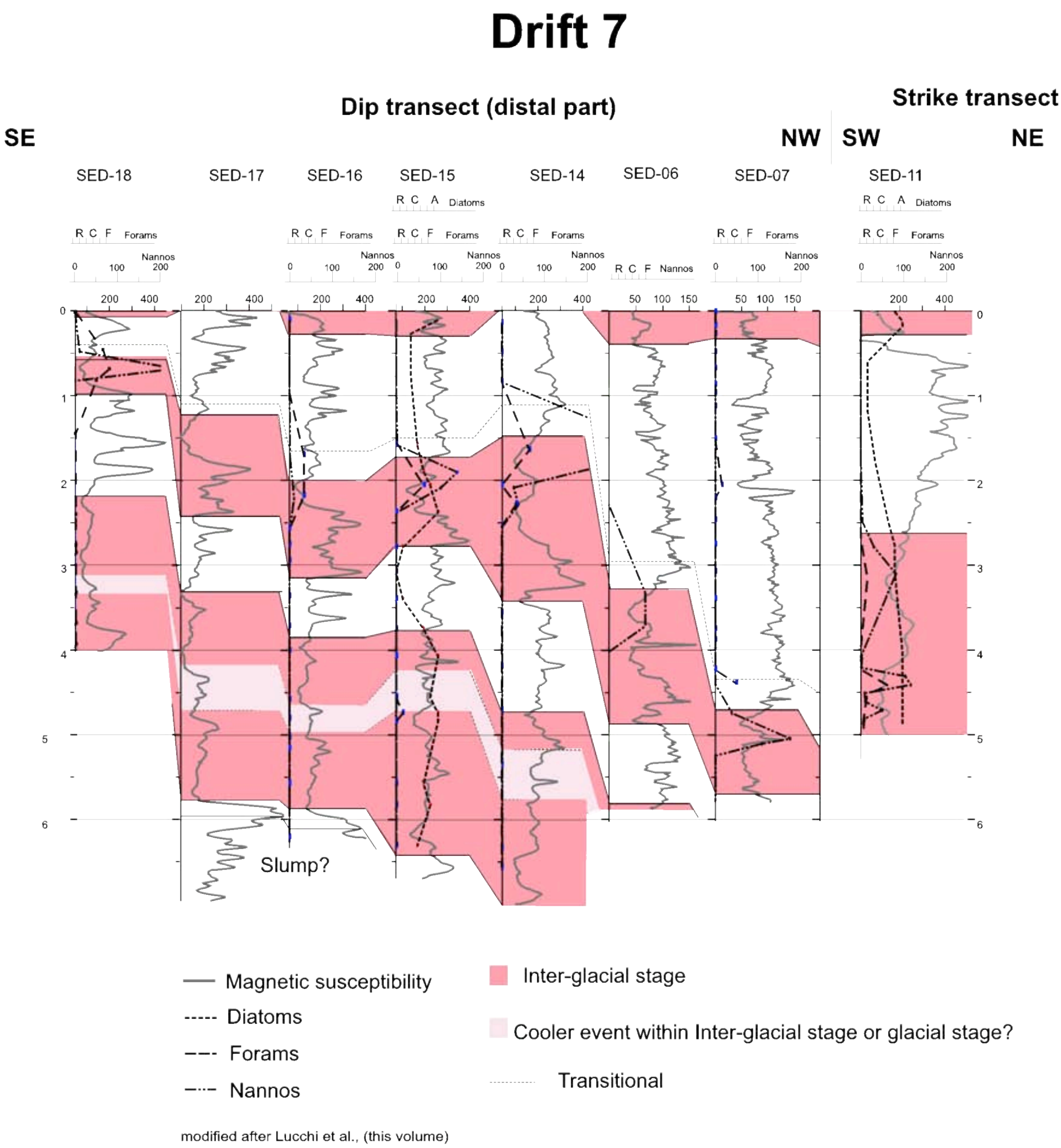

Figure 1. Microfossil distribution on the gentle (NE) and distal (NW) sides of Drift 7.

Seismic Velocity Analysis, Vertical Seismic Profile, Logging and Laboratory Physical Properties, ODP Leg 178, Antarctic Peninsula

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We have re-analysed the porosity, bulk density, and seismic velocity information collected from continental rise sites 1095, 1096, and 1101, ODP Leg 178 (Barker et al., 1999) (Fig. 1). The purpose of this study is three-fold:

1) to provide a comprehensive, composite digital set of data readily available for future studies aimed at well-seismic correlation;

2) to critically analyse overlapping sets of physical parameters and acoustic velocity collected with different methods (downhole logging, core logging, laboratory determination, derivation from seismic data), and in different holes of the same site. These data not always provide the same information, due to difficulties encountered at each specific hole, or due to methodological differences;

3) to provide a basic correlation between these parameters and multichannel seismic data.

The down hole logging (performed only at Sites 1095 and 1096) did not provide reliable data at least regarding sediment bulk density and porosity. This is because of poor hole conditions encountered in a fine grained, generally underconsolidated formation. Between core logging and laboratory measurements on core samples, we privilege the latter. This is because the multiple hole drilling strategy, and the generally good core recovery, allowed the collection of a high number of properly and evenly spaced measurements (generally one per core section) on cores.

The vertical profile of porosity and density allows us to identify anomalous consolidation trends in all three sites, likely induced either by rapid sediment accumulation or/and presence of biogenic silica in the sediment. The velocity profiles obtained also with vertical seismic profiles and tomographic inversion of travel times, allowed us to perform a travel time-depth correlation between site survey multichannel seismic profiles and borehole data.

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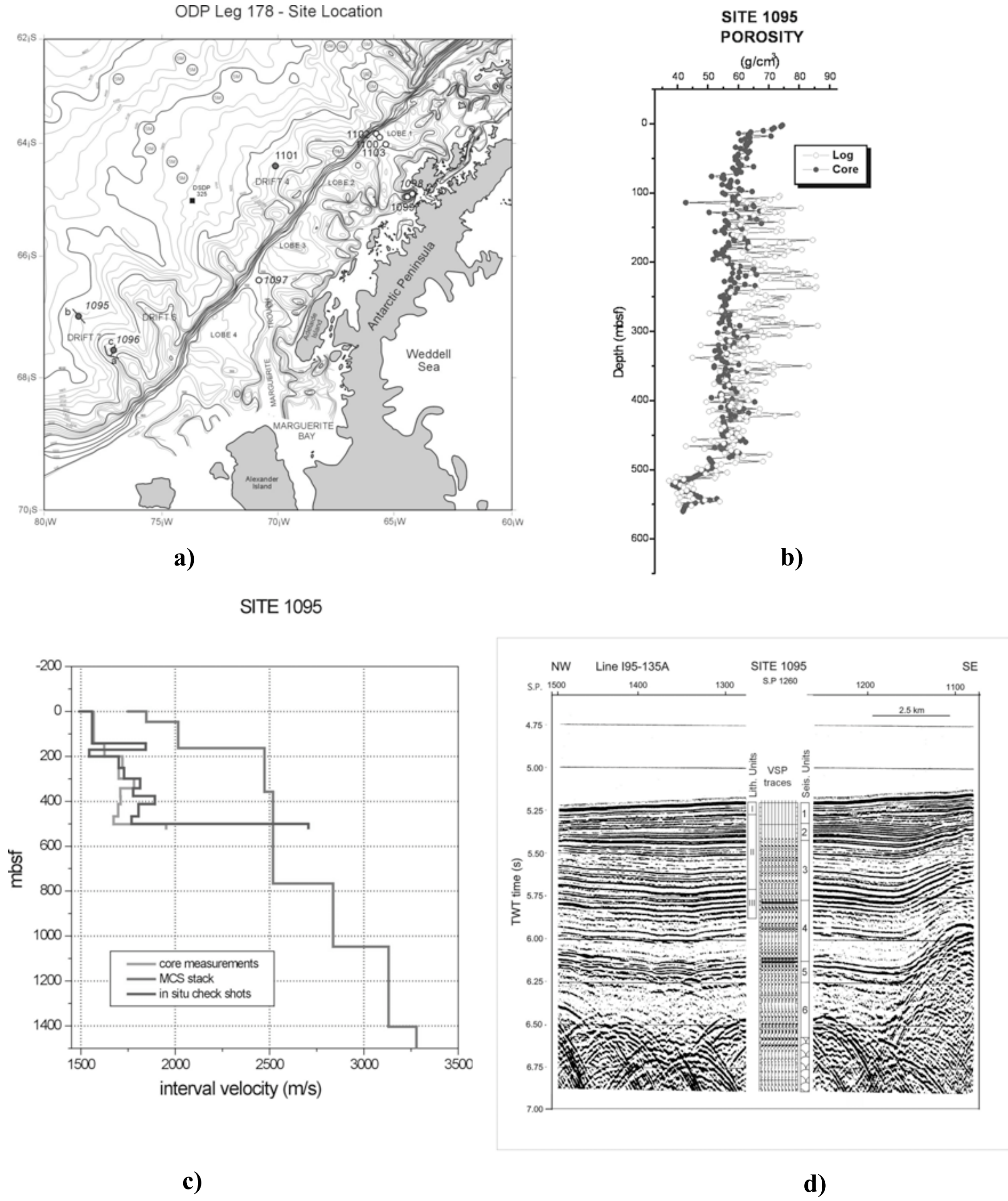

Figure 1. **a)** Location map of ODP Sites 1095, 1096, and 1101. **b)** Comparison between the downhole logging (APLC, APS) porosity (grey curve) and porosity from the index properties (IP) measurements in the laboratory (black curve). **c)** Comparison among interval velocities obtained with the *in situ* velocity check-shots (VSP), stacking velocities and core log velocity. **d)** Vertical Seismic Profile and tie in two way travel times between lithostratigraphic and seismostratigraphic units.

Pliocene Coarse-Grained Debris at Ocean Drilling Program Site 188-1165, Prydz Bay, Antarctica

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Site 188-1165 Hole B was drilled on the Wild Drift on the Continental Rise off Prydz Bay, East Antarctica (64˚ 22.77'S, 67˚ 13.14'E, 3537 m) (Shipboard Scientific Party, 2001). We are carrying out detailed analyses of sand-sized material at that site, using methodology described by Allen and Warnke (1991). Our efforts are currently concentrated on the interval between 15 and 50 mbsf, which contains the Gauss normal polarity Chron (2.581 to 3.580 Ma) including the Kaena (3.040 to 3.110 Ma) and Mammoth (3.220 to 3.330 Ma) Subchrons which are well identified at this site (timescale of Berggren et al., 1995). This interval is important because it contains the PRISM2 (Middle Pliocene Palaeoenvironmental Reconstruction) time slab (3.15 to 2.85 Ma) described by Dowsett et al. (1999). The global ice volume, and consequently, sea-level stand during this period of past global warmth is important because it may provide an indication of how Earth may respond to future global warming (Dowsett et al., 1999). Although our investigations are still in progress, preliminary results are available.

• Texturally, all samples fall in the mud category as follows: mud, sandy mud, slightly gravelly mud, slightly gravelly sandy mud. One sample was gravelly mud. Textural classification is after Folk (1980).

• All samples, regardless of textural classification, have a sand-sized component (0.0625 to 2 mm), but many samples are without a gravel component. The 0.15 to 2 mm fractions of the sand-sized components consist primarily of lithogenous (terrigenous) material — biogenous components (mainly radiolarians) are rare. Lithogenous components are quartz, feldspar, mafic minerals, lithic fragments of all three rock families, coal, etc. Quartz consists of several populations, including clear and clouded quartz, quartz with rutile and other inclusions, and quartz as component of lithic fragments.

• Although some quartz grains are well rounded, a few having the characteristics of wind-blown grains, the vast majority of quartz grains exhibit the mechanical breakage features typical of glacial environments such as conchoidal fractures, step-like fractures etc. No, or very little, rounding is discernible on these grains.

• A remarkable component of the same sand-size fractions is "garnet-coloured" garnet. It is optically indistinguishable from garnet recently discovered in a few Pleistocene samples in piston core TN0-57-6-PC4, raised in the South Atlantic (42˚ 52.1' S; 8˚ 57.7'E, 3751 m), suggesting that icebergs calving from marine termini in Prydz Bay may occasionally reach that far distant site. Garnet grains show mechanical breakage features indicative of glacial environments.

The stability of the Antarctic Ice Sheets during the Pliocene was and is the subject of much debate. This debate centres on the Gauss Chron, 2.581 to 3.58 Ma on the Berggren et al. (1995) timescale. The two opposing views of Pliocene ice stability are: (1) the ice sheets were relatively stable (Robin, 1988; Hodell and Warnke, 1991; Kennett and Hodell, 1993; Warnke et al., 1996; Burckle et al., 1996); or (2) the ice sheets fluctuated significantly in size (Webb and Harwood, 1991; Hambrey and Barrett, 1993; Quilty, 1993). Our preliminary results can provide some guides in this debate.

At this time, we cannot confidently identify transport mechanisms for the sand-sized components of our samples: Near-bottom currents, sea-ice rafting, and rafting by icebergs probably all were involved. The overwhelming preponderance of mechanical-breakage (i.e. glacial) features on the quartz grains indicates that most of the quartz grains were subjected to grinding by glaciers. This fact also indicates that during the time period studied here, Antarctic glaciers reached the coast and had marine termini. Indeed, Antarctic icebergs travelled as far as the Meteor Rise in the South Atlantic as described by Warnke et al. (1996).

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Radiolarian Biostratigraphy of Site 1165, ODP Leg 188, Antarctic Margin near Prydz Bay

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Well-preserved radiolaria from an expanded Neogene section were recovered from ODP Leg 188, Site 1165, Holes l165B and 1165C, a drillsite on the base of the continental rise near Prydz Bay. Thirty two diatom and radiolarian datums were recognised during the cruise in the ~999 m long composite section, and provide the primary basis for initial age estimates. These data indicate a relatively continuous lower Miocene to upper Pliocene section that underlies a thin Quaternary cover. All of the well-preserved and age diagnostic radiolarian samples were found at ~488 metres below seafloor (mbsf) and above.

Middle and high latitude Cenozoic radiolarian zones of Lazarus (1992) and Abelmann (1992) were applied to Leg 188 radiolarian material. The middle Miocene to Pleistocene zonation of Lazarus is based on the earlier schemes of Hays (1965), Chen (1975), Keany (1979), and Caulet (1991) and refined by Lazarus (1992) using sediments recovered on Legs 119 and 120. The early to middle Miocene zonation of Abelmann (1992) is based on radiolarian studies from Legs 113 and 120. Table 1 shows the ages of biostratigraphically useful radiolarian datums from these zonations calibrated to the Berggren et al. (1995b) geomagnetic polarity time scale.

Over 400 samples have been prepared and analysed from Site 1165. Samples were taken from the cores both at regular intervals, and from lithologies that are more likely to yield good radiolarian preservation in order to locate biostratigraphic events more accurately within cores. About 10 cm^3 of sediment/sample was disaggregated and boiled with 10% H_2O_2 and 1% Calgon solutions. Some samples were cleaned with 10% HCl when necessary. Samples were washed on a 63-µm or 45-µm mesh sieve then briefly ultrasonified. Strewn slides were made of the best yielding samples with Canada Balsam as a mounting medium. The 10 zones currently recognised in Core 1165B and 1165C are summarised in Table 2. Work continues on both the preparation of samples and study of strewn slides, particularly for the interval between 300 and 488 mbsf.

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Table 1. Summary of radiolarian biostratigraphic datums recognised in Holes 1165B and 1165C

Radiolarians			**Age , Ma***
LO	*Prunopyle titan*	>	3.5
FO	*Helotholus vema*	<	4.57
LCO	*Lychnocanoma grande*	>	5.03
FO	*Acrosphaera? labrata*	<	7.79
LO	*Cycladophora spongothorax*	>	9.12
FO	*Acrosphaera australis*	<	10.36
LO	*Cycladophora humerus*	>	10.53
LO	*Acinonomma golownini*	>	10.77
FO	*Cycladophora spongothorax*	<	12.55
FO	*Cycladophora humerus*	<	14.18
FO	*Cycladophora golli regipileus*	<	19.11

*Ages recalculated to Berggren 1995 by Weinheimer in Leg 178 Shipboard Scientific Party, 2000

Table 2. Radiolarian zones recognised in Cores 1165B and 1165C, ODP 188

Zones	**Samples**	**Meters below sea floor**
Phi (Lazarus, 1992)	3H-2, 19-20 and 3H-2, 94-95	18-19.3
Base: last occurrence of *Helotholus vema*. Top: last occurrence of *Eucyrtidium calvertense*. *E. calvertense* appears in these samples but *H. vema* is absent.		
Upsilon (Lazarus, 1992)	3H-4, 19-20 - 6H-4, 19-20	21-49.5
Base: first appearance of *Helotholus vema* which occurs in all the above samples. Top: last occurrence of *H. vema.*		
Tau (Lazarus, 1992)	6H-6, 94-95	53.8
Base: last appearance of *Amphymenium challengerae* which appears in the underlying samples.		
Amphymenium challengerae (Lazarus, 1992)	8H-3, 19-20 and 8H-6, 19-20	67-71.5
Base: first appearance of *A. challengerae*. This species is present in all the above samples.		
Acrosphaera? labrata (Lazarus, 1992)	9H-1, 94-95 - 11H-5, 19-20	74.8-98.45
Base: first occurrence of *A.? labrata*. This species was present in all the above samples.		
Siphonosphaera vesuvius (Lazarus, 1992)	13H-2, 19-20 - 13H-4, 19-20	108-111
Base: last occurrence of *C. spongothorax*. Top: first occurrence of *A.? labrata. S. vesuvius* is present in these samples.		
Acrosphaera australis (Lazarus, 1992)	14H-2, 19-20 - 22X-3, 94-95	117.5-180
Base: evolutionary transition *A. murrayana* to *A. australis*. *A. australis* is common in all the above samples. Top: last occurrence of *C. spongothorax* which is present in these samples. *Ceratocyrtis stigi* is present in Sample 1165B-16H-CC and is reported to occur toward the top of the *A. australis* Zone.		
Cycladophora spongothorax (Lazarus, 1992)	22X-7, 19-20 - 24X-3, 94-95	184.7-198.75
Base: first appearance of *C. spongothorax*. This species is present in all the above samples. *Actinomma golownini* is present and is reported to have its last appearance near the top of the *C. spongothorax* Zone.		
Actinomma golownini (Abelmann, 1992)	not recognised	
Cycladophora humerus (Abelmann, 1992)	34X-2, 94-95 - 34X-6, 94-95	284.2-290.2
Base: first appearance of *Cycladophora humerus* which is present in the above samples. Top: first appearance of *Actinomma golownini.*		
Eucyrtidium punctatum (Abelmann, 1992)	not recognised	
Cycladophora golli regipileus (Abelmann, 1992)	40X-7, 19-20 and 54X-5, 19-20	346.75-478.8
The base of this zone is represented by the first occurrence of *Cycladophora golli regipileus* which was identified in these samples.		

Quaternary-Pliocene Diatom Biostratigraphy of Prydz Bay (ODP Leg 188 Sites 1165 and 1166)

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Quaternary-Pliocene sediments were recovered from the continental shelf (Site 1166) and shelf slope (Site 1165) of Prydz Bay, Antarctica, during ODP Leg 188 (O'Brien et al., 2001). Age interpretations for these sections were based on diatom and radiolarian biostratigraphy with palaeomagnetic control in limited intervals. Diatom biostratigraphy relied on zonal schemes devised from the Southern Ocean, Kerguelen Plateau deep-sea sections (e.g. Harwood and Maruyama, 1992), and Antarctic continental shelf, Ross Sea sections (Winter and Harwood, 1997). Both zonal schemes were applicable to Site 1166 strata; however, at Site 1165 the more oceanic Kerguelen Plateau zonation was most useful. Fossiliferous horizons were sporadic throughout Hole 1166A. Quaternary sediments were recovered from the top of Hole 1166A, and two upper Pliocene sediments beds from between ~114 and ~115 metres below the seafloor surface. The Pliocene beds in Hole 1166A are either disconformable or conformable, depending upon the application of the Kerguelen Plateau or Ross Sea zonal schemes. This disparity arises from the biostratigraphic application of the last occurrence of *Thalassiosira insigna*. This taxon biostratigraphically overlaps with *Thalassiosira vulnifica* in Hole 1166A, as it does on the Kerguelen Plateau, but does not biostratigraphically overlap with *T. vulnifica* in the Ross Sea. *Thalassiosira elliptipora* also has a different biostratigraphic range on the Kerguelen Plateau to that from the Ross Sea. At Site 1166 *T. elliptipora* occurs in moderate abundance within the range of *T. vulnifica*, which is consistent with observations from the Ross Sea. These data suggest that the Pliocene Prydz Bay diatom assemblages at Site 1166 have affinity with both the open-ocean and Antarctic continental shelf assemblages. Quaternary-Pliocene sediment recovered from Hole 1165B contain rich diatom assemblages, although in variable states of abundance and preservation. The Kerguelen Plateau diatom zonation was applicable to Hole 1165B. However, a few datums appear to be diachronous relative to other Southern Ocean sites and some taxonomic refinements are needed, such as:

• The last occurrence of *Fragilariopsis barronii* is unclear, as it is difficult to distinguish this taxon from earlier forms of *Fragilariopsis kerguelensis* and *Fragilariopsis ritscherii*.

• The first occurrences of *Fragilariopsis praeinterfrigidaria* and *Thalassiosira inura* are contemporaneous on the Kerguelen Plateau, but at Site 1165 *F. praeinterfrigidaria* occurs before *T. inura*.

• The first occurrence datum of *Thalassiosira oestrupii*, as recorded on the Kerguelen Plateau, is unreliable at Site 1165.

Diatoms and silicoflagellate assemblages from Holes 1165B and 1166A indicate variability in the Pliocene palaeoenvironment of Prydz Bay. Silicoflagellates (*Dictyocha*) and diatoms with a subantarctic affinity were noted in the lower Pliocene from Site 1165. Research that identifies cool and warm climatic phases from these proxies is in progress. Upper Pliocene sediment from Site 1166 contains a relatively high amount of the diatom *Eucampia antarctica* var. *recta* winter intercalary valves than winter terminal valves, in contrast to the modern distribution in Prydz Bay (Fryxell, 1991). These data suggest that intervals in the upper Pliocene of Site 1166 had lower concentrations of winter sea-ice than occurs today.

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Early and Middle Miocene Cycles in Downhole Logs from Site 1165, Prydz Bay, Antarctica

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Subtle rhythmic alternations between high porosity and low porosity sediment ("cycles") were observed in the Early and Middle Miocene of ODP Site 1165, offshore of Prydz Bay, Antarctica (Shipboard Scientific Party, 2001). The cycles were not immediately apparent from initial visual inspection of the core, but are evident in the downhole logs, particularly the resistivity logs. A post cruise study has been initiated to:

(a) determine which components of the sediment are responsible for the observed cycles (varying carbonate cementation or abundance of diatoms?);

(b) assess whether the cycles have a regular periodicity, and if so, use them to attempt a cyclostratigraphic dating of the poorly dated lower section of the hole; and

(c) assess the sedimentological and palaeoenvironmental causes of the cycles, in the context of the Southern Ocean and the Antarctic ice sheet.

In the lower part of the hole, the logs are punctuated by high amplitude spikes, which are caused by calcified beds, or intervals containing carbonate nodules, observed in the core. In addition to these clear log spikes, the sediment between them contains smaller, regularly spaced log peaks, or cycles (see Figure). Shipboard determination of the average thickness of these cycles and the (poorly constrained) sedimentation rate, lead to the working hypothesis that the cycles are precessionally controlled (~19/23 ky periodicity). We aim to analyse the major sediment components and mineralogy of closely spaced core samples from a small number of well-developed cycles, in order to determine which components of the sediment are behaving cyclically and causing the log signature.

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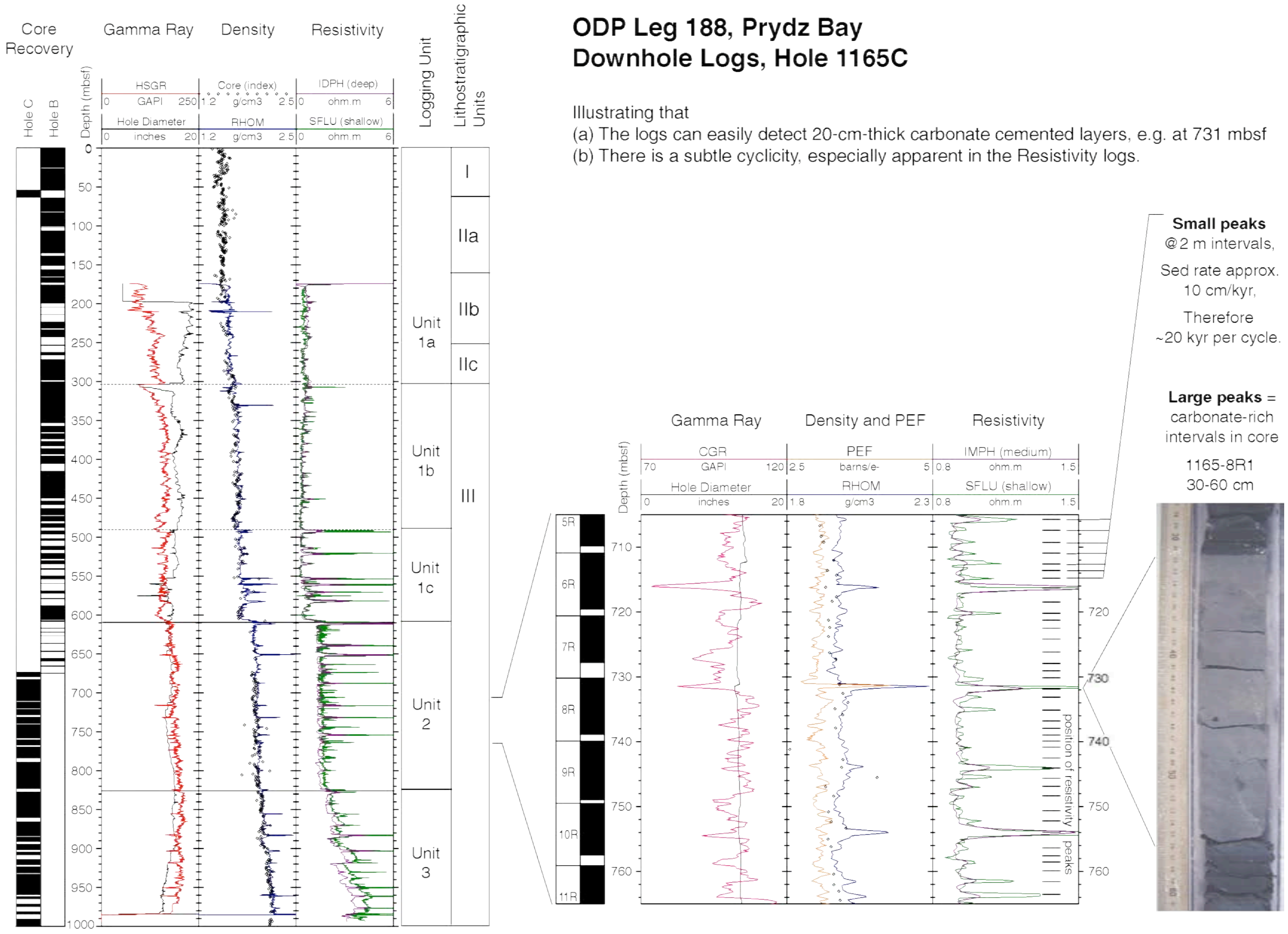

ODP Leg 188, Prydz Bay
Downhole Logs, Hole 1165C

Illustrating that
(a) The logs can easily detect 20-cm-thick carbonate cemented layers, e.g. at 731 mbsf
(b) There is a subtle cyclicity, especially apparent in the Resistivity logs.

Eocene-Oligocene Antarctic and Southern Ocean Climatic Deterioration: Phase Relationships between Climatic and Oceanic Cooling

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A new high-resolution Eocene-Oligocene benthic $\delta^{18}O$ stratigraphy is presented from ODP Site 689 (Maud Rise, South Atlantic; Fig. 1) (Barker et al., 1988). The Late Eocene record contains evidence of distinctive bottom-water cooling and warming trends with a 0.5‰ amplitude and a periodicity of 2-3 m.y., and culminates in a major 1.2‰ shift across the Eocene-Oligocene boundary and the Chron C13r/C13n transition. Environmental magnetic records from the CIROS-1 and CRP-3 cores drilled on the Antarctic margin in the Ross Sea also record climatic cooling and warming with a similar periodicity in the Late Eocene and major cooling across the Eocene-Oligocene boundary. The environmental magnetic signal is controlled by changing terrestrial weathering conditions on the Antarctic craton. Sea level shoaling and sedimentary facies indicative of ice grounding across the Antarctic shelf is not apparent in the CIROS-1 record until some 5 m.y. later at the early/late Oligocene boundary, although glacial facies are indicated in the CRP-3 core in the earlier Oligocene. Magnetic polarity stratigraphy allows direct comparison of the CIROS-1, CRP-3, and ODP Site 689 records. These correlations indicate that early Late Eocene episodes of cooling and warming at Maud Rise were initially out-of-phase with terrestrial climate in Antarctica by ~1 m.y. with Antarctic climate appearing to lead bottom water response. By latest Eocene/earliest Oligocene time (Chron C15n-C13n), however, Antarctic warming and cooling cycles were in-phase with bottom-water temperatures at Maud Rise, including the major cooling across the Eocene-Oligocene boundary. Despite the significance of the $\delta^{18}O$ shift at the Eocene-Oligocene boundary, it appears to indicate cooling only and Antarctica does not appear to have supported a major ice sheet until some 5 m.y. later in the latest early Oligocene.

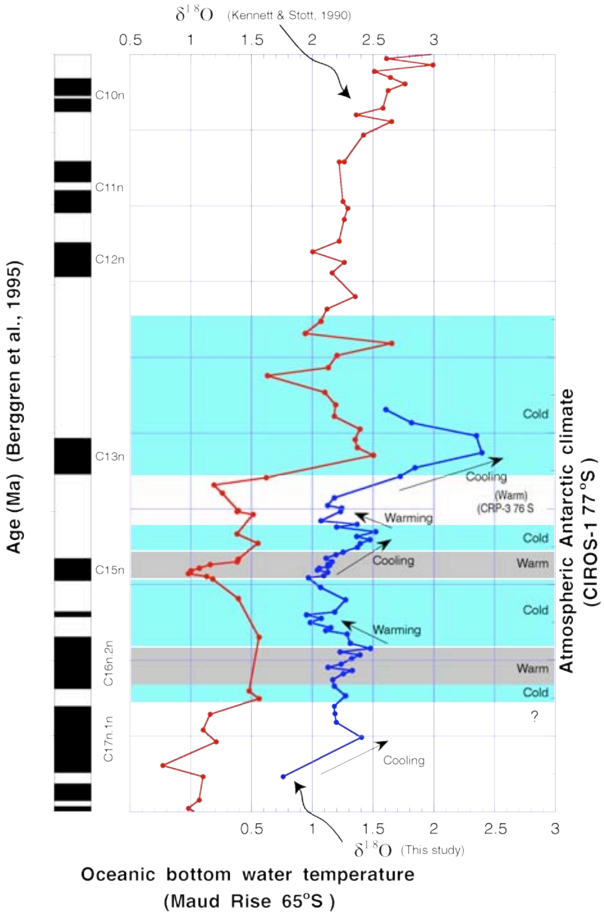

Figure 1. Comparison of Antarctic bottom water (AABW) temperatures from ODP Site 689 (Maud Rise) with Antarctic terrestrial climate (derived from CIROS-1 and CRP-3) across the Eocene-Oligocene boundary. AABW records are derived from $\delta^{18}O$ of cibicidoides. Left hand $\delta^{18}O$ record is original data from Kennett and Stott (1990). Right hand $\delta^{18}O$ record is new high-resolution record. It is offset for comparison. Terrestrial climatic interpretation is from environmental magnetic records of CIROS-1 (Sagnotti et al., 1998) and CRP-3 (Sagnotti et al., 2001). Palaeomagnetic chronology is combined from Wilson et al. (1998), Florindo et al. (2001), and Spiess (1990).

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Future Antarctic Margin Drilling - The ANDRILL Initiative and McMurdo Sound Portfolio

ANDRILL Steering Committee*

Deep-sea sediment records together with global climate models predict that Antarctic ice sheets have played an important role in the global climate and ocean system. However, the role of the Antarctic cryosphere in long- and short-order variations and major transitions is poorly understood and remains largely unproven. Due to the long-term existence of immense ice sheets and major erosional episodes during ice sheet expansion, stratigraphic records exposed on the Antarctic continent are rare and incomplete. Stratigraphic records from the Antarctic margin are comparatively more complete and their locations are ideally suited for recording and dating ice sheet oscillations and associated oceanic variations. In McMurdo Sound, these records are also key to deciphering the development of the West Antarctic Rift.

ANDRILL (ANtarctic DRILLing) is a multinational initiative to recover Antarctic margin stratigraphic records in a series of portfolios around the Antarctic continent using Cape Roberts Project technology (Cape Roberts Science Team, 1998) (Figs. 1 and 2). The McMurdo Sound Portfolio proposes a 7-8 year program of acquisition of new geophysical data and drilling with the following major aims:

1) To obtain high-resolution (1-100 k.y.), seismically linked, chronologically well-constrained, stratigraphic records from the Victoria Land Basin;

2) To document the fundamental behaviour of ancient ice sheets, and to better understand the factors driving ice growth and decay;

3) To decipher long and short-term evolution and timing of the development of the West Antarctic Rift system, associated volcanism, uplift of the adjacent rift-shoulder – the Transantarctic Mountains, associated tectonic stress regimes, and tectonic forcing of climate.

Currently proposed Ocean Drilling Program (ODP) Antarctic margin drilling (482-Antarctica glacial history/Wilkes Land Margin; 489-Ross Sea Record of Antarctic Ice Sheet Evolution; 503-East Antarctic Ice Shield and Weddell Basin) will not be realised before the end of the ODP program in 2003. This stratigraphic drilling initiative, therefore, represents the only possibility to recover stratigraphic records from the Antarctic margin within the next five years.

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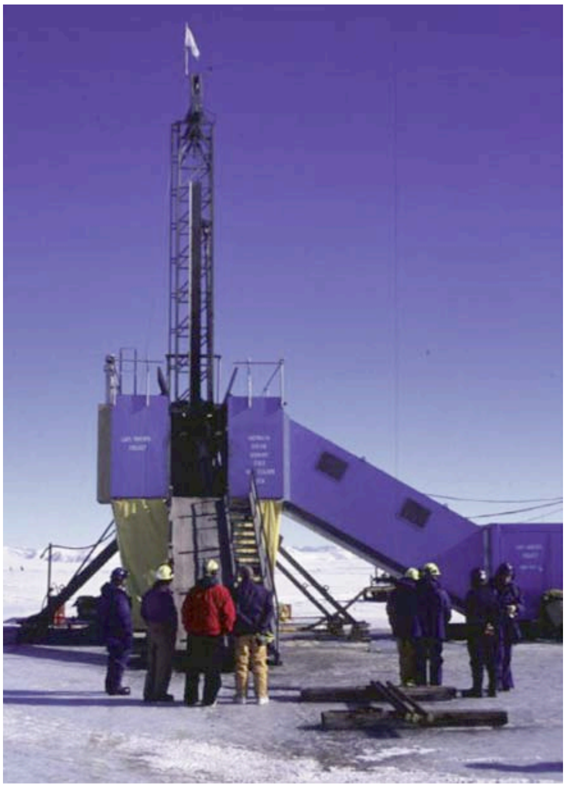

Figure 1. Cape Roberts Project technology. Seasonal and permanent ice fringes much of the Antarctic continent and provides an ideal platform for drilling and recovering marginal sedimentary basin records. Recent technological developments employed by the Cape Roberts Project drilling now allow deep sampling (c. 1500 m below sea surface) of stratigraphic successions that have accumulated on the Antarctic margin. The CRP drilling technology uses a floating ice platform and a recirculating mud system that routinely obtains >90% core recovery in glacigene strata. It can also drill on land and from a lake ice platform. Plans are in hand to modify the system to drill also through thick ice shelves and into the seabed beneath.

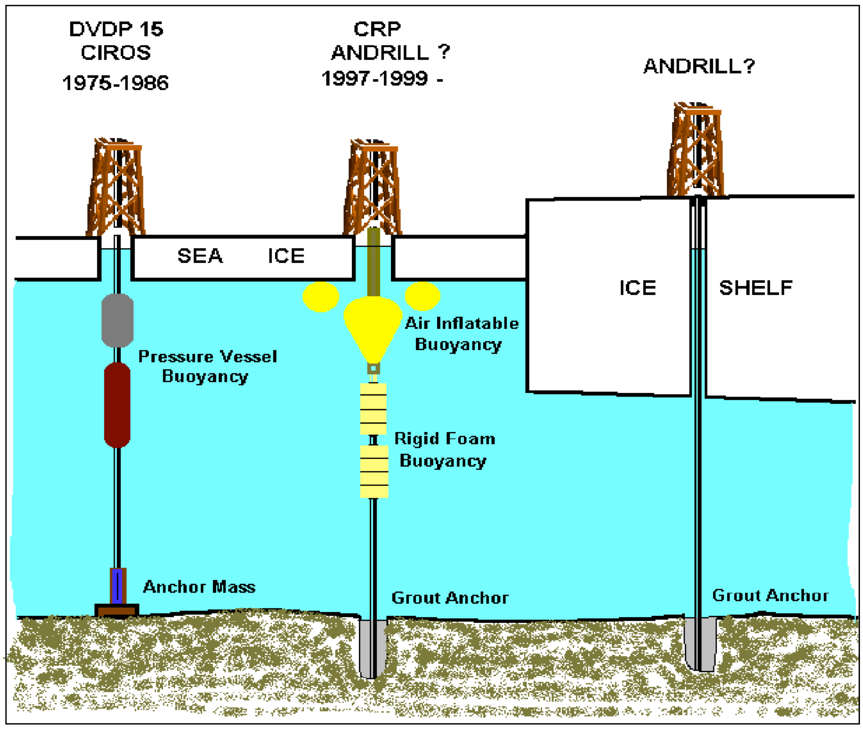

Figure 2. Sea riser styles used from 1975 to 1999 and proposed for ANDRILL Sea Ice and Ice Shelf Drilling. From 1975 to 1986 a riser tensioned with an anchor mass and integral steel pressure vessel buoyancy was used. From 1997 to 1999 CRP used a riser anchored into the sea floor and tensioned with a combination of rigid "syntactic foam" buoyancy and adjustable air filled buoyancy. Both risers are self-supporting and float free of the sea ice. The third style uses the ice shelf for support after anchoring into the sea floor (from A. Pyne).

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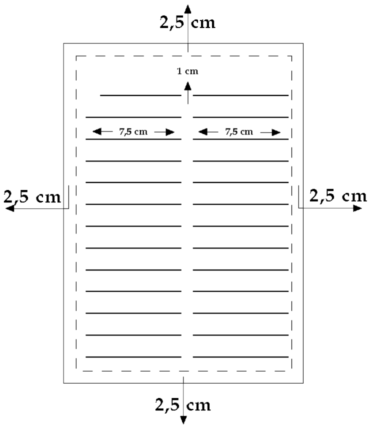

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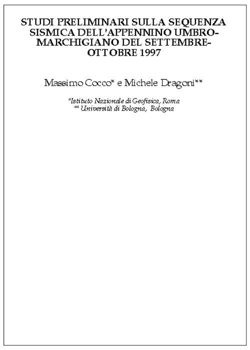

STUDI PRELIMINARI SULLA SEQUENZA SISMICA DELL'APPENNINO UMBRO-MARCHIGIANO DEL SETTEMBRE-OTTOBRE 1997

Massimo Cocco* e Michele Dragoni**

**Istituto Nazionale di Geofisica, Roma*
*** Università di Bologna, Bologna*

Testo:
carattere: times
corpo: 11
interlinea: 12 pt
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Massimo Cocco e Michele Dragoni: *Studi Preliminari sulla sequenza sismica...*

...nella sua configurazione definitiva, che si prevede raggiunta nel programma triennale seguente a quello in oggetto (2000-2002), la rete sarà composta da circa cento stazioni di cui venti dotate di terne sismometriche.

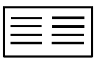
1. Reti Locali

Congiuntamente allo sviluppo della Rete Sismica Nazionale Centralizzata è previsto il completamento e lo sviluppo di alcune reti permanenti di monitoraggio locale al fine di approfondire lo studio di particolari aree di rilevante interesse scientifico e il potenziamento della struttura il cui compito è quello di effettuare un monitoraggio sismometrico temporaneo in occasione di forti eventi o nel caso di programmate campagne di...

1.1. Reti Locali Permanenti

1.1.1. Rete Colli Albani
Nel corso degli anni 1995-1996 sono state installate e collegate alla sede dell'istituto, tramite ponte radio, la quasi totalità delle otto stazioni previste. Nel triennio in oggetto è ...

2

testo in due colonne: 

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Running header: a partire da pagina 2
carattere: times, centrato
corpo: 9
autori: carattere normale
titolo: carattere corsivo (se troppo lungo va concluso con "...")
riga sotto l'header: sottile, 3 pt dal testo dell'header

esempio running header:

Massimo Cocco e Michele Dragoni: *Studi preliminari sulla sequenza sismica...*

Titoli paragrafi e sottoparagrafi:
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esempio numerazione: 1.
distanza dal testo precedente: n. 2 andate a capo
distanza del testo dal titolo del paragrafo: n. 1 andate a capo

Sottoparagrafo:
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esempio numerazione: 1.1.
distanza dal testo precedente: n. 2 andate a capo
distanza del testo dal titolo del sottoparagrafo: n. 0 andate a capo

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esempio numerazione: 1.1.1.
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nomi: stile corsivo
anno: stile normale

esempi citazioni: [*Bianchi e Rossi,* 1992] - [*Crosson et al.*, 1991]

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esempio bibliografia:

Crosson, R.S., M. Martini, R. Scarpa e S.C. Key (1996). *The Southern Italy earthquake of the 23 November 1980: an unusual pattern of faulting*. Bull. Seismol. Soc. Am., 76, 395-407.
Pantosti, D. e G. Valensise (1990). *Source geometry and long term behavior of the 1980 fault based on field geologic observations*, in: Proceedings November 1990 (Istituto Nazionale di Geofisica, Roma), 45-50.
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esempio didascalia:

Figura 1. Distribuzione cumulativa del numero di terremoti dal 4 settembre al 28 ottobre 1997.

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