ISSN 1122-8628

TERRA ANTARTICA
AN ANTARCTIC EARTH SCIENCE JOURNAL

Volume 6, Number 1/2 - 1999

Studies from the Cape Roberts Project
Ross Sea, Antarctica
Initial Report on CRP-2/2A

GUEST EDITORS

Christopher R. Fielding & Michael R.A. Thomson

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1999

	UE countries	*Other countries*
Professionals	27 Euros	32 Euros
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Overcharge for air mail despatch: 8 Euros/year

Orders for subscriptions should be sent to *Terra Antartica Publication* (see addrress below). Back issues are still available (except Volume 1); prices are the same as 1999.

The price of one single issue is 40 Euros.

Terra Antartica Publication

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Foreword

This volume is the third of several special issues of *Terra Antartica* to present the results of the Cape Roberts Project, in which the Antarctic programmes of Australia, Britain, Germany, Italy, New Zealand, and the United States of America are collaborating to take a series of cores off the Antarctic coast. The coring is being carried out with a drilling rig set on the fast sea-ice to investigate climatic and tectonic history of the region (Barrett & Davey, 1992; International Steering Committee, 1994). The first season's drilling in 1997 was curtailed at a depth of 148 mbsf (metres below sea floor) after an unusual storm-generated ice break-out, but the results obtained have wide implications for the regional geological history and are reported in both the Initial Report on CRP-1 (Cape Roberts Science Team, 1998) and a series of papers comprising the Scientific Report on CRP-1 (Hambrey & Wise, editors, in press).

Here we report on the successful drilling of CRP-2/2A to a depth of 624 mbsf, continuing the sampling of strata beneath those cored in CRP-1 last year. Sea-ice conditions were good and the refurbished sea riser functioned well, but drilling conditions were difficult in the boulder bed 5 m thick just below the sea floor and in the loose sand beds at several levels down to 550 mbsf. Nevertheless the problems were overcome with skill, experience and persistence of the drilling team. The Cape Roberts Science Team of 60 scientific, technical and support staff also had its challenges in describing, sampling and reporting on core from one of the most complex depositional settings on earth, and to a tight publication deadline. We thank all of those who took part in the project for their commitment to producing and reporting on the core in a timely way. We also look forward in late 1999 to the next Cape Roberts special issue, the Scientific Report, with a more detailed analysis of results of the 1998 drilling.

Peter Barrett

Carlo Alberto Ricci

November 1998

ACKNOWLEDGEMENTS

The Cape Roberts Project has been made possible through the financial and logistical support of the national Antarctic programmes of Germany, Italy, New Zealand, United Kingdom, the United States of America, and for Australia the James Cook University/University of Queensland consortium. In addition, DMT, Essen, Germany, helped to support the project by providing access to the CoreScan® and software at reduced rates. We are grateful to Dr G. Rafat, DMT, for his time in setting up the CoreScan® at the Drill Site laboratory. We also thank Lisa Peters and Rich Esser, New Mexico Geochronology Research Laboratory, New Mexico Tech, Socorro, USA, for their help in the accelerated processing of the samples for $^{40}Ar/^{39}Ar$ analysis.

We are grateful to Steve Kottmeier, and Robbie Score and her staff for the excellent support provided for the Crary Science & Engineering Center operation at McMurdo Station. Thanks also to Jay Burnside and the science construction stuff. The help of divers from CSEC (Rob Robbins, Christian MacDonald and minder Robbie Score) for installing and recovering the air bags under the sea ice beneath the drill rig was also appreciated. Murray Knox carried out the levelling of the sea ice at the drill site and John Alexander interpreted the data. John Alexander, as Scott Base Liaison Officer, also smoothed the communications and logistics path between McMurdo Station, Scott Base and Cape Roberts. We also thank Pat Cooper and his drilling team for persevering until success was achieved, and Jim Cowie, Alex Pyne and support staff for their difficult work in the WINFLY period, maintenance of Cape Roberts camp and supplies, and for the checking maintenance and storage for the next drilling season. Andy Archer (ASA, Denver) processed DMSP satellite images, and Bob Onstott (ERIM) processed SAR images of the early season sea ice for Cape Roberts Project operations.

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Terra Antartica
Initial Report on CRP-2/2A
1999, **6**(1/2), 1-173

Studies from Cape Roberts Project
Initial Report on CRP-2/2A, Ross Sea, Antarctica

Cape Roberts Science Team*

Abstract - The site for CRP-2, 14 km east of Cape Roberts (77.006°S; 163.719°E), was selected to overlap the early Miocene strata cored in nearby CRP-1, and to sample deeper into the east-dipping strata near the western margin of the Victoria Land Basin to investigate Palaeogene climatic and tectonic history. CRP-2 was cored from 5 to 57 mbsf (metres below the sea floor) (core recovery 91%), with a deviation resulting in CRP-2A being cored at the same site. CRP-2A reached down to 624 mbsf (recovery 95%), and to strata with an age of *c.* 33-35 Ma. Drilling took place from 16 October to 25 November 1998, on 2.0-2.2 m of sea ice and through 178 m of water.

Core fractures and other physical properties, such as sonic velocity, density and magnetic susceptibility, were measured throughout the core. Down-hole logs for these and other properties were run from 63 to 167 mbsf and subsequently from 200 to 623 mbsf, although density and velocity data could be obtained only to 440 mbsf because of hole collapse. Sonic velocity averages *c.* 2.0 km s^{-1} for the upper part of the hole, but there is an sharp increase to *c.* 3.0 km s^{-1}, and also a slight angular unconformity, at 306 mbsf, corresponding most likely to the early/late Oligocene boundary (*c.* 28-30 Ma). Velocity then increases irregularly to around 3.6 km s^{-1} at the bottom of the hole, which is estimated to lie 120 m above the V4/V5 boundary. The higher velocities below 306 mbsf probably reflect more extensive carbonate and common pyrite cementation, in patches, nodules, bedding-parallel masses and as vein infills. Dip of the strata also increases down-hole from 3° in the upper 300 m to over 10° at the bottom. Temperature gradient is 21° km^{-1}. Over 2 000 fractures were logged through the hole. Borehole televiewer imagery was obtained for the interval from 200 to 440 mbsf to orient the fractures for stress field analysis.

Lithostratigraphical descriptions on a scale of 1:20 are presented for the full length of the core, along with core box images, as a 200 page supplement to this issue. The hole initially passed through a layer of muddy gravel to 5.5 mbsf (Lithological Sub-Unit or LSU 1.1), and then into a Quaternary diatom-bearing clast-rich diamicton to 21 mbsf (LSU 2.1), with an interval of alternating compact diamicton and loose sand, and containing a rich Pliocene foraminiferal fauna, to 27 mbsf (LSU 2.2). The unit beneath this (LSU 3.1) has similar physical properties (sonic velocity, porosity, magnetic susceptibility) and includes diamictites of similar character to those of LSU 2.1 and 2.2, but an early Miocene (*c.* 19 Ma) diatom assemblage at 28 mbsf (top of LSU 3.1) shows that this sub-unit is part of the older section.

The strata beneath 27 mbsf, primary target for the project, extend from early Miocene to perhaps latest Eocene age, and are largely cyclic glacimarine nearshore to offshore sediments. They are described as 41 lithological sub-units and interpreted in terms of 12 recurrent lithofacies. These are 1) mudstone, 2) inter-stratified mudstone and sandstone, 3) muddy very fine to coarse sandstone, 4) well-sorted stratified fine sandstone, 5) moderately to well-sorted, medium-grained sandstone, 6) stratified diamictite, 7) massive diamictite, 8) rhythmically inter-stratified sandstone and mudstone, 9) clast-supported conglomerate, 10) matrix-supported conglomerate, 11) mudstone breccia and 12) volcaniclastic sediment.

Sequence stratigraphical analysis has identified 22 unconformity-bounded depositional sequences in pre-Pliocene strata. They typically comprise a four-part architecture involving, in ascending order, 1) a sharp-based coarse-grained unit (Facies 6, 7, 9 or 10), 2) a fining-upward succession of sandstones (Facies 3 and 4), 3) a mudstone interval (Facies 1), in some cases coarsening upward to muddy sandstones (Facies 3), and 4) a sharp-based sandstone-dominated succession (mainly Facies 4). The cyclicity recorded by the strata is interpreted in terms of a glacier ice margin retreating and advancing from land to the west, and of rises and falls in sea level. Analysis of sequence periodicity awaits a firmer chronology. However, a preliminary spectral analysis of magnetic susceptibility for a deep-water mudstone within one of the sequences (from 339 to 347 mbsf) reveals ratios between hierarchical levels that are similar to those of the three Milankovitch orbital forcing periodicities.

The strata contain a wide range of fossils, the most abundant being marine diatoms. These commonly form up to 5% of the sediment, though in places the core is barren (notably between 300 and 412 mbsf). Fifty samples out of 250 reviewed were studied in detail. The assemblages define ten biostratigraphical zones, some of them based on local or as yet undescribed forms. The assemblages are neritic, and largely planktonic, suggesting that the sea floor was

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mostly below the photic zone throughout deposition of the cored sequence. Calcareous nannofossils, representing incursions of ocean surface waters, are much less common (72 out of 183 samples examined) and restricted to mudstone intervals a few tens of metres thick, but are important for dating. Foraminifera are also sparse (73 out of 135 samples) and represented only by calcareous benthic species. Changing assemblages indicate a shift from inshore environments in the early Oligocene to outer shelf in the late Oligocene, returning to inshore in the early Miocene. Marine palynomorphs yielded large numbers of well-preserved forms from most of the 116 samples examined. The new *in situ* assemblage found last year in CRP-1 is extended down into the late Oligocene and a further new assemblage is found in the early Oligocene. Many taxa are new, and cannot as yet contribute to an improved understanding of chronology or ecology. Marine invertebrate macrofossils, mostly molluscs and serpulid tubes, are scattered throughout the core. Preservation is good in mudstones but poor in other lithologies.

Climate on land is reflected in the content of terrestrial palynomorphs, which are extremely scarce down to *c.* 300 mbsf. Some forms are reworked, and others represent a low growing sparse tundra with at least one species of *Nothofagus*. Beneath this level, a significantly greater diversity and abundance suggests a milder climate and a low diversity woody vegetation in the early Oligocene, but still far short of the richness found in known Eocene strata of the region. Sedimentary facies in the oldest strata also suggest a milder climate in the oldest strata cored, with indications of substantial glacial melt-water discharges, but are typical of a colder climate in late Oligocene and early Miocene times. Clast analyses from diamictites reveal weak to random fabrics, suggesting either lack of ice-contact deposition or post-depositional modification, but periods when ice grounded at the drill site are inferred from thin zones of *in-situ* brecciated rock and soft-sediment folding. These are more common above *c.* 300 mbsf, perhaps reflecting more extensive glacial advances during deposition of those strata.

Erosion of the adjacent Transantarctic Mountains through Jurassic basalt and dolerite-intruded Beacon strata into basement rocks beneath is recorded by petrographical studies of clast and sand grain assemblages. Core below 310 mbsf contains a dominance of fine-grained Jurassic dolerite and basalt fragments along with Beacon-derived coal debris and rounded quartz grains, whereas the strata above this level have a much higher proportion of basement-derived granitoids, implying that the large areas of the adjacent mountains had been eroded to basement by the end of the early Oligocene.

There is little indication of rift-related volcanism below 310 mbsf. Above this, however, basaltic and trachytic tephras are common, especially from 280 to 200 mbsf, from 150 to 46 mbsf, and in Pliocene LSU 2.2 from 21 to 27 mbsf. The largest volcanic eruptions generated layers of coarse (up to 1 cm) trachytic pumice lapilli between 97 and 114 mbsf. The thickest of these (1.2 m at 112 mbsf) may have produced an eruptive column extending tens of km into the stratosphere. A source within a few tens of km of the drill site is considered most likely.

Present age estimates for the pre-Pliocene sequence are based mainly on biostratigraphy (using mainly marine diatoms and to a lesser extent calcareous nannofossils), with the age of the tephra from 112 to 114 mbsf (21.44±0.05 Ma from 84 crystals by Ar-Ar) as a key reference point. Although there are varied and well-preserved microfossil assemblages through most of the sequence (notably of diatoms and marine palynomorphs), they comprise largely taxa either known only locally or as yet undescribed. In addition, sequence stratigraphical analysis and features in the core itself indicate numerous disconformities. The present estimate from diatom assemblages is that the interval from 27 to 130 mbsf is early Miocene in age (*c.* 19 to 23.5 Ma), consistent with the Ar-Ar age from 112 to 114 mbsf. Diatom assemblages also indicate that the late Oligocene epoch extends from *c.* 130 to 307 mbsf, which is supported by late Oligocene nannofossils from 130 to 185 mbsf. Strata from 307 to 412 mbsf have no age-diagnostic assemblages, but below this early Oligocene diatoms and nannofossils have been recovered. A nannoflora at the bottom of the hole is consistent with an earliest Oligocene or latest Eocene age.

Magnetostratigraphical studies based on about 1 000 samples, 700 of which have so far undergone demagnetisation treatment, have provided a polarity stratigraphy of 12 pre-Pliocene magnetozones. Samples above 270 mbsf are of consistently high quality. Below this, magnetic behaviour is more variable. A preliminary age-depth plot using the Magnetic Polarity Time Scale (MPTS) and constrained by biostratigraphical data suggests that episodes of relatively rapid sedimentation took place at CRP-2 during Oligocene times (*c.* 100 m/My), but that more than half of the record was lost in a few major and many minor disconformities. Age estimates from Sr isotopes in shell debris and further tephra dating are expected to lead to a better comparison with the MPTS.

CRP-2/2A has recorded a history of subsidence of the Victoria Land Basin margin that is similar to that found in CIROS-1 70 km to the south, reflecting stability in both basin and the adjacent mountains in late Cenozoic times, but with slow net accumulation in the middle Cenozoic. The climatic indicators from both drill holes show a similar correspondence, indicating polar conditions for the Quaternary but with sub-polar conditions in the early Miocene-late Oligocene and indications of warmer conditions still in the early Oligocene. Correlation between the CRP-2A core and seismic records shows that seismic units V3 and V4, both widespread in the Victoria Land Basin, represent a period of fluctuating ice margins and glacimarine sedimentation. The next drill hole, CRP-3, is expected to core deep into V5 and extend this record of climate and tectonics still further back in time.