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# Scientific Logistics Implementation Plan for the ANDRILL McMurdo Ice Shelf Project

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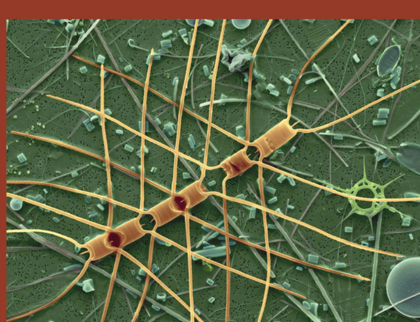

ANDRILL

# SCIENTIFIC LOGISTICS IMPLEMENTATION PLAN

## FOR THE ANDRILL MCMURDO ICE SHELF PROJECT

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ANDRILL CONTRIBUTION 7

Tim R. Naish, Richard H. Levy, Ross D. Powell
and MIS Science and Operations Team Members

Cover Photos by T Naish and M Berg
Diatom Image from MSNBC. See story at http://www.msnbc.msn.com/id/6058538/
Drexel University's Dee Breger colorized this scanning electron micrograph of a microplankton sample pulled from the depths of the Antarctic Sea. The photograph won honorable mention in the 2004 International Science and Engineering Visualization Challenge.

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## Forward

This Scientific Logistics Implementation Plan (SLIP) is intended as a guide of activities for the ANDRILL McMurdo Ice Shelf (MIS) Project science community, as distinct from the Operations Plan, which is for the management of drilling operations in Antarctica. The SLIP has been prepared by the Co-Chief Scientists, Staff Scientist, and Discipline Team Leaders through extensive consultation with the Science Team, Operations Team, and Curatorial Staff. Thus it represents the collective view of the project leadership.

A project such as this is extremely complex, with its combination of national scientific, logistics, management and financial cultures, as well as the challenges of the operating environment. The success of the project will depend largely on the understanding and cooperative spirit that we will all need to take with us to the ice. This plan is designed to help establish this understanding. The plan is intended to provide a scientific overview of the project, its goals and objectives, as well as an outline of the management systems and scientific procedures to be implemented both during drilling and post drilling phases. The plan is not intended to be overly prescriptive, but rather is an implementation guide for achieving the goals and objectives of the MIS Project as outlined in the Scientific Prospectus (Naish et al., 2005).

The first section summarizes the goals of the MIS Project within the context of the ANDRILL Program, its origins and structure (Chapter 1), and then goes on to present an overview of site survey data and discussion of drill site selection (Chapter 2). The main body of the SLIP addresses science management and operation procedures to be followed at the drill site and McMurdo Station. It includes: (i) staff functional relationships and responsibilities, (ii) core management, sampling and curation, (iii) communications and (iv) data management (Chapter 3). Chapter 4 outlines the activities and procedures of the various science disciplines and individual scientists during drilling operations and subsequent post drilling analysis and interpretation prior to the core workshop (core characterization phase). The final part of this plan addresses policy and procedures governing publication from the web-based results and the Initial Science Report through to Science Results Volume(s) and syntheses papers (Chapter 5). ANDRILL places significant emphasis on education and public outreach, and this plan outlines the activities of educators participating on ice as part of the ARISE program, media activities and policy guidelines for dealing with media, as well as planned public outreach activities (Chapter 6).

The MIS project will recover the first long sedimentary core record from under a major ice shelf. To achieve this, a new innovative drill system has been developed that incorporates aspects of the successful Cape Roberts Project system, such as wireline rotary coring through a sea-riser, with new soft-sediment coring tools and a hot-water drill over-reamer. The hot-water drill was tested successfully during the 2005-2006 Antarctic field season. It will ensure that the sea-riser remains free from the ice shelf during drilling operations. While we expect all systems to run smoothly, Antarctic fieldwork of this nature always carries risks due to weather and mechanical and technical problems. An advantage of operating on the ice shelf, as opposed to the sea-ice, is that we have a longer season for coring and if necessary for working through problems. **A cautionary word, however, is that this will be a long season for the science team. If all goes to plan we will recover 1200m of core between the 24$^{th}$ of October and the 27$^{th}$ of December. It is important that individuals prepare for this, by establishing sustainable work routines within their teams, and by ensuring they spend some time on recreational activities. We plan to run field excursions during the course of the season, and establish a roster of regular days off.**

Soon we will be together On-Ice and working with other team members based in home laboratories and institutions. After 5 years of planning and preparation the first ANDRILL Program drilling project will be underway. We are the pioneers of this new multi-decadal initiative to recover stratigraphic records from the Antarctic continental margin. As Co-Chiefs of the MIS project we are excited about this opportunity to contribute substantial new knowledge of the role of Antarctica in the global system, and look forward to working with this world-class science team on what we are sure will be a successful and highly-rewarding endeavor.

*- Tim Naish and Ross Powell, MIS Project Co-Chief scientists*
*7 August 2006*

# 1. BACKGROUND AND SCIENTIFIC OBJECTIVES

## 1.1 SUMMARY & RELATED DOCUMENTS

Response of Antarctic ice sheets to projected greenhouse warming of up to 5.8°C by the end of the century is unknown. Models on which predictions are based need to be constrained by geological proxy data from the ancient ice sheets during times when Earth is known to have been warmer than today. The marine-based West Antarctic Ice Sheet (WAIS) and its fringing ice shelves are hypothesized (Clark et al., 2002; Weaver et al., 2003; Stocker, 2003) and documented (Scherer et al., 1998) to have collapsed during past “super-interglacial” warm extremes when global sea-level was more than 5m higher than today. Recent collapse of small ice shelves along the Antarctic Peninsula (Doake and Vaughn, 1991; Skvarca, 1993; Rott et al., 1996; Vaughn and Doake, 1996; Doake et al., 1998; Rott et al., 1998; Skvarca et al., 1999; Rott et al., 2002) highlights the vulnerability of these glacial components to global warming. The Ross Ice Shelf appears to represent one of the most vulnerable elements of the WAIS system. Future demise, on timescales of decades to centuries, may well provide an important precursor to eventual WAIS collapse.

The key aim of this research project is to determine past ice shelf responses to climate forcing, including variability at a range of timescales. To achieve this aim the ANtarctic Geological DRILLing Program (ANDRILL) will drill a stratigraphic core from a platform located on the northwest corner of the Ross Ice Shelf - the McMurdo Ice Shelf (MIS) sector, east of Hut Point Peninsula, Ross Island. Drilling will be undertaken in the austral summer of 2006-2007 from the 24th of October to the 27th of December (Fig. 1).

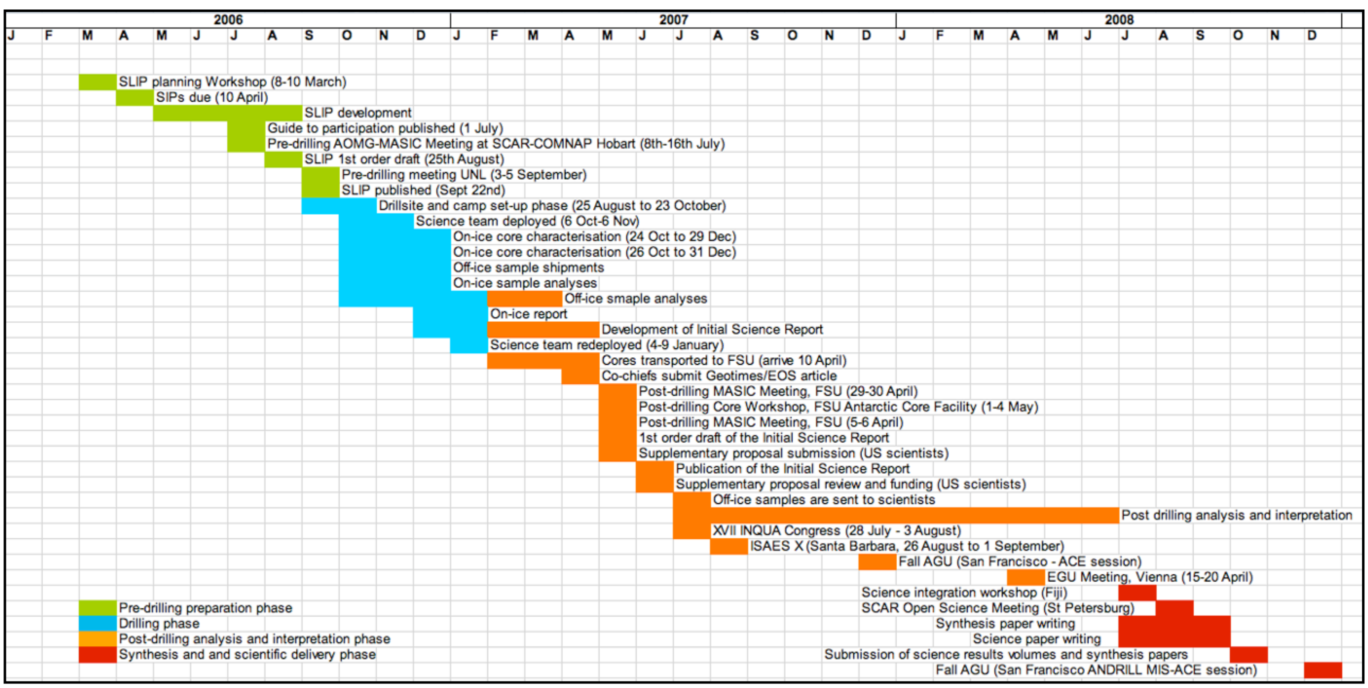



**Fig. 1**

MIS Project Timeline.

The primary target for the MIS site is a 1200 m-thick body of Plio-Pleistocene glacimarine, terrigenous, volcanic, and biogenic sediment that has accumulated in the Windless Bight region of a flexural moat basin surrounding Ross Island (Horgan et al., 2005). A single 1200 m-deep drill core will be recovered from the bathymetric and

depocentral axis of the moat in approximately 900m of water. Drilling technology will utilize a sea-riser system in a similar fashion to the Cape Roberts Project (CRP), but will employ a combination of hydraulic piston coring (in upper soft sediments) and continuous wireline diamond-bit coring. Innovative new technology, in the form of a hot-water drill and over-reamer, will be used to make an access hole through ~ 200 m of the ice shelf and to keep the riser free during drilling operations.

The purpose of this SLIP is to provide a scientific overview of the project, its goals and objectives, as well as outlining management systems and scientific procedures to be implemented during both On-Ice (drilling) and post-drilling phases. It also includes information on scientific practice by participating scientists and discipline teams, and plans and policy for publications, education and public outreach activities. The plan provides a "roadmap" for research participants on the MIS Project to ensure the scientific objectives are met and delivered. Other key documents for the MIS project are:

ANDRILL Conribution 1 (Harwood et al., 2002), a report on the ANDRILL international planning workshop held at Oxford University in April 2001. This outlines the history of geological drilling around Antarctica, reviews the state of geology and geophysical knowledge in Western Ross Sea, presents a range of scientific drilling targets and science initiatives, describes a management structure for the new program, and addresses logistical and environmental considerations

A science proposal prepared by the proponents of ANDRILL McMurdo Sound Portfolio of Projects for international peer-review. ANDRILL International Science Proposal (2003), ANDRILL Contribution 2.

A Comprehensive Environmental Evaluation (CEE) prepared for the ANDRILL McMurdo Sound Portfolio, by Antarctica New Zealand. This document has been circulated and approved by the Antarctic Treaty System, and is the project's guide to sound environmental practice.

A Scientific Prospectus for the ANDRILL McMurdo Ice Shelf Project, ANDRILL Contribution 4 (Naish et al., 2005). This document outlines the science objectives and rationale for the MIS project and was used to help facilitate staffing applications.

A Guide to Participation for the ANDRILL MIS Project, ANDRILL Contribution No.6 (ANDRILL Science Management Office & McMurdo ANDRILL Science Implementation Committee, 2006). This document provides information for individual scientists participating in the project and living on McMurdo Station. It also covers logistical issues concerning travel of individuals and equipment to and from Antarctica.

The Record of Understanding between Parties Contributors and annexes. This document serves as an intention of long-term cooperation among Parties Contributors to the McMurdo Sound Portfolio of the ANDRILL Program (2001-2010). The RoU was signed in 2005. It commits Parties Contributors to a schedule of payments as outlined in the budget of the Project Plan for logistical and operational costs. It also formalizes a management structure involving an ANDRILL Operations Management Group (AOMG) and the McMurdo Sound ANDRILL Science Implementation Committee (M-ASIC).

ANDRILL Project Plan prepared by Antarctica New Zealand. The Project Plan provides detailed information concerning operational and logistical requirements, and a budget for implementation by Antarctica New Zealand

as Operator to achieve the science goals of the approved ANDRILL McMurdo Sound Portfolio (McMurdo Ice Shelf and Southern McMurdo Sound Projects).

A series of MIS site survey data reports have been compiled by Geological and Nuclear Sciences and Victoria University, Antarctic Research Centre, New Zealand, covering seismic and other geophysical investigations of the geology and basin structure, as well as shallow sub-ice shelf sediment cores and oceanographic observations. These include Bannister and Naish (2002), Horgan et al. (2003), Wilson et al. (2004), Barrett et al. (2005), Carter et al. (2006), Henrys et al. (2006).

### 1.2 THE ANDRILL PROGRAM: BACKGROUND AND OVERVIEW

ANDRILL is a multinational co-operative program with objectives to recover stratigraphic intervals for use in interpreting Antarctica's climatic, glacial and tectonic history over the past 65 m.y., at various scales of age resolution (1 to 100,000 years). The key motivation for ANDRILL stems from a lack of knowledge of the complex role the Antarctic cryosphere (ice sheets, ice shelves and sea-ice) plays in the global climate system. Understanding the history of ice volume variation and associated physical changes in the Antarctic region is critical for assessing the interaction of ice sheets with other elements of the Earth System, such as ocean, atmosphere, lithosphere and biosphere. Accurate assessment of the scale and rapidity of changes affecting large ice masses is of vital importance because ice-volume variations: (a) lead to changing global sea-levels, (b) affect Earth's albedo, (c) control the latitudinal gradient of the Southern Hemisphere and thus heat transport via atmospheric and oceanic circulation, and (d) influence the distribution of ice shelves and seasonal sea-ice, which are commonly attributed to forming cold-bottom waters that drive global ocean circulation. General circulation models indicate that polar regions are the most sensitive to climate warming (and cooling), thus the projected global rise in mean temperature of 1.4-5.8°C by the end of the century (IPCC; Houghton et al., 2001) is likely to be even greater in the Antarctic, with a significant impact on the Antarctic cryosphere.

The ANDRILL Program recognizes that efforts to understand the role of Antarctic drivers on global climate variability require a fundamental knowledge of Antarctic cryospheric evolution, not only in recent times, but also for earlier periods when global temperature and atmospheric $pCO_2$ were similar to levels that might be reached by the end of this century. Due to a lack of Cenozoic strata exposed on land and a limited number of drill cores on the continental margin of Antarctica, our understanding of Antarctica's climate history relies heavily on inferences from low latitude climate-proxy records, such as deep-sea oxygen isotope records and sequence stratigraphic interpretations of non-glaciated passive margins (Fig. 2). Although a number of high-quality sedimentary archives that record past ice sheet behavior have become available recently from the CRP (e.g. Naish et al., 2001a & b; Wilson et al., 2004) and from ODP legs 178 (e.g. Domack et al., 2001) and 188 (e.g. Grutzner et al., 2003), they remain too few to allow a comprehensive understanding of Antarctica's influence on global climate.

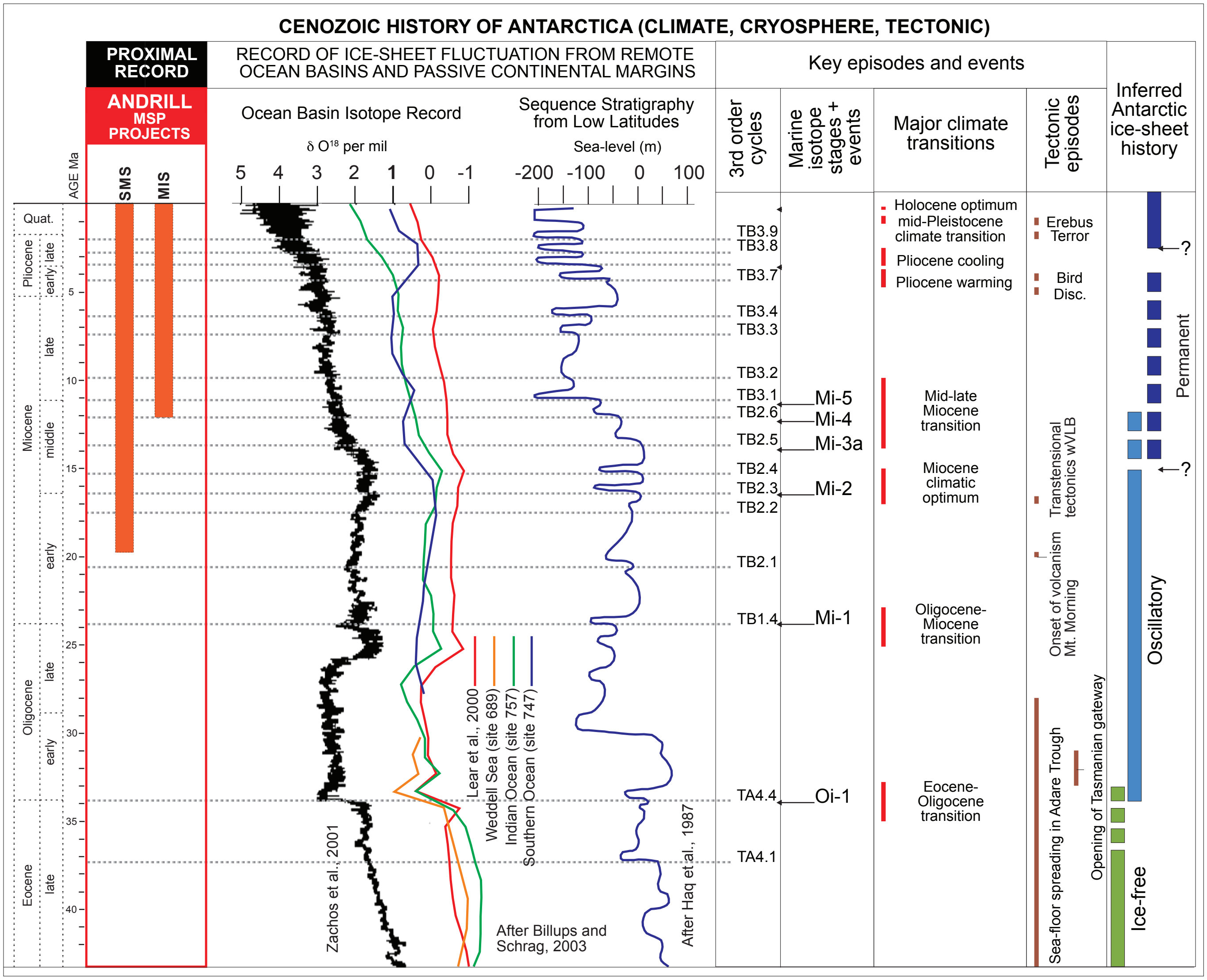



**Fig. 2**

Each ANDRILL McMurdo Sound Project aims to recover stratigraphic intervals that preserve an Antarctic margin record of episodes and events of regional and global importance. These new data will provide direct calibration points for Antarctic cryospheric behavior and resulting glacio-eustasy that is currently interpreted from remote ocean basins and from passive continental margins (From ANDRILL International Science Proposal, 2003).

### 1.2.1 Program Structure

The ANDRILL Program is managed through two branches of science and operations. ANDRILL's inaugural science program was developed by proponents of drillsites, national representatives and national steering committees (Germany, Italy, New Zealand and United States) into an international science proposal, which was prepared by the community-endorsed ANDRILL Science Committee (ASC) and ANDRILL Science Management Office (SMO). Upon review and approval of this proposal, Program Managers from the above nations established the McMurdo-ANDRILL Science Implementation Committee (M-ASIC), and requested that the ANDRILL Operations Management Group (AOMG) task a Program Operator (Antarctica New Zealand) to manage the operations and logistical support of the two approved drilling projects. The staff of the SMO at the University of Nebraska-Lincoln coordinates the research and educational activities of ANDRILL Science Team, and works on behalf of the M-ASIC and ASC. Support for the SMO's science management function is provided by the U.S. National Science Foundation. ANDRILL's operations and logistical effort is supported by contributions from the above member nations of the AOMG, who provide funding at levels agreed to in a Record of Understanding to

Antarctica New Zealand, the ANDRILL Project Operator. Additional details regarding the ANDRILL organization, management and key staff positions are described in Appendix A of the MIS Project Guide to Participation (ANDRILL Contribution 6).

### 1.2.2 The McMurdo Sound Portfolio of stratigraphic drilling objectives

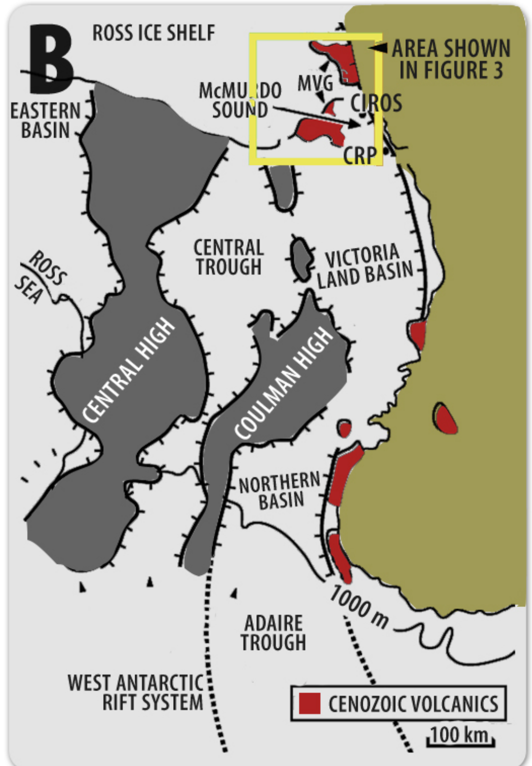




**Fig. 3**
General location of McMurdo Sound in western Ross Sea adjacent to the northwestern corner of the Ross Ice Shelf and the Transantarctic Mountains.
Inset (B) shows the regional tectonic setting
(After ANDRILL International Science Proposal, 2003).

ANDRILL proposes to focus its initial efforts on the McMurdo Sound region, because it has a reasonably well-understood stratigraphic and tectonic framework, and is situated at a critical juncture among components of the West Antarctic Rift system, including the Victoria Land Basin (VLB), the Transantarctic Mountains (TAM) and the Erebus Volcanic Province (Figs. 3, 4, & 6). Fault and flexural-related subsidence associated with rifting and volcanic loading has provided Early Cenozoic – Recent stratigraphic accommodation space adjacent to the rising TAM (Figs. 5 & 6). The combination of a high sediment supply from TAM and the accommodation provided by tectonic subsidence of the VLB has allowed the region to act as a “high-fidelity sedimentary recorder” for the past 50 m.y., helping preserve the contained sediments from many of the erosive events that often remove ice-proximal records during glacial advances.

McMurdo Sound is also one of a limited number of locations that have been influenced by three significant components of the Antarctic cryospheric system: East Antarctic Ice Sheet (EAIS), Ross Ice Shelf (RIS)/West Antarctic Ice Sheet (WAIS), and Ross Embayment sea-ice. Moreover, the McMurdo Sound has the best-understood sedimentary record from the Antarctic margin due to acquisition over the past 30 years of integrated seismic and drill-core data. These data greatly improve our ability to select drill sites with the greatest potential for

achieving ANDRILL science goals (outlined in the ANDRILL International Science Proposal, 2003 & ANDRILL Contribution 2).

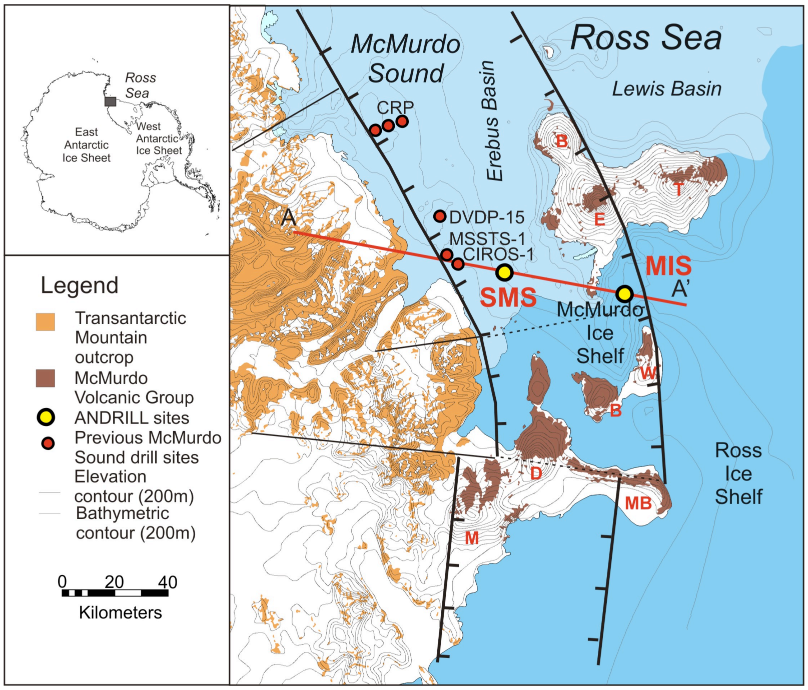



**Fig. 4**

Location of key geographical and tectonic features in southern McMurdo Sound. Volcanic centres of the Erebus Volcanic Province include Mt Erebus (E), Mt Terror (T), Mt Bird (B), White Island (W), Black Island (B), Mt Discovery (D), Mt Morning (M) and Minna Bluff (MB). Location of cross-section A-A' (Fig. 5) is shown.

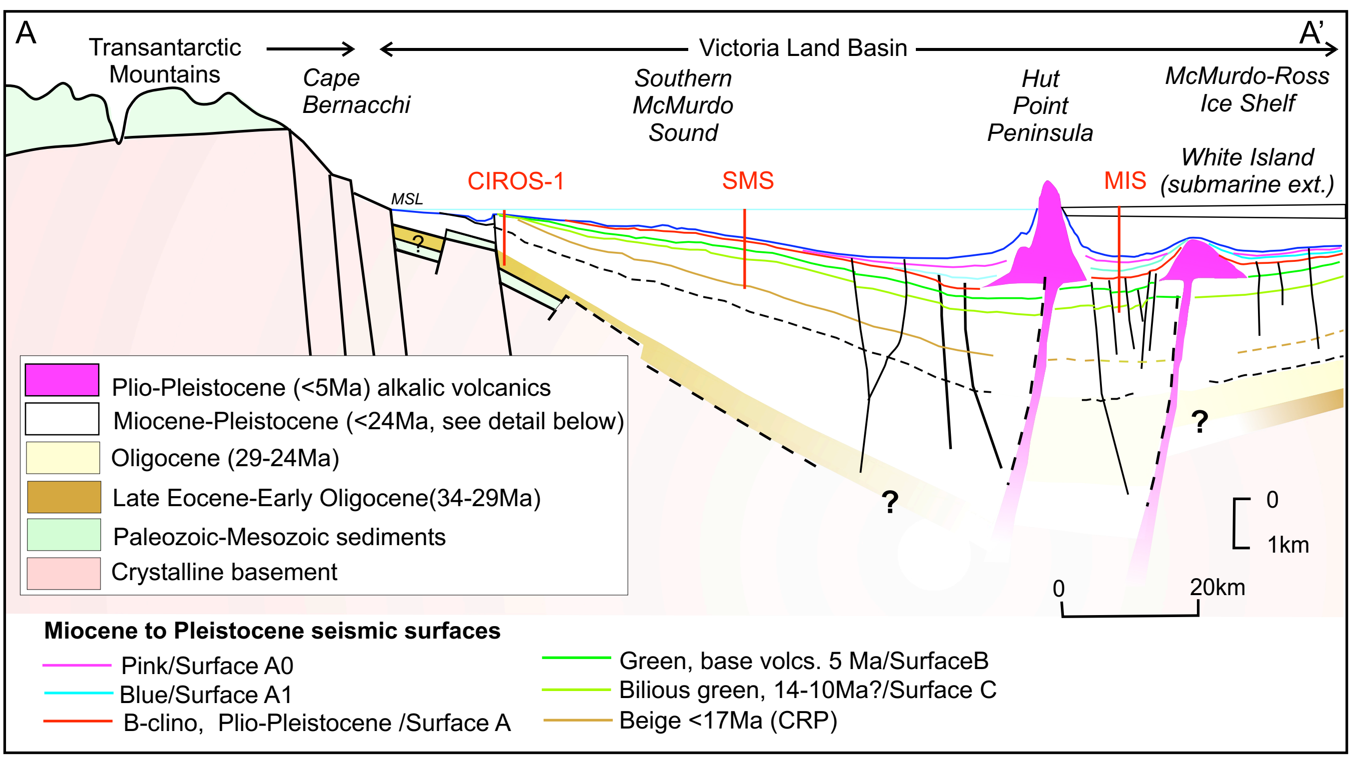



**Fig. 5**

Schematic structural-stratigraphic cross-section across the Victoria Land Basin shows the stratigraphic context of the MIS and SMS drillsites with respect to previous drilling in Southern McMurdo Sound. The cross section is compiled from interpreted seismic reflection data (Fig. 12), previous drill core data (Barrett, 1986; 1989) and models for the evolution of the Victoria Land Basin (Fielding et al., 2005; Wilson et al., in review).

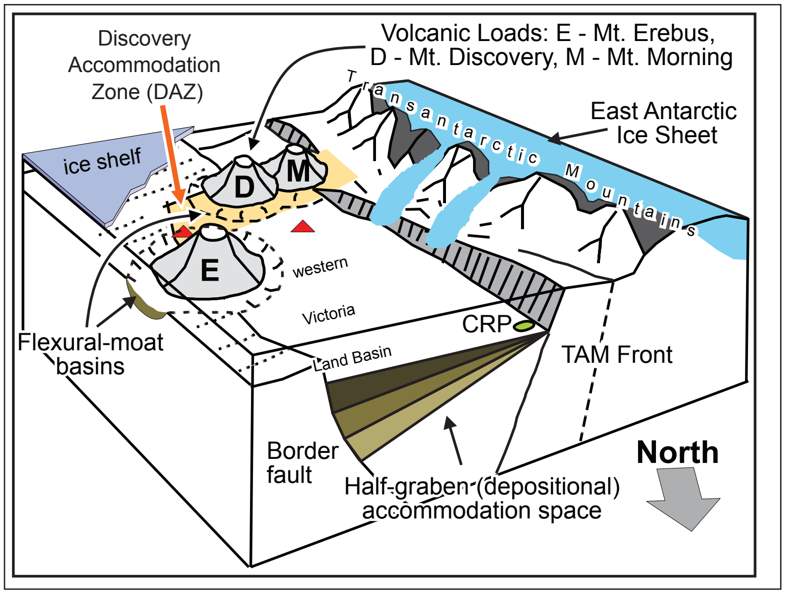



**Fig. 6**

Schematic stratigraphic and structural cartoon of the Victoria Land Basin (VLB) shows development of accommodation space within a half graben, tilted to the east and bounded by a major down-to-the-west border fault system that controls the stratigraphic architecture of the basin-fill, which dips and thickens to the east. The Discovery Accommodation Zone (DAZ) is a transverse element where the rift-flank steps westward ~100 km (Wilson, 1999). Localized accommodation space is superimposed on the rift basin where Neogene volcanoes of the Erebus Volcanic Province have progressively depressed the crusts forming flexural-moat basins. The depositional accommodation space provided by the rift and flexural moat basins provides an unparalleled opportunity to recover stratigraphic records with high-resolution chronology provided by the dating of volcanic detritus integrated with biostratigraphic and magneto-stratigraphic techniques.

(From ANDRILL International Science Proposal, 2003).

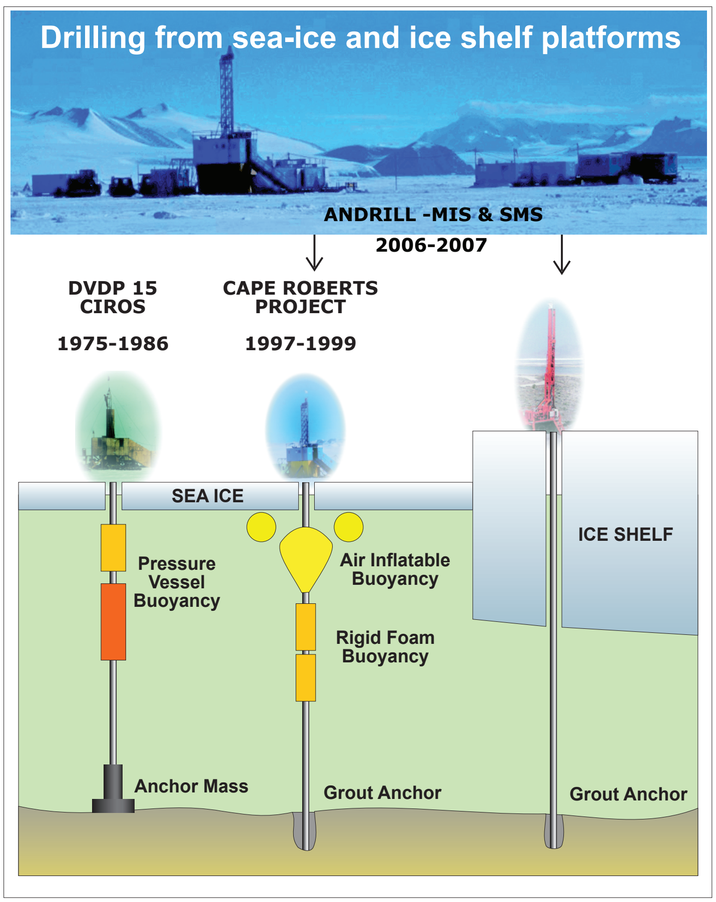



**Fig. 7**

The ANDRILL Program must address unique logistical and drilling requirements to achieve its science goals. New drilling tools have been developed (drill rig, coring tools, and riser system) from proven drilling technology that was employed during the Cape Roberts Project.

(From ANDRILL International Science Proposal, 2003).

The drill system developed by the ANDRILL Program represents a significant technological evolution from the highly successful CRP drill system (Fig. 7). The drill system will have the capacity to operate on both shore-fast-ice and ice shelf platforms and to recover continuous long stratigraphic records (up to 1200 m) from water depths of up to 1000 m.

Two projects within the McMurdo Sound Portfolio have been supported by the national science funding agencies and Antarctic Programs of the U.S.A., New Zealand, Italy, and Germany. The first Project, which is the subject of this SLIP, will be drilled from the McMurdo Ice Shelf during the 2006-2007 austral field season. Drilling from a shore-fast sea-ice platform in Southern McMurdo Sound is scheduled for the following field season in 2007-2008 (see SMS Scientific Prospectus, http://andrill.org/support).

### 1.3 REGIONAL TECTONIC AND STRATIGRAPHIC SETTING

Ross Island lies at the southern end of the Victoria Land Basin (VLB), a structural half-graben, approximately 350 km-long, hinged on its western side at the Transantarctic Mountain front (Wilson, 1999). Major rifting in the VLB has occurred since the latest Eocene, perhaps having been initiated in the Cretaceous, and has accommodated up to 10 km of sediment (Cooper and Davey, 1985; Brancolini et al., 1995). Late Cenozoic extension in the VLB is associated with alkalic igneous intrusions (e.g. Beaufort Island and Ross Island) and led to the development of the Terror Rift (Cooper et al., 1987).

Ross Island volcanic complex lies at the southern end of the Terror Rift (McGinnis et al., 1985) and is considered to be associated with the latest phase of rifting. The complex comprises the central cone of Mt. Erebus which is surrounded by Mt. Bird, Mt. Terror and Hut Point Peninsula each separated by ~ 120º. The radial distribution likely results from crustal doming and associated radial fracturing, due to mantle upwelling as a plume or hotspot (Kyle et al., 1992). Loading of the crust by the Ross Island volcanic pile has produced as much as 1.8 km net subsidence beneath Ross Island and the development of an enclosing moat (Stern et al., 1991). Local accommodation space created by the subsidence is superimposed on the regional pattern of accommodation space created by Late Cenozoic rifting (Figs. 5 & 6).

Originally described by Cooper et al. (1987), the Terror Rift is located within the Victoria Land Basin, in the western Ross Sea. It comprises two parts, the Discovery Graben and the Lee Arch. Faults reach the seafloor within the Terror Rift, indicating that it is the youngest faulting within the Western Antarctic Rift System (WARS). Cooper et al. (1987) proposed a “magmatically intruded Lee Arch” along the eastern margin of the Terror Rift. New seismic lines from the Drygalski Ice Tongue, in the north, to south of Ross Island show that the ‘arch’ is a structural feature not associated with magmatic intrusion or doming (Hall 2006, unpublished data). North and south of Ross Island, the arch has been extensively intruded by Late Cenozoic volcanic rocks that obscure the structural geometry. The arch can be projected southward where it forms the eastern uplifted margin of a half graben that has accommodated up to 3 km of Neogene sediment beneath Windless Bight. Here, the load-induced subsidence caused by Ross Island has contributed significantly to the generation of accommodation space, especially during the last c. 2 m.y.

Cretaceous and Paleogene are predicted to occur within the axis of the VLB (e.g. Davey and Brancolini et al., 1995), however, to strata date latest Eocene sediments are the oldest post-Paleozoic strata actually recovered by stratigraphic drilling. The Eocene strata occur at the western margin of the basin and unconformably overlie Devonian sediments of the Taylor Group (Davey et al., 2001). Since the latest Eocene, sedimentation along the western margin of the VLB has evidently kept pace with or exceeded the rate of subsidence resulting in the development of a 1.5 to 2 km-thick sediment wedge that thickens seaward to approximately 7 km underneath Ross Island (Fig. 5).

The wedge comprises glacimarine conglomerates, diamicts, and sandstones with interbedded mudstones of nearshore and shelf affinity (Barrett, 1989; Cape Roberts Science Team, 2000). Numerous unconformities occur within the Oligocene and lower Miocene strata recovered in CIROS-1 and CRP drillcores (Fig. 4). A number of these unconformities have been correlated with sub-horizontal erosion surfaces in regional seismic lines (Henrys et al., 2000; Fielding et al., 2001), implying widespread grounding of an extensive ice terminus on the continental

shelf during glacial periods. Coastal glacier behavior has been linked to mass changes in the interior East Antarctic Ice Sheet, which feeds through outlet glaciers in the Transantarctic Mountains. .

Interglacial-glacial periods during the Oligocene – lower Miocene are recorded by sedimentary sequences displaying vertical cyclical facies successions of ice retreat and re-advance (Powell et al., 2001) in association with relative bathymetric deepening and shallowing, respectively (Naish et al., 2001b). The frequency of oscillation in ice extent, which controls the finer-scale stratigraphic architecture of the basin-fill, corresponds to Milankovitch orbital forcing as inferred from global oxygen isotope records (Naish et al., 2001a). The lack of long and continuous Plio-Pleistocene glacimarine drill core records in western VLB is probably due to sediment bypass across the western margin, due to lack of accommodation, and/or erosion of these younger strata during periodic glacial expansions of the WAIS and grounding of the RIS over the last 5 m.y. However, marine seismic data (Bartek et al., 1991, 1996; Wilson et al., 2004, unpublished data NBP-0401), and new seismic data presented here, suggest such records do exist farther east in the VLB and within the depocentral axis of the Terror Rift where flexural moats have formed in association with Plio-Pleistocene volcanic centers.

### 1.4 THE MCMURDO ICE SHELF (MIS) PROJECT: RATONALE

Ice shelves, large floating bodies of ice fed by ice sheets, are extremely sensitive early indicators of climate changes affecting ocean and atmospheric temperatures. Warming around the Antarctic Peninsula over the last 50 years has led to some catastrophic collapses of its fringing ice shelves, most notably the Larsen Ice Shelf collapse of March 2002 (e.g. Doake and Vaughn, 1991; Skvarca, 1993; Vaughn and Doake, 1996; Rott et al., 1996; Doake et al., 1998; Rott et al., 1998; Skvarca et al., 1999; Rott et al., 2002). Future stability of the RIS, the world's largest ice shelf system, which is coupled to the behavior of the WAIS, is of wide interest in the context of current global warming projections (IPCC) (Houghton et al., 2001). Despite calving of a 40 km-wide strip of ice from its northern margin in 2000, the RIS is currently considered to be stable. However, recent glaciological evidence indicates that the RIS is becoming increasingly undernourished with at least one of its ice stream feeders from West Antarctica stagnating and at least one other slowing down (Joughin and Tulaczyk., 2002). Rapid fluctuations in the flow velocity of ice streams near the WAIS grounding line are being observed (Joughin et al., 2002; Bindschadler et al., 2003; Bougamont et al., 2003), and suggest that over timescales of decades to centuries ice shelves may represent the most vulnerable element of the WAIS-RIS system, and that their collapse may come rapidly (MacAyeal; 1992). Their demise will provide an important precursor to eventual collapse of the West Antarctic Ice Sheet.

Collapse of the RIS could affect climate, WAIS extent, and sea level in a number of ways. Firstly, a large-scale discharge of meltwater, coupled with a reduction in ice shelf area, could slow down the production of salty bottom water around Antarctica. Such an effect could significantly alter the global thermohaline ocean circulation system, which has been suggested to cause abrupt climate changes of global extent in a decade or *less (*Clark et al., 2002; Weaver et al., 2003; Stocker, 2003)*.* Secondly, Earth's albedo (the fraction of incident solar radiation reflected) will change as 560,000 $km^2$ of permanent ice cover is replaced with shallow ocean, consequently amplifying regional warming (ice-albedo feedback). Lastly, the exchange of heat and water vapor between the ocean and the atmosphere could lead to accelerated loss and eventual collapse of the marine-based WAIS in as little time as just a few centuries, raising sea-level by 5 to 6 m (e.g. Alley and Bindschadler, 2001).

Of particular concern is that the fundamental behavior of the RIS is poorly understood and models on which predictions are based need to be constrained by new data (Bentley, 2004; Huybrechts 2004), including those

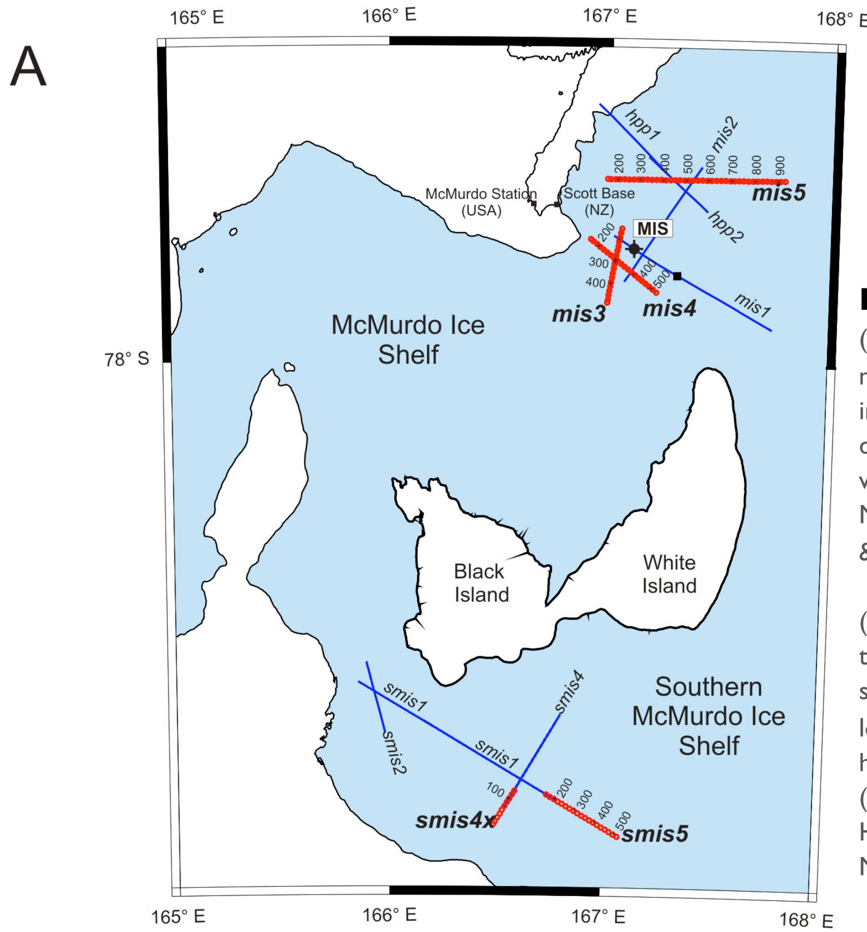
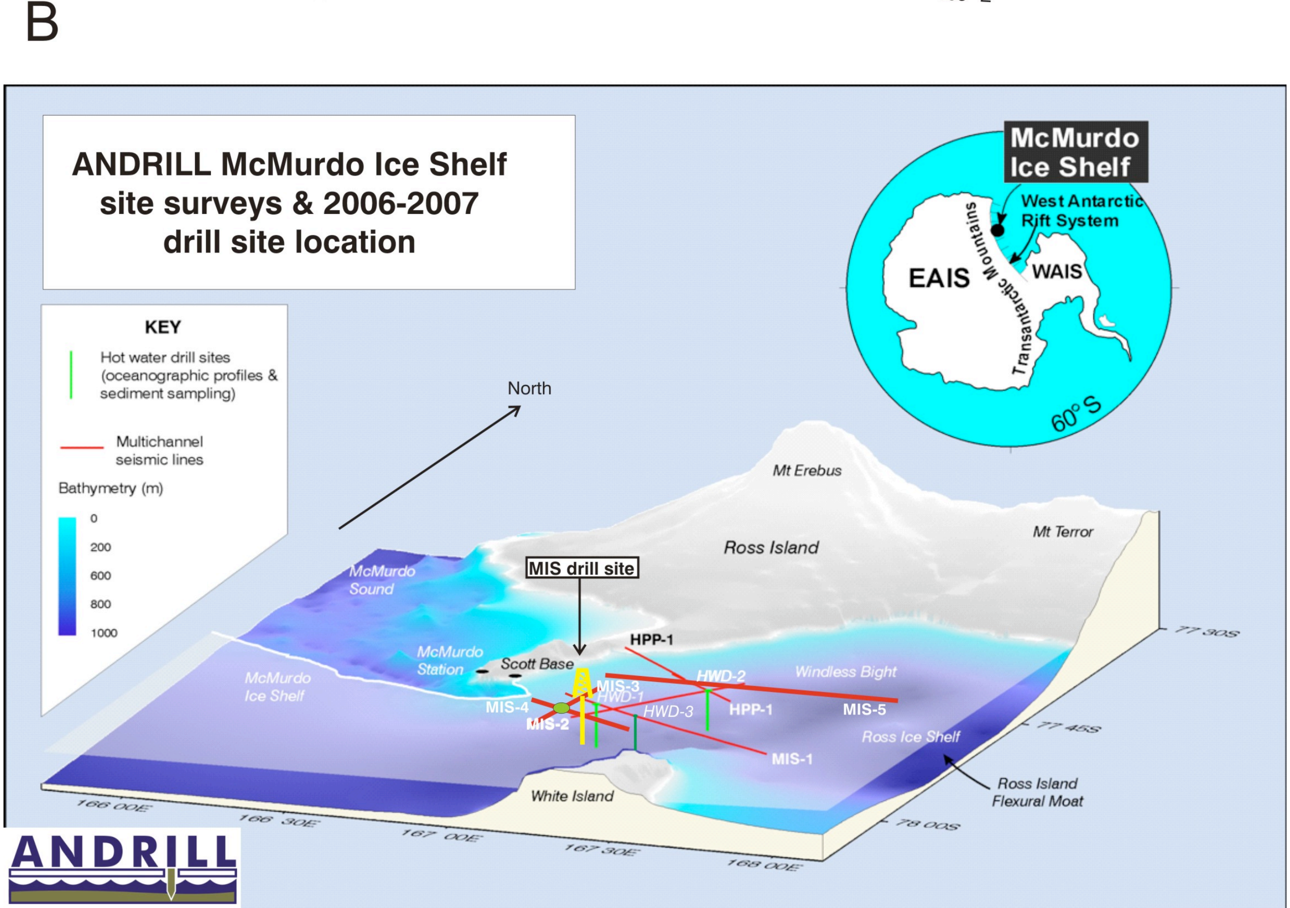



**Fig. 8**
(A) Location of multichannel seismic lines in the vicinity of the MIS drill site. MIS 3, 4 and 5 were acquired in 2005, MIS 1 in 2001 and MIS 2 & HPP 2 in 2002.

(B) 3-D visualization of the Windless Bight region showing bathymetry, the location of seismic lines, hot water drill sites (HWD-1 & 2, 2003, HWD-3, 2006) and the MIS drill site.



gathered from records of the ancient RIS during times when Earth was known to be warmer than it is today. For example, sectoral collapses of WAIS-RIS are thought to have occurred both 125,000 and 400,000 years ago during "super-interglacial" warm periods (Marine Isotope Stage 5e and 11) (Scherer et al., 1998; EPICA Community Members, 2004), when sea-level may have been 5-20 m higher than today (Neuman and Hearty, 1996).

In the austral summer of 2006/07 the ANDRILL Program will drill at a site on the McMurdo Ice Shelf (MIS) on the northwestern corner of the RIS where it is pinned to Ross Island (Figs. 4 & 8). The site is situated in 900 m of water. Drilling aims to recover a continuous 1000 m-long sediment core from a sedimentary basin formed by the progressive emplacement of the Ross Island volcanic complex on the crust during the last 2 m.y., in tandem with regional Neogene transtension. New multi-channel seismic reflection data (Fig. 9 & 12) reveal a well-stratified, regionally extensive sedimentary succession of at least 1.2 km below the sea-floor in the deepest part of the depression (e.g. Horgan et al., 2005) (Fig. 9). We anticipate recovering a relatively complete sequence for periods when phases of volcanic-loading of the crust are likely to have helped over-deepen the basin – the last 2

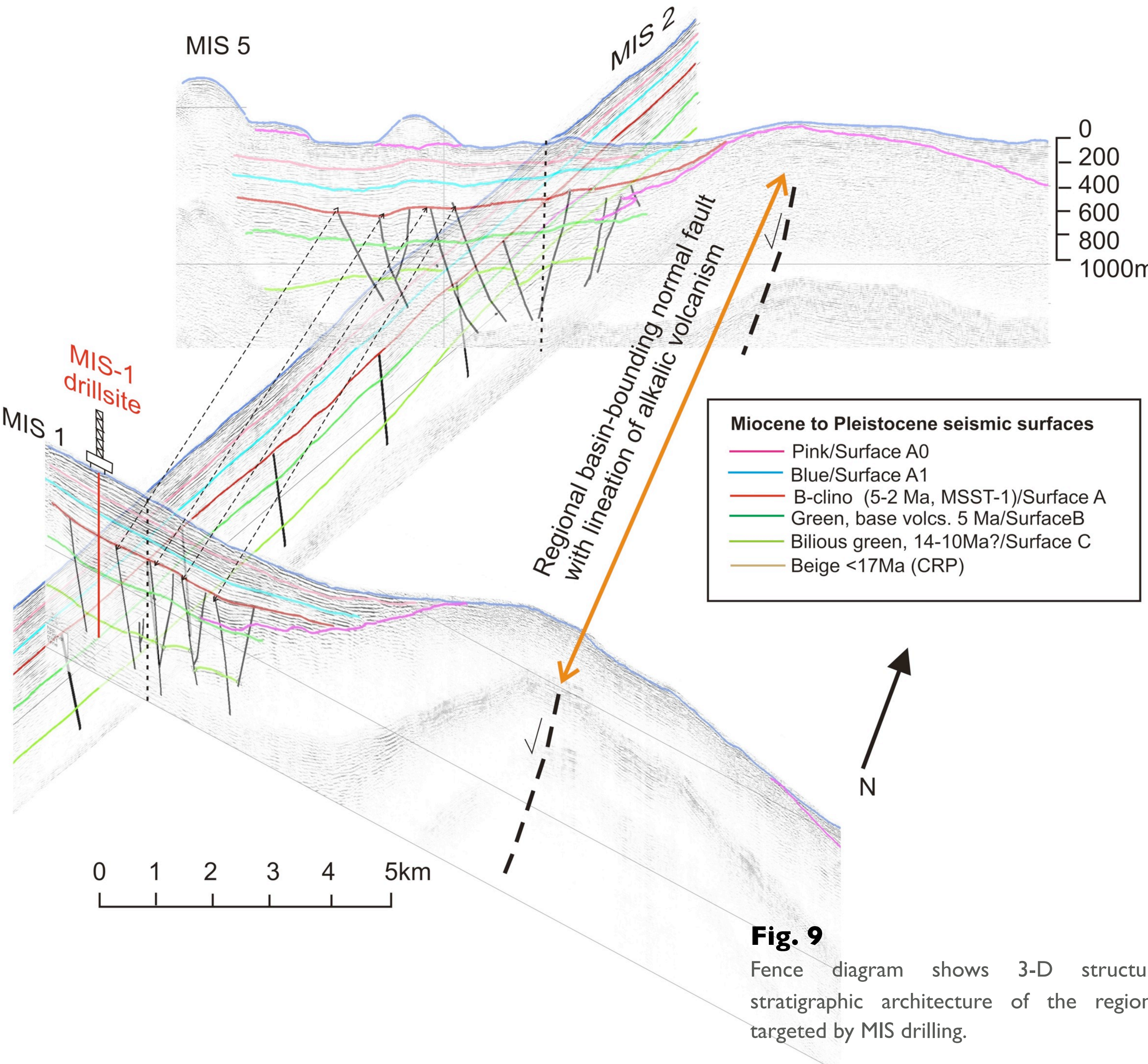



**Fig. 9**
Fence diagram shows 3-D structural and stratigraphic architecture of the region to be targeted by MIS drilling.

m.y. (Stern et al., 1991; Wilson et al., 2003; Horgan et al., 2004), providing a mechanism to accumulate and preserve a sedimentary fill below the sole of the ice sheet/ice shelf during its past expansions.

Radiometric age determinations on volcanic rocks from Ross Island (Wright and Kyle, 1990a and b; Kyle, 1990a, Esser et al., 2004; Tauxe et al., 2004) date the timing of crustal loading by the volcanic pile and allows us to infer that the sediments preserved in the basin have accumulated over the past 5 m.y. The MIS Project will recover the first long stratigraphic record from beneath a major ice-shelf system. Analysis of the environmental proxies contained within the cored sediments will significantly advance our knowledge of ice shelf behavior during past climatic optima and in a future warmer world.

## 1.5 SCIENCE OBJECTIVES

### 1.5.1 Key Climatic Questions

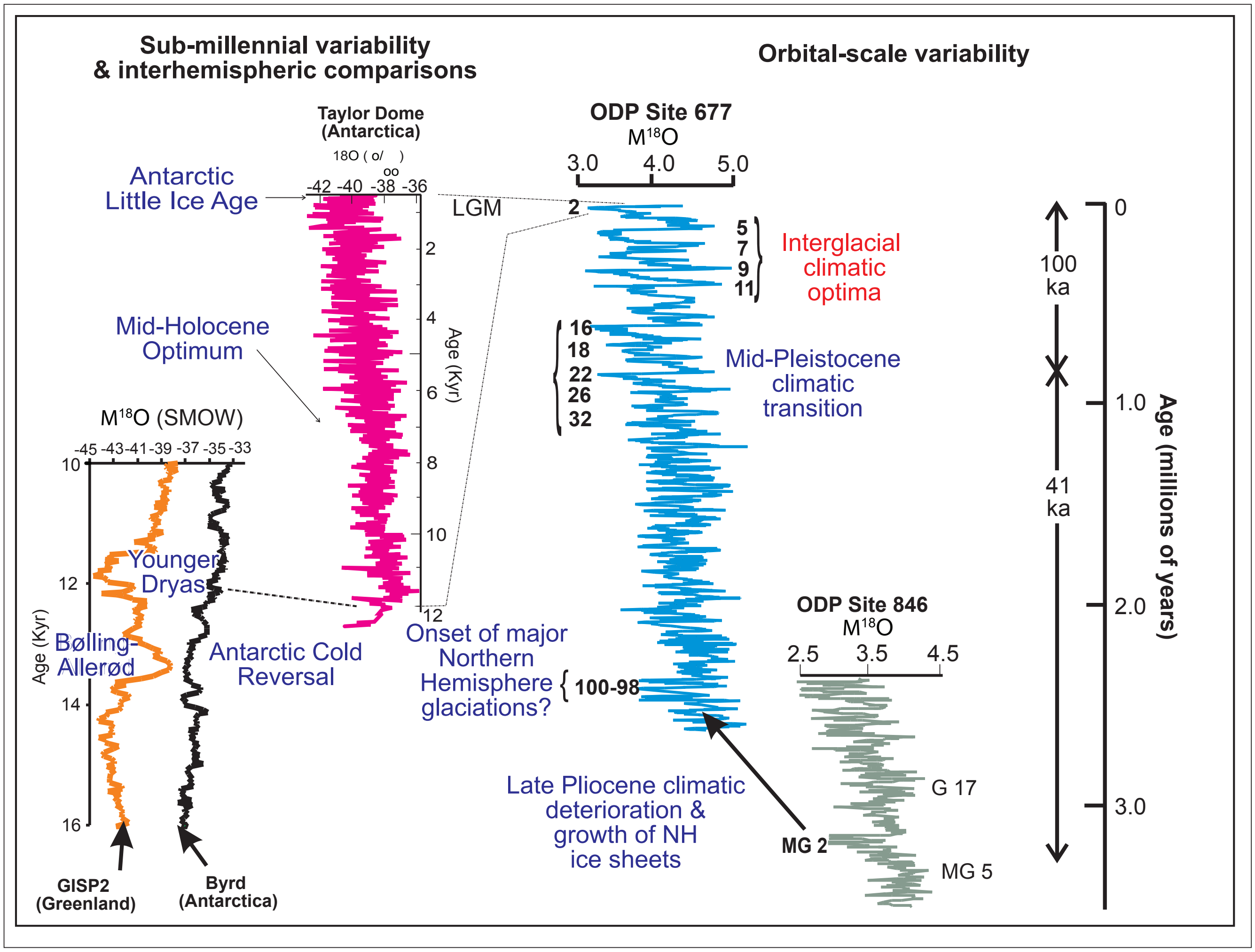
Cycles in oxygen isotope records from deep-sea sediment cores spanning the last 3 m.y. (Fig. 10) have been taken to indicate global sea-level fluctuations of up to 120 m, which have occurred primarily as a consequence of Earth's orbital cycles (40 & 100 ky) on high-latitude Northern Hemisphere temperature and ice volume. Although increased ice mass on Antarctica is thought to account for up to 20% of the observed oxygen isotope signal at the LGM (18 ka), behavior of the inherently unstable, marine-based WAIS and its ice shelves in response to Quaternary glacial-interglacial climate variability remains poorly understood. Concern over the future integrity of the WAIS, and recognition that changes to the more vulnerable RIS will provide precursory warning signals, necessitates a better understanding of the fundamental behavior of the RIS during past glacial-interglacial climatic extremes.

Moreover, at both orbital and millennial-scales, the trigger for Northern Hemisphere climate change may well lie in the south, and likely includes variations in Antarctic meltwater discharge (Clark et al., 2002; Weaver et al., 2003) and Southern Ocean surface warming (Stocker, 2003). Prior attempts to constrain the rate, magnitude and timing of ice-shelf/ice-sheet advance and retreat in western Ross Sea have been hampered by lack of long, high-resolution sediment core records that are relatively continuous. Moreover, the resolution of seismic data has been too low to resolve facies and sequences on the scale of sediment core records, thus restricting accurate regional mapping of ice margin behavior. Although, some previous shallow core studies have contributed to an understanding of the retreat from the last maximum extent of the WAIS system in the Ross Sea (Licht et al., 1996; Domack and Harris, 1998; Domack et al., 1999), a coring program is yet to reach back to interglacial warm climate extremes such as MIS 11 (about 400 ka).

The MIS project will contribute to our understanding of the behavior of the RIS as a dynamic element of the global climate system. We are motivated by the question…

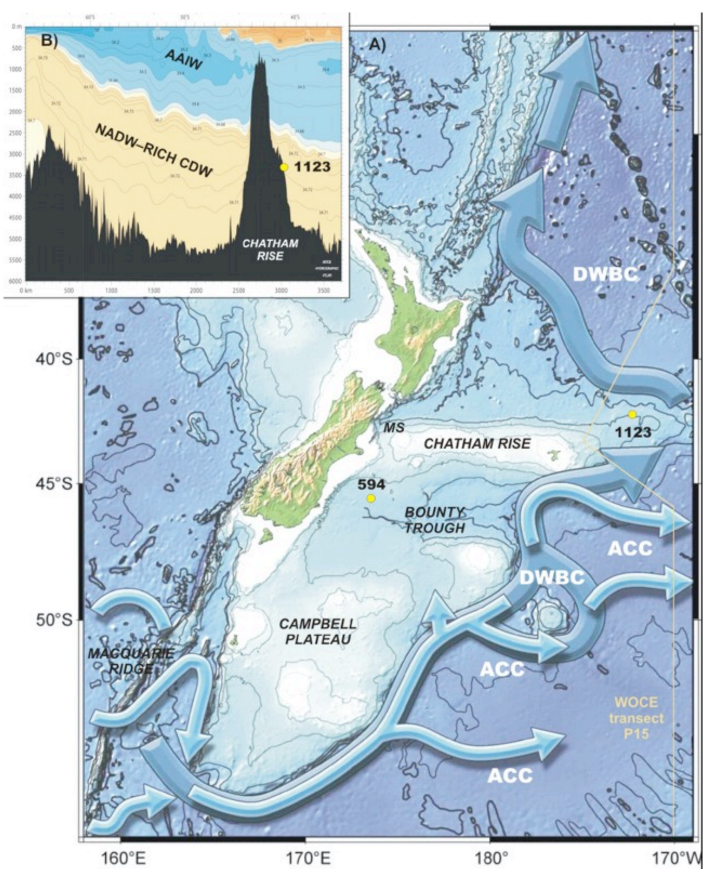
***"How will the Ross Ice Shelf behave as global average temperatures continue to rise over the next few centuries?"***

Are the atmosphere and ocean systems coupled to the RIS and WAIS such that climatic warming is likely to trigger (or have past climatic changes have already triggered) widespread break-up and collapse of the ice shelf? Attempts to predict the future behavior of the ice shelf will require models to be tested with geological data of past




## Fig. 10

Global proxy records of climate variability at orbital and sub-millennial scale for the past 3.5 m.y. The MIS Project will provide proximal cryospheric paleoenvironmental data on these timescales. ( From ANDRILL International Science Proposal, 2003).




## Fig. 11

Deep western boundary current (DWBC) inflow to the Pacific along eastern New Zealand and past ODP Site 1123. In the south, the inflow is over-ridden and dominated by the Antarctic Cicumpolar Current (ACC). North of the Campbell Plateau the DWBC decouples and transports 40% of the volume of the world's deep water into the Pacific Basin. The role of Antarctic cryosphere on global thermohaline ocean circulation is a key objective of the MIS Project. Inset shows salinity profile (red) along World Ocean Circulation Experiment transect P15, running from ~67°C across the eastern end of Chatham Rise near Site 1123, which is bathed by Circumpolar Deep water (CDP) bearing the high salinity signature of North Atlantic Deep Water. Underlying Antarctic Bottom Water in the base of the DWBC is not shown (Crundwell et al., in review; L. Carter).

conditions. Therefore, a specific goal of this project is to…

***"Determine ice shelf responses to climate forcing, including variability at a range of temporal scales ($10^2$-$10^4$ years), and previous possible ice shelf collapses over the past 5 m.y."(Fig. 10)***

Water masses in the Ross and Weddell Seas comprise some of the coldest and densest in the world and are important contributors to Antarctic Bottom Water (AABW) that helps drive the global thermohaline conveyor system. AABW and associated CDW decouple from the Antarctic Circumpolar Current to enter the Pacific Ocean via the Earth's largest abyssal current that flows along the eastern margin of New Zealand (e.g. Carter et al., 2004; Fig. 11). Modelling studies imply that melt-water released during periods of retreat or collapse of the WAIS reduces the density of southern deep-water masses. Less dense southern water masses can potentially strengthen thermohaline circulation and cause the North Atlantic to warm (Weaver et al., 2003; Stocker, 2003). The concept of a Southern Ocean "flywheel" in global ocean circulation and climate involving Antarctic ice-wasting and associated meltwater discharge will be tested by this project. Therefore, another high-level goal is to…

***"Relate RIS variability to thermohaline circulation as expressed by variations in abyssal Pacific inflow along eastern New Zealand to the Pacific Ocean, and the phasing of these histories with northern hemisphere records"***

The behavior of Antarctic ice sheets during two major Quaternary global climate transitions are key objectives of the MIS project:

(a) The interval from 3.0 to 2.5 Ma is one of the most significant climate transitions of the Cenozoic. It is marked by the progressive expansion of ice on Northern Hemisphere continents and coincident global cooling, which at about 2.6 Ma initiated a pattern of glacial-interglacial cycles controlled by long-term periodic variations in Earth's orbit. The geological evidence for this is now widespread and is expressed in a range of polar to equatorial depositional environments including deep ocean sediments (e.g. Shackleton et al., 1995), shallow-marine continental margin sequences (e.g. Naish et al., 1997; Cronin et al., 1994) and continental records including loess (e.g. Ding et al., 2002), lacustrine (Adam et al. 1990) and glacifluvial (Kukla, 1997) sediments. However, currently there are very few good quality proximal Antarctic geological records of this climate transition; therefore, a key objective of the MIS project is to…

***"Document the behavior of Antarctic ice sheets during late Pliocene global cooling and their contribution to this event. Does this transcontinental period correspond to major expansion of WAIS and development of the Ross Ice Shelf?"***

(b) The Mid-Pleistocene transition (MPT) marks a fundamental change in the response of Earth's climate system to orbitally-driven variations in seasonal insolation. For the last 35 m.y. the growth and decay of polar ice sheets can be explained largely by a linear response to the 41 kyr-duration obliquity cycle (Raymo et al., 1989; Zachos et al., 2001a). This is, however, not the case for 100 kyr-duration cycles that dominate Late Pleistocene climate. Although not well understood, certain periods of Earth history including the Late Pleistocene, have been influenced by a climatic response at the 100 kyr frequency band that typically coincides with times of large ice sheet development on polar continents (e.g. Holbourn et al., 2005; Zachos et al., 2001b; Naish et al., 2001a; Mudlesee and Schulz, 1997). Significant non-linear positive feedbacks are required to explain such large responses of the climate system to relatively weak eccentricity forcing (e.g. Imbrie et al., 1993) that may involve

ocean-atmosphere circulation (e.g. Broecker and Denton, 1989), the carbon cycle (e.g. Shackleton, 2000; Medina-Elizalde and Lea, 2005), and the internal dynamics of large continental ice sheets (e.g. Clark and Pollard, 1998). Onset of the MPT is marked in benthic $\delta^{18}O$ records by the end of a major period of climatic deterioration between Marine Isotope Stages (MIS) 25–22, characterized by a 1–1.5‰ shift towards more positive $\delta^{18}O$ values. The MPT itself comprises a period of unstable, progressively lower frequency climate cycles, thought to be associated with an interim state of reduced deepwater circulation and shifting frontal systems (Schmieder et al., 2000; Hall et al., 2001), during the progressive development of larger ice sheets on Northern Hemisphere continents. Termination of the MPT has been linked in the Southern Hemisphere with abrupt reinforcement of abyssal circulation, and the full establishment of 100 kyr ice age cycles at the time of glacial events MIS 16 (~650 kyr; Mudlesee and Shulz (1997)), MIS 14 (~530 kyr; Schmieder et al. (2000)), or MIS 12 (~420 kyr; Hall et al. (2001)). Large ice sheet development is clearly implicated in the transition to the 100 kyr climate cycle, however, the role of Antarctic ice sheets is poorly understood. Key questions to be addressed are…

***"What is the role of the Antarctic cryosphere in the MPT, and did WAIS and RIS expand during the MPT? Does increased production of AABW to the Pacific Basin (e.g. Hall et al., 2001) following the MPT imply increased deepwater production from the Ross Sea region?"***

### 1.5.2 Key Tectonic Questions

Uncertainties in history and pattern of rifting in western Ross Sea make this region one of the least understood components of the global plate motion circuit. The impact of obtaining new age and structural control from even one drillhole was demonstrated by CRP, which showed that the VLB contains a thick Oligo-Miocene fill rather than Cretaceous and older Paleogene sequences as formerly proposed. Competing tectonic models for West Antarctic rifting invoke specific timing for rifting and uplift events. The only direct means to test these models is by acquiring improved age control for basin formation from stratigraphic drilling linked with regional geophysical data. Structural and stratigraphic analyses of the McMurdo Sound Portfolio (MSP) sites aim to document the pattern of VLB rift evolution.

***The evolution and origin of the Transantarctic Mountains and West Antarctic continental rift system.***

*(a) How did the Victoria Land Basin rift evolve in time and space?*
*(b) What is the timing of proposed orthogonal and transtensional rifting episodes in the western Ross Sea (e.g. Wilson, 1995; Salvini et al., 1997)?*
*(c) Which surface processes and/or thermo- mechanical response(s) of the lithosphere resulted in the unusual high-elevation Transantarctic Mountains rift flank adjacent to the highly stretched crust of the Victoria Land Basin?*
*(d) What do the volcanic loads emplaced within the rift tell us about the rheology and mechanical response of the continental lithosphere?*

The Transantarctic Mountains (TAM) represent one of the major young mountain chains on Earth, attaining elevations over 4500 m and extending over 2500 km into the interior of Antarctica. The TAM are generally considered a rift-flank uplift, yet uplift history, landscape evolution rates and processes, mechanisms of uplift and links with rifting all remain debated or poorly constrained (for reviews see Kerr et al., 2000 and Fitzgerald, 2002). The MIS Project will provide new constraints on the timing of rifting and uplift which, when integrated with

modeling studies, are critical to establishing how rift-related thermo-mechanical and erosional processes are related to the development of this unusual extensional orogen.

The McMurdo Sound region provides a natural geodynamic experiment allowing investigation of the rheology of continental lithosphere and the response of the underlying asthenosphere to rifting and the imposition of volcanic loads. Anomalous gravity signatures, apparent timing discrepancies for rifting vs. uplift, and modeling studies all suggest that the rheology and mechanical response(s) of Antarctic lithosphere to rifting may have been unusual compared to other rift systems (Stern et al., 1991 ten Brink et al, 1993; Karner et al., 2003; Buck et al., 2003). The ANDRILL MIS Project will document sediment and volcanic load histories and obtain stratigraphic records that can be used for tectonic subsidence analysis, tracking the lithospheric response to evolving loads. Such documentation of continental rheologies is a major objective of the IODP initiative on "Continental Breakup and Sedimentary Basin Formation" (http://www.iodp.org/isp.html).

***The characteristics of rift-basin stratal architecture in a tectonic system influenced by glacial processes.***

*(a) How can we discriminate tectonic subsidence and glacio-eustatic base-level change in a glaciated rift basin?*
*(b) What are the unique geomorphic and sedimentary characteristics of a rift/rift-flank system developed in a glaciated setting?*

In the Victoria Land Basin, rift fault patterns, glacio-eustasy, glacial erosion, sediment flux from basin margins, and magmatism all have controlled basin evolution and stratal architecture within it. Discriminating the relative influence of each requires comparison of stratigraphic records between locales where different forcing factors are expected to dominate (e.g. Gawthorpe et al., 1994; Gawthorpe and Leeder, 2000; Gupta and Cowie, 2000). The temporal and spatial array of the MIS and SMS drill sites provide the means to establish differences in tectonic subsidence, helping to isolate it from glacio-eustatic and other effects.

Antarctica is key to developing a better understanding of the net effects of plate-boundary and glaciotectonic forces on plate-interior stress regimes. Ice mass load changes can suppress or induce seismicity, depending on the ambient stress regime (Stewart et al., 2000; Muir-Wood, 2000). At present, there are almost no *in situ* data from Antarctica to test stress models. The MIS Project provides a unique opportunity to obtain *in situ* stress measurements by mapping drilling-induced fractures in the core and borehole and by downhole hydraulic fracture measurements. This will allow improved modeling of the influence of fluctuating ice mass on stress regimes (Ivins and James, 2001; Liu, 2003), illuminating processes operating in recently glaciated regions of the Northern Hemisphere, where seismic risk is of societal concern (e.g. Muir-Wood, 2000).

***The nature of feedbacks among climate, the cryosphere and solid Earth geodynamics.***

*(a) Were the rising Transantarctic Mountains a driver for cooling and the inception of glaciation? Or, did global cooling and associated changes in erosional/depositional regimes influence the uplift of the Transantarctic Mountains?*
*(b) Do the Transantarctic Mountains represent an unusually ancient landscape, preserved for millions of years in the frigid polar environment?*
*(c) How does volcanism, and postulated mantle plume activity, relate to rifting and uplift of the TAM?*
*d) What feedbacks occurred between volcanism and glacial dynamics?*

*e) How does the intraplate stress regime integrate plate boundary forces and the influence of changing ice mass loads?*

Climate-controlled surface processes may be as important as tectonic forces in creating mountain ranges (Pinter & Brandon, 1997; Willett and Brandon, 2002; Montgomery et al., 2001; Meigs and Sauber, 2000; Stern et al., 2005). The TAM represent an end-member of unique interest in understanding feedbacks between surface processes and mountain building because it is an extensional orogen developed in a polar environment where glacial erosion and transport of sediment is a dominant influence. Establishing the role of glacial erosion in exhumation and isostatic uplift of the TAM requires information about the timing of erosion and evolution of geomorphic-sedimentary environments (fluvial, alpine glaciation, ice sheets [wet- and frozen-base]) through the Cenozoic. Stratigraphic records of TAM erosion and depositional environments obtained by ANDRILL will constrain exhumation history and paleoenvironments during time intervals when onshore records are unobtainable.

Fluctuating ice sheets in Antarctica are linked in time and space with one of the most voluminous alkaline volcanic provinces in the world (LeMasurier and Thompson, 1990). The thermal, atmospheric and paleogeographic influences of Cenozoic magmatism in the Antarctic interior are likely to have had significant influence on climate and ice sheet dynamics (Briffa et al., 1998; Prueher and Rhea, 2001). Records from the MIS Project will improve our knowledge of the temporal and spatial evolution of magmatism along the TAM, and the relative timing of magmatism, glaciation and faulting. Understanding the temporal relationship of extension and magmatism will help to address the question of whether magmatism was triggered by extensional tectonism, or whether a rising mantle plume has caused local crustal thinning, unrelated to regional rifting events in the Antarctic interior. In addition, it may show whether glacial loading and unloading has served as a ‘pumping mechanism’ that has induced melting, as documented in Iceland (Slater et al., 1998; Sigvaldason, 1992; Maclennan et al., 2002). Time-space evolution of volcanoes also had a significant influence on the available pathways for advance of the ice sheets and ice shelves from the Antarctic interior to the continental margin. As the Erebus Volcanic Province developed over the last > 25 m.y, the paleogeography of the region changed and barriers to ice flow developed (e.g. Kyle, 1981). By improving knowledge of the spatial-temporal development of the volcanoes at this critical position, the MIS Project will provide new constraints on the paths of TAM glacial outflow and links between East and West Antarctic ice.

# 2. SITE SURVEYS AND A STRATIGRAPHIC INTERPRETATION OF DRILL TARGET INTERVAL

## 2.1 SEISMIC STRATIGRAPHY

Ross Island volcanic complex began forming with the emplacement of the basaltic shield volcanoes of Mt. Bird and Mt. Terror between c. 4.6 and 1.3 Ma (Wright and Kyle, 1990a, b). However, the most significant development of the complex has occurred over the last 1 m.y. during an eruptive phase that produced the 3794 m-high composite vent of Mt. Erebus (Moore and Kyle, 1990; Esser et al., 2004). Loading by the Ross Island volcanic pile of the lithosphere at the southern end of the Terror Rift has progressively depressed the crust resulting in a sub-circular flexural moat around the periphery of the island.

Multi-channel seismic reflection data collected from the MIS sector of the RIS reveal the stratigraphic architecture of the moat-fill on the southeastern side of Ross Island (Bannister, 1993; Melluish et al., 1995; Bannister and Naish, 2002; Horgan et al., 2003; Horgan et al., 2005; Henrys et al., 2006). The moat region has accommodated a well-stratified, regionally extensive sedimentary succession of 1.8 km below the sea floor in the deepest part of the depression. Three seismic stratigraphic units are identified that generally thicken and dip towards Ross Island and are bounded by angular (onlap) unconformities (Horgan et al., 2005). These units are deposited in accommodation space inferred to have been created during phases of volcanic load-induced subsidence superimposed on basin-scale transtensional subsidence associated with development of the Terror Rift (Figs. 12 & 13):

Unit III. Moderate- to low-amplitude discontinuous reflectors that are dislocated and tilted by normal faulting and interpreted to represent coarse-grained glacigenic and fine-grained marine sediments with likely intercalated volcanic ash.

Unit II. Moderate- to high-amplitude continuous reflectors that onlap Unit III and are interpreted to represent coarse-grained glacigenic and fine-grained marine sediments with likely intercalated volcanic ash.

Unit I. Relatively continuous low-amplitude to seismically opaque reflectors (Unit IC), onlap Unit II and grade upwards into moderate- to high-amplitude reflectors below the sea floor (Units IB and IA). Units IB and IA are separated by Surface A0 which locally truncates Unit IB and is characterized by onlap above.

Figure 14 shows the pattern of N-S normal faulting and major structural lineations within the Terror Rift. The location of lines used to construct two west to east seismic cross-sections (Fig. 12) are shown on this map. These cross-sections reveal an eastward dipping and thickening package of strata dislocated by N-S trending high-angle normal faults and bounded in the east by a N-S line of intruded volcanic bodies, the southern most body forming the edifice of White Island (Figs. 4 & 5). The volcanism is coeval with Pliocene to recent extension in Terror Rift and appears to be associated with a major west-dipping normal fault forming the eastern margin of a half graben that can be traced from Minna Bluff (Henrys et al., 2006) to Drygalski Ice Tongue (Hall, 2005). A gravity survey acquired along the MIS 5 line shows a positive water-adjusted free air anomaly east of the graben over the volcanics, which may also be indicative of a shallow basement horst block.

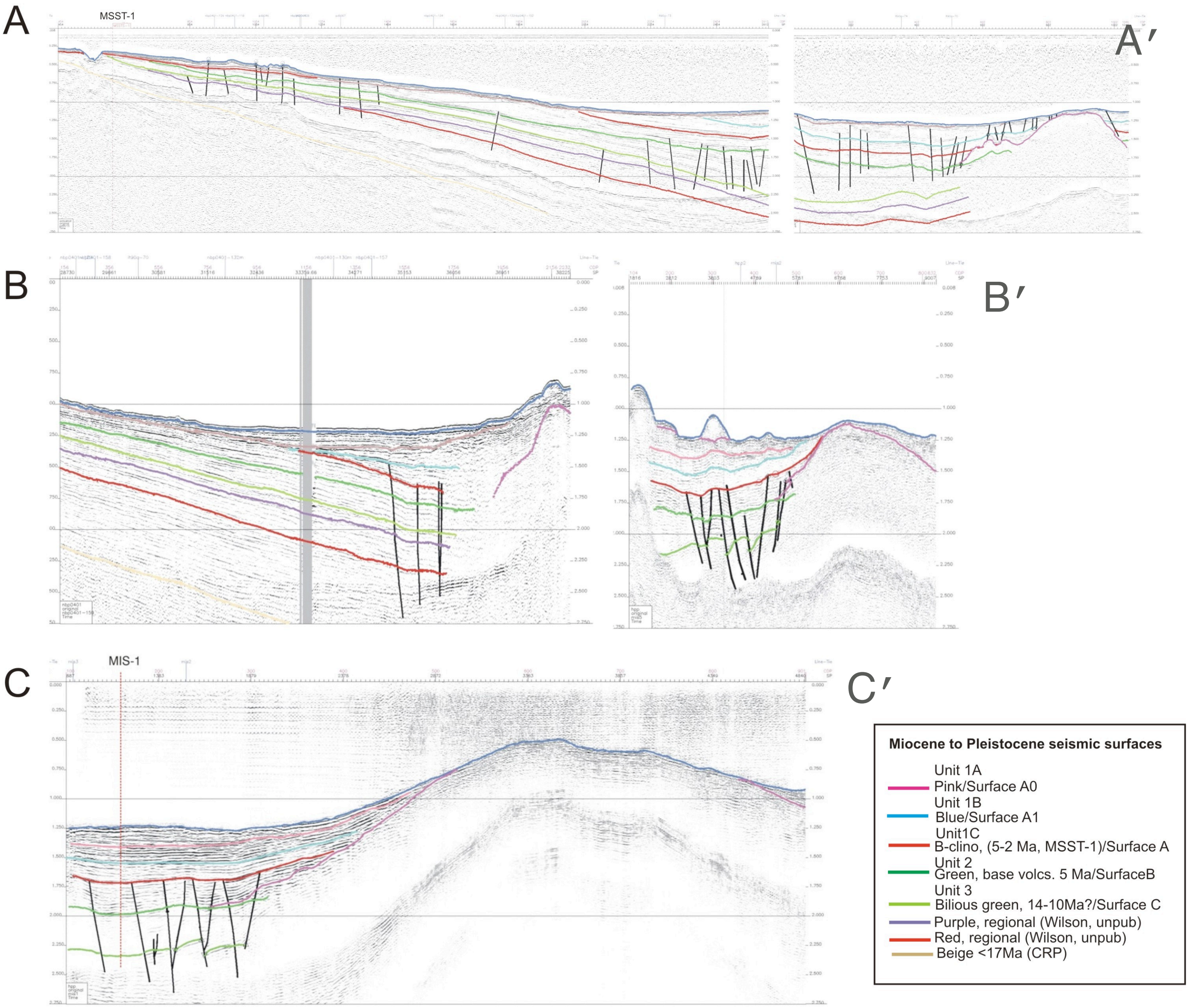
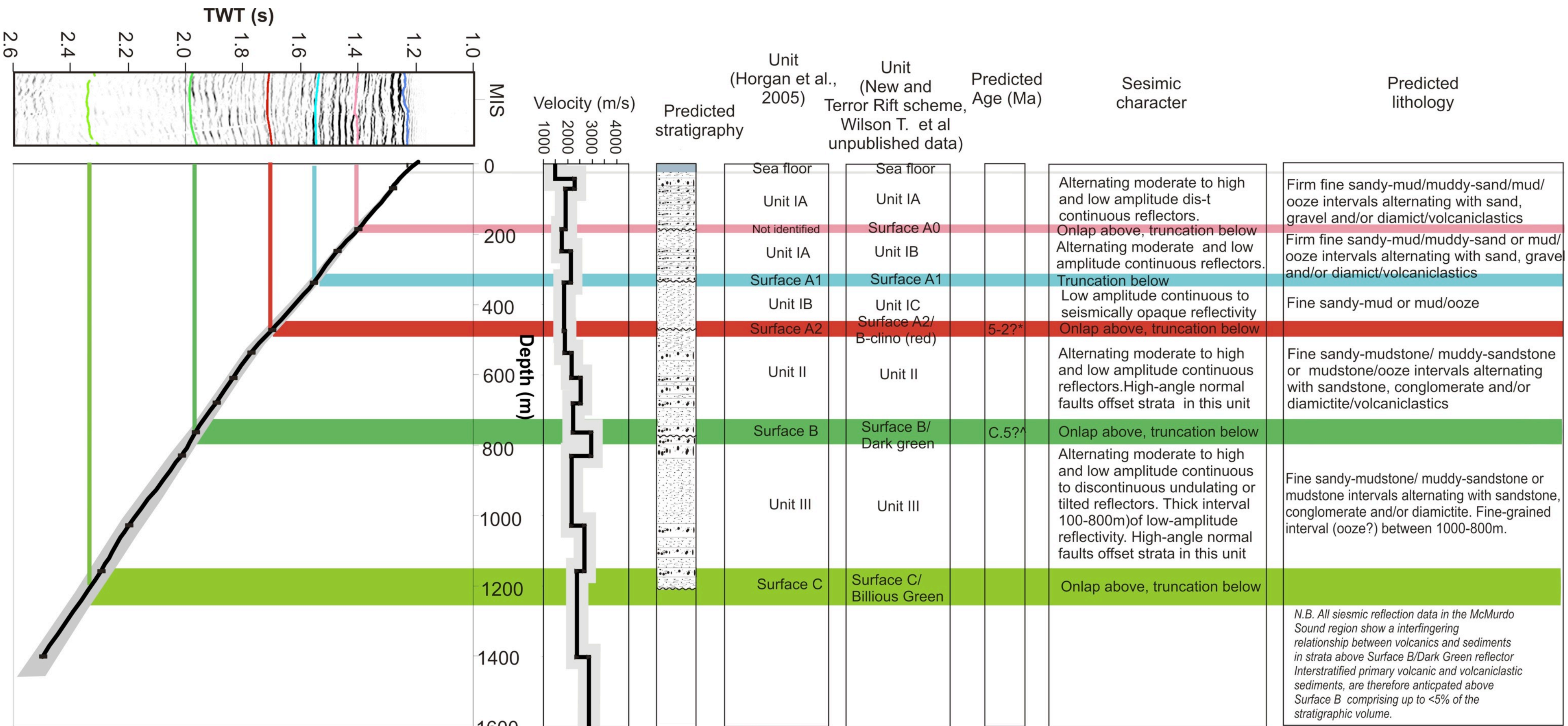



**Fig. 12**

A) Seismic cross-section of the Victoria Land Basin from MSSTS-1 around the northern end of Ross Island based on PD9015 and PD9016 marine seismic lines (Hall, 2006). (B) Seismic cross-section of the Victoria Land Basin using NBP0401-159 (Whittaker, 2005) and MIS 5 shows the geometry of strata infilling the Ross Island flexural moat (above red/b-clino reflector) overlying westward thickening and dipping strata of the Terror Rift. (C) Seismic line MIS-1 on which the MIS drill site is located)




* Age based on correlation with MSST-1
^ Age based on published and unpublished radiometric dating of the Erebus Volcanic Province (Ross Island, Black island, White Island, Mt Discovery)

**Fig. 13**

Seismic velocity to depth conversion and interval velocity analysis at the MIS drill site. A stratigraphic prognosis is inferred on the basis of limited age information and lithofacies interpretation of the seismic characteristics.

## 2.1.1 Seismic Stratigraphic Interpretation and Age Relationships: A Prognosis for MIS Drilling

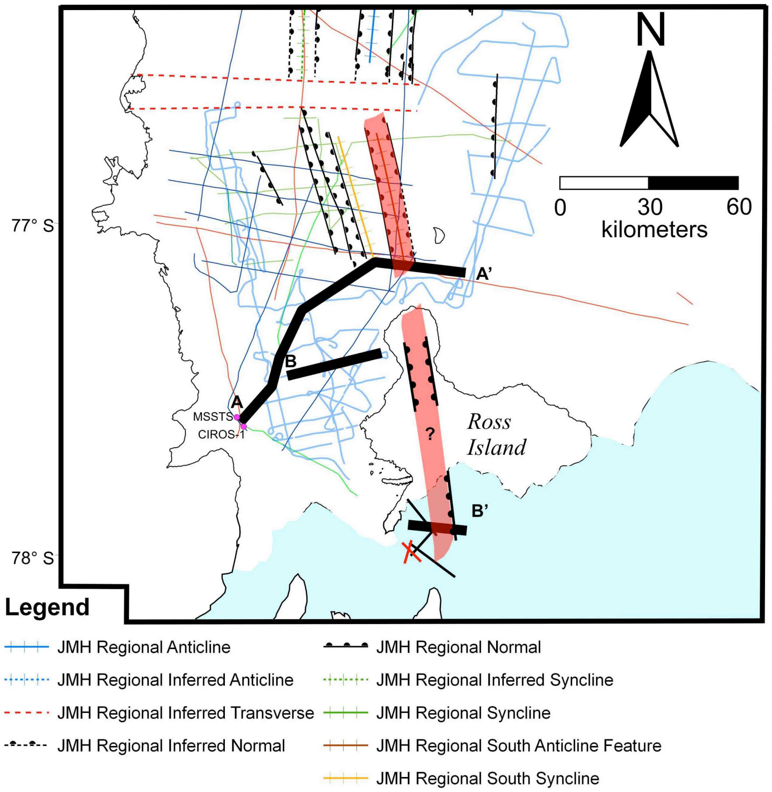



**Fig. 14**

Map showing structural fabric of the Victoria Land Basin/ Terror Rift. The location of seismic cross-sections in Fig.12 are shown. Noteworthy is the N-S trending sedimentary depocentre (coloured pink), which is the target for the MIS Project, and its eastern boundary marked by an anticline cored by alkalic volcanics (Hall, 2006).

The geometry of the three seismic units described above has been interpreted in terms of inferred accommodation space generated by progressive emplacement of over 4600 km$^3$ of Ross Island volcanic centers (Esser et al., 2004) on the crust in southern Terror Rift (Horgan et al., 2005) in combination with basin-scale subsidence associated with Neogene transtensional normal faulting. The chronology of the eruptive history of Ross Island (Kyle, 1990b; Esser et al., 2004) indicates several phases of volcanism and associated load-induced subsidence within the adjacent flexural moat: Mt. Bird loading between 4.6-3.8 Ma (Wright and Kyle, 1990a) was followed by a hiatus of over a 1 m.y. There was then continuous loading due to emplacement of Mt. Terror from 1.7-1.3 Ma (Wright and Kyle, 1990b), Hut Point Peninsula from 1.6 - 0.33 Ma (Kyle, 1981, 1990a; Tauxe et al., 2004) and Mt. Erebus between 1.3 Ma and present day (Esser et al., 2004).

Flexural modeling of the lithosphere in response to these loads being emplaced at their respective times is being carried out presently and will be presented in a future paper (Wilson et al., in prep). Initial results are consistent with the accommodation space implied from the seismic stratigraphic architecture of the moat fill for Unit I and probably Unit II. Recent compilations (Whittaker, 2005; Hall, 2005) of the seismic stratigraphy of Southern McMurdo Sound incorporating a grid of new multichannel marine data (Wilson et al., 2004) reveal a clear relationship between volcanism and sedimentation in Terror Rift. Between Ross Island and the Drygalski Ice Tongue, volcanic bodies consistently overlie the green reflector and their inferred deposits are intercalated with strata of seismic Units I & II. On this basis we infer an age of c. 5 Ma for the green surface (Figs. 12 & 13). Thus, Units I & II are of probable Plio-Pleistocene age, and their accommodation space was provided through a combination of progressive crustal flexure from volcanic loading, especially in Unit I, superimposed on basin-scale extension, which is likely to have been more influential on the geometry of Unit II. The red reflector, b-clino, (Figs. 12 & 13) has also been mapped regionally west and north of Ross Island where it marks the base of westward-prograding clinoforms, and around the periphery of Ross Island marks the base of the flexural moat-fill. Tentative correlation of this horizon with an unconformity immediately below an interval of Pliocene mudstone in the MSSTS-1 drill core implies an age for Unit I of < 5 Ma.

Probable lithofacies are inferred from the nature of seismic reflectivity, lateral continuity of the reflectors, and internal geometry of the seismic units, all considered within the context of the probable depositional setting. In general, seismically-opaque or low-amplitude units are interpreted as predominantly fine-grained lithologies (e.g. mudstone and volcanic ash). Intervals of moderate to high-amplitude reflectivity are interpreted as coarse-grained or alternating coarse- and fine-grained lithologies (e.g. diamictite, conglomerate, sandstone, and/or coarse volcanic deposits). The stratigraphic interpretation and prognosis presented here is for a single drill site located near the intersection of lines MIS-1 and MIS-2 (Figs. 8, 9 & 13).

Unit III, which comprises up to 350 m of moderately reflective strata deformed by normal faulting, is interpreted as alternating coarse- (diamictite, conglomerate, lapilli and sandstone) and fine-grained (pelagic mud and ash) lithologies with a thick lower velocity interval of probable mudstone between 1000 and 800 m below sea floor (Fig. 13) that has been accommodated by rifting.  Local truncation of subjacent strata near normal fault blocks at the top of Unit III is intriguing. It may represent significant bathymetric shallowing and erosion by currents and/or grounding of ice on structural highs prior to the emplacement of volcanic loads on the crust. Subsequent onlap of the strata at the beginning of deposition of Unit II implies rapid regional subsidence and reorientation of the seafloor perhaps in association with the beginning of alkalic volcanism in the region.

Unit II, which comprises relatively continuous moderately to highly reflective strata up to 300 m-thick, is interpreted as infilling the Terror Rift and possible accommodation space associated with the early development of the flexural moat, by alternating coarse- (diamictite, conglomerate, lapilli and sandstone) and fine-grained (pelagic mud and ash) lithologies, that progressively fine-upward.

Unit I, which comprises up to 400 m of relatively continuous strata that display increasing reflectivity upward, is interpreted to represent progressive infilling of the Ross Island flexural moat from seismically opaque fine-grained sediments (pelagic mud and ash) to highly reflective coarse-grained deposits (diamictite, conglomerate, lapilli and sandstone) with intervening fine-grained (pelagic mud and ash) lithologies. Onlap of strata at the beginning of deposition of Unit I is interpreted as rapid regional subsidence and reorientation of the seafloor coincident with the onset of significant volcanic activity from Ross Island (< 2 Ma). The predominance of seismically-opaque facies within the lower 100 m (Unit IC) is consistent with initial rapid subsidence and bathymetric deepening, prior to infilling and shoaling to more proximal coarse-grained glacimarine facies in the upper 300 m (Units IB and IA).

The close vicinity of the MIS Project drill site to Ross Island and nearby White Island to the south ensures that volcanic sediments should be well-represented in the core. Subtle differences occur in the compositions between volcanic material from Mt Erebus compared to Bird, Terror and Hut Point, which radially surround Erebus (Kyle, 1990b). Erebus lavas define the Erebus lineage (Kyle et al., 1992) and are more evolved in composition and have olivine throughout the magmatic fractionation series. Lavas in the three areas surrounding Erebus are characterized by DVDP lineage lavas (Kyle, 1981), which usually contain kaersutite in the more evolved lavas. Volcanic eruptions usually produce, almost instantaneously, significant volumes of fragmented material (pyroclasts) that are easily transported. With Hut Point Peninsula being the closest landmass to the MIS Project drill site, eruptions at Hut Point should cause episodic rapid influxes of volcaniclastic material. Evidence of subglacial eruptions are rare on Ross Island suggesting that ice cover was not extensive, so one can also expect deposition of fall tephra from the more explosive phonolitic vents on Ross Island.

### 2.1.2 Faulting and Deformation

High-angle, north-south trending faults, aligned with the structural grain of the Terror Rift, offset horizontal to sub-horizontal strata below 1.7 s two-way travel time (TWT) (about 1600 m), with normal throws of up to 100 ms TWT (about 90 m) in lines MIS-1 and HPP-2 (Figs. 9 & 12). These faults generally do not offset strata above seismic Unit III; however, they do appear to mildly deform sub-horizontal reflections in the base of seismic Unit II (see below). The strike of the eastern most faults in line MIS-1, are inferred to intersect line MIS-2 at a very acute angle, which may explain the loss of coherency below seismic Unit II in the line. The cessation of normal faulting within Unit II may represent a change in local stress regime, as the concentric pattern of crustal flexure is progressively superimposed on the pre-existing regional pattern of extension within the Terror Rift, or perhaps the lack of obvious dislocation is due to the more ductile nature of softer sediments in the upper 700 m.

## 2.2 BATHYMETRY

Bathymetry appears to deepen away from Ross Island to a maximum water depth of 1.2 s TWT (950 m) about 7 km east of Hut Point Peninsula along the HPP-1/HPP-2 composite line. Farther eastward along this line the moat begins to shallow to a depth of 810 m. South and farther to the east a pronounced bathymetric shallowing from 950 to 400 m occurs along the MIS-1 line as it passes over the northern sub-seafloor extension of deformation associated with White Island volcano, and then progressively deepens beyond this to 700 m. We note that all bathymetric conversions from TWT to meters require assumptions concerning ice shelf thickness and the velocity characteristics of the ice shelf and water column.

## 2.3 OCEANOGRAPHY

Ross Sea shelf waters originate from Circumpolar Deep Water (CDW) that has up-welled near the Antarctic Slope Front (e.g., Jacobs et al., 1985). Through the introduction of brine rejected from freezing ice, precipitation and meltwater, together with cooling and mixing processes, the following shelf water masses form:

- Antarctic Surface Water (AASW),
- High and Low Salinity Shelf Water (HSSW and LSSW),
- Ice Shelf Water with shallow and deep components (SISW and DISW).

The extent of ice shelf modification of CDW makes the Ross Sea a significant source of very cold, saline bottom water that helps drive the global thermohaline Ocean Conveyor system (e.g., Jacobs et al, 1985). The data obtained from HWD-3, site during February 2006 (Carter et al., 2006) together with previous observations from the 2003 Antarctic fieldwork (e.g., Barrett et al, 2005) provide short-term observations of water mass variability in the vicinity of the MIS Project drillsite in this key “bottom water factory”.

In 2003 (Barrett et al., 2005), oceanographic measurements were obtained from beneath the MIS at hot-water drill sites HWD-1 and HWD-2 in Windless Bight (Fig. 8). Water column measurements from the two locations show that the net current direction is to the east from McMurdo Sound through to the RIS, with speeds averaging 5 to 7 cm/sec but at times reaching 17 cm/sec. Flow measurements obtained at a third, shallower location at the ice shelf edge near Scott Base, were in the same net direction but were faster – up to 60 cm/sec.

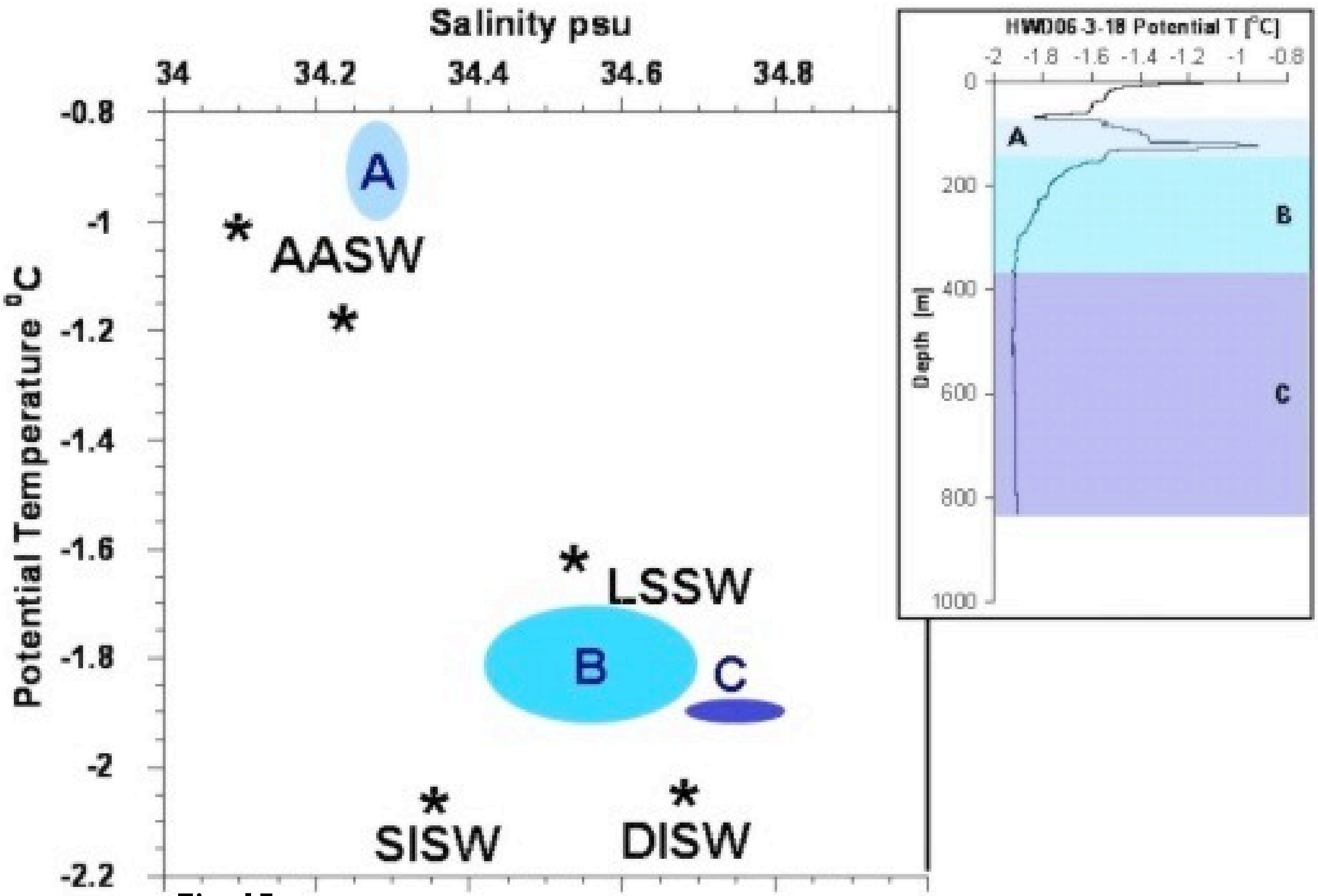


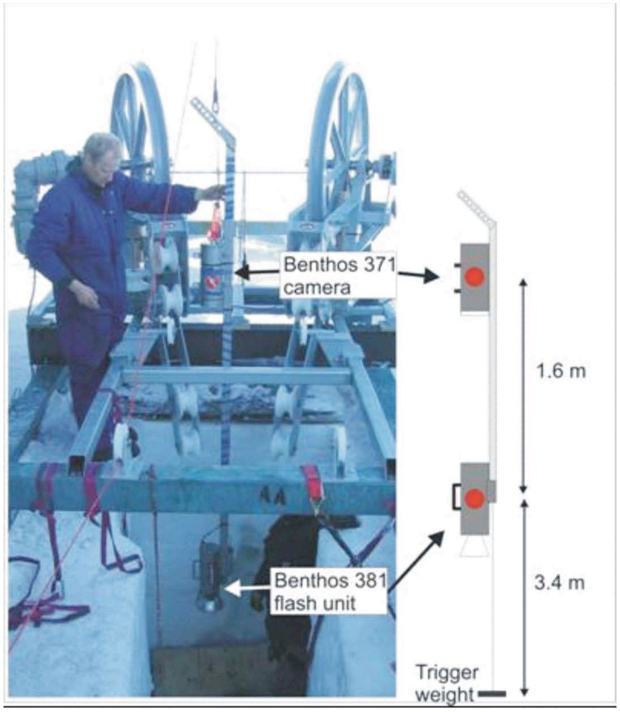

**Fig. 15**

Mean T/S plot of main shelf water masses including Antarctic Shelf Water [AASW], Low Salinity Shelf Water [LSSW], Shallow Ice Shelf Water (DISW). A, B and C refer to water mass zones at Site HWD-3 as indicated from inset of potential temperature profile (Carter et al., 2006).

Water column profiles beneath HWD-1 and 2 also encountered waters with extremely low temperatures and high densities. Salinity and temperature measurements are similar to those recorded 25 years ago at the first hole drilled through the RIS some 400 km south of the MIS site at J9 (Jacobs *et al.*, 1979). These sub-ice shelf water masses, which comprise Deep Ice Shelf Waters (DISW) and High Salinity Shelf Waters (HSSW), are some of the coldest and densest in the world.

CTD casts made over tidal cycles in the austral summer of 2006 observed the same basic water mass structures as the 2003 casts, however there were are also significant differences (Fig. 15) (see Carter et al., 2006). Zone A was substantially warmer in 2006 (1ºC warmer than in 2003). However, such warming is not unusual as revealed by two years of continuous temperature records collected in McMurdo Sound by Hunt et al. (2003). Their data

show a strong seasonal warming of up to 1.0° C in January-February of 1999-2001. Spot measurements by Heath (1977) and Littlepage (1965) suggest similar summer incursions in the region. In the case of the 2006 data, the incursions are sourced directly to Antarctic Shelf Water. One possibility for the 2003 event could be a change in circulation in McMurdo Sound and Windless Bight, instigated by a



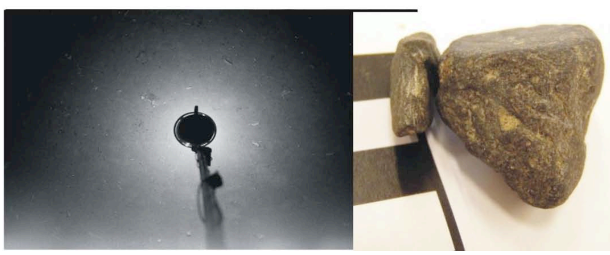
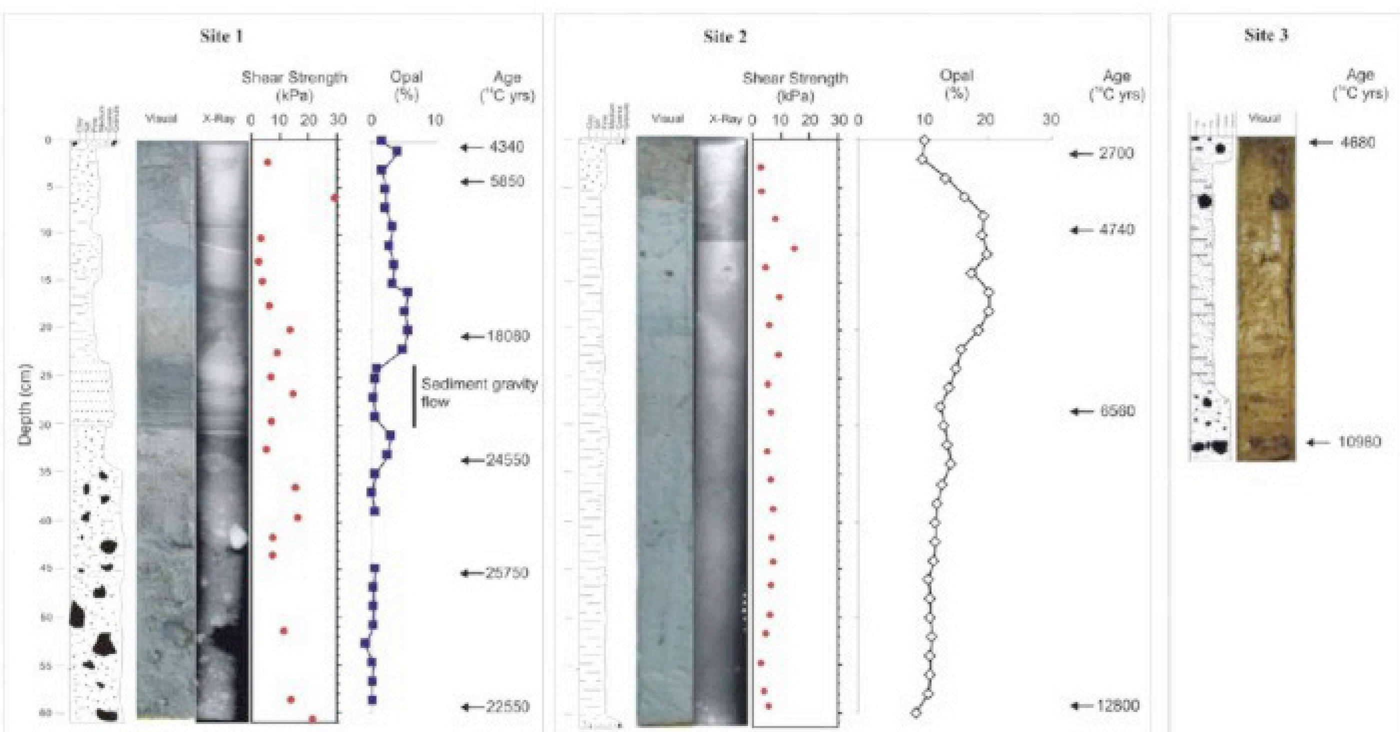



**Fig. 16**

Benthos camera system in operation at HWD-3 in February 2006 shows a pebbly sea-floor with evidence of abundant benthic biological activity. Also shown is a striated clast from the diamicton immediately under the sea-floor (Carter et al., 2006).

**Fig. 17**

Composite stratigraphic logs for short cores recovered from sites HWD-1 to 3, showing, graphic log, photography, x-radiograph, shear strength, opal content and radiocarbon chronology (Barrett et al., 2005; Carter et al., 2006).



blocking effect of the Sound by the giant B15 iceberg. It may be that the iceberg altered the circulation to inhibit incursions of Antarctic Shelf Water from the open continental shelf.

### 2.4 SEAFLOOR AND SUB-SEAFLOOR SEDIMENTS IN THE VICINITY OF THE MIS DRILLSITE

A high-amplitude seafloor arrival is observed in all profiles with the exception of the western end of the HPP-1 line, where the profile runs up onto Hut Point Peninsula. Shallow sediment cores (up to 80 cm-long) were acquired in 2003 from the seafloor near the intersections of both MIS-1 and HPP-2 with MIS-2 (Barrett et al., 2004; Fig. 8) and in 2006 from a site 5 km east of the MIS Project drill site on the MIS-1 line (Carter et al., 2006). The three sites, respectively located 5, 12 and 10 km east of the shelf edge near Scott Base, were covered by ice 70, 143 and 98 m-thick, and lay at water depths of 926 m, 923 m and 754 m.

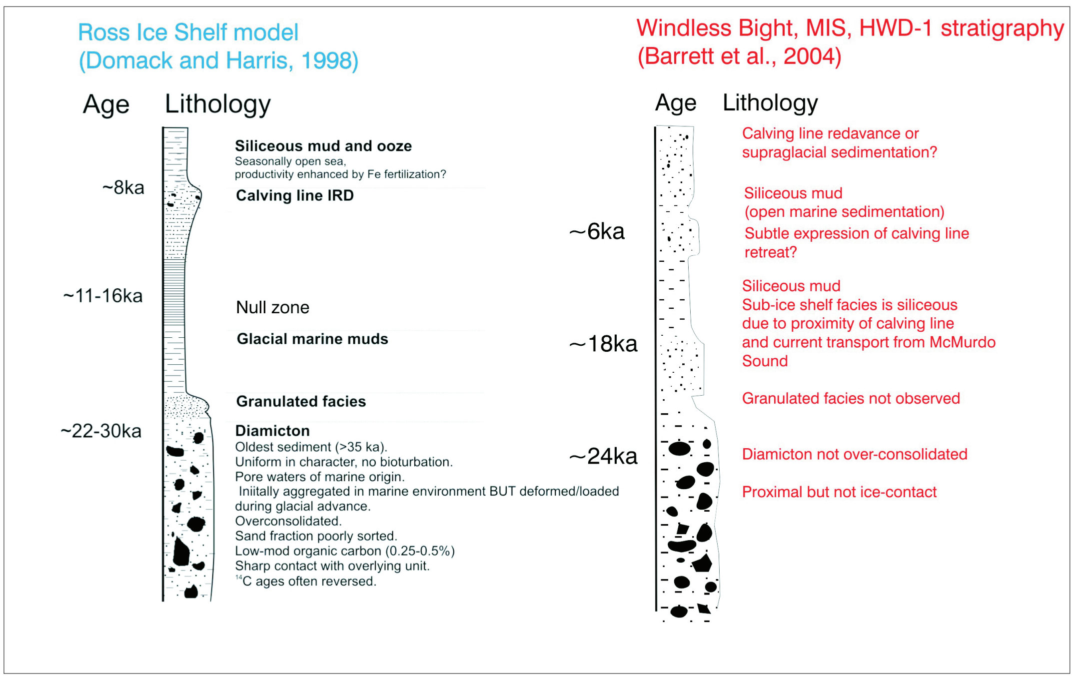



**Fig. 18**
Depositional models developed for the Pleistocene-Holocene glacial-interglacial transition in Ross Sea (Domack and Harris, 1998; Domack et al., 1999) and beneath the McMurdo Ice Shelf in the Ross Island flexural moat.

Seafloor samples recovered in 2003 sites comprise soft mud, diatoms, foraminifera and micro-molluscs (Barrett et al., 2005). Diatom taxa recovered from the samples usually live in open marine waters and are inferred to have been carried under the ice shelf by currents (Fig. 9). Recovery of the foraminifera and micro-mollusc assemblages was unexpected as (a) these assemblages are typically found locally at shallower depths and (b) we had assumed that the cold and deep corrosive (from carbonate under-saturation) waters would inhibit carbonate preservation. Photographs of the seafloor taken in 2006 (Fig. 16) show no visible bedforms indicating that current velocities are very low across the seabed. A large number of gravel clasts up to ~10 cm in diameter and an abundant benthic fauna are apparent. Sediment recovered in the grab sample from this site reveals an extremely poorly sorted, unconsolidated, sandy diamict.

In the longest of the three cores (Fig. 17) closest to the MIS Project drill site the transition from fine-grained diatomaceous sediment to a loosely consolidated diamicton occurs at ~ 30 cm. The diamicton is interpreted to have been deposited beneath floating ice at a location proximal to the grounding line of the WAIS as it last retreated through the MIS area after having occupied most of the Ross Sea during the last glacial maximum (Licht

et al., 1996; Conway et al., 1999; Domack et al., 1999; Hall and Denton, 2000a, b). Shear strength measurements from the diamicton indicate that the sites have not been over-compacted or eroded by grounded ice. This observation, together with the variable nature of the sediment recovered in the cores, supports our conjecture that the planned 1000 m-deep hole will recover a relatively complete and sensitive record of Ross Ice Shelf history for the past 5 m.y.

**2.5 TOWARDS A GLACIAL-INTERGLACIAL DEPOSITIONAL MODEL**

The aim of the sub-seabed coring was to test and develop a depositional model for sedimentation in the Ross Island flexural moat below the ice shelf during the Last Glacial Maximum and the Pleistocene-Holocene deglacial transition. The model presented here is based on data from the cores described above and is compared with previously published models that were: (a) developed from direct study of a modern system (Powell et al., 1996; Dawber and Powell, 1998) and (b) inferred from the record of Holocene glacial retreat in Ross Sea sediments (Domack and Harris, 1998; Domack et al., 1999; Fig. 18). The last glacial-interglacial transition is constrained in these latter studies by radiocarbon chronologies, and should provide a basis for interpreting older Pleistocene glacial-interglacial sequences to be recovered in the ANDRILL MIS drilling.

Domack et al. (1999) describe a “typical” glacial to open-marine vertical succession of facies based on studies of a number of sediment cores from Western Ross Sea that includes in ascending stratigraphic order: (a) over-consolidated massive, mud-rich diamictons of subglacial affinity, (b) a granulated sandy, muddy gravel facies associated with the lift-off zone, (c) well-sorted, very fine sand interpreted as sub-ice shelf near the grounding-line, which passes upwards into (d) a siliceous mud representing deposition in an open marine environment. In some cases a sandy volcaniclastic facies marks the transition from sub-ice-shelf to open marine conditions and the passage of the calving line.

The deglacial facies succession from the Ross Island flexural moat below the McMurdo Ice Shelf differs in three important ways from the Domack et al model. First, the last glacial diamicton is not over-consolidated, and appears more like the glacimarine diamicton accumulating by sub-ice-shelf rainout near the grounding line of modern Mackay Glacier (Powell et al, 1996). The normal consolidation of the diamicton indicates that the WAIS-RIS may not have grounded in the over-deepened moat regions during the LGM. Secondly, in a similar way to the modern Mackay Glacier (cf. Powell et al., 1996), the granulated “lift-off zone” facies is absent, but a well-sorted sand above the diamicton may indicate proximity to the grounding line. Thirdly, sub-ice-shelf mud facies comprise siliceous open-marine biogenic components owing to the proximity of the drill sites to the calving line and strong currents sweeping northwards up the moat from McMurdo Sound. The sweeping-in of biogenic material under the floating ice is similar to that occurring beneath the modern Mackay Glacier-Tongue (Dawber and Powell, 1998). Sandy mud facies near the top of the core at HWD-1 site may reflect subtle fluctuations in the position of the calving line during the Holocene.

On the basis of the depositional models outlined above, it should be possible to reconstruct fluctuations in ice shelf extent for the MIS area using predictable sedimentological and biogenic criteria. These criteria represent a range of states including full glacial (grounded and floating) ice sheet, present day interglacial ice shelf with proximal calving line, and ice-free “super-interglacial” open marine conditions.

### 2.6 CHRONOSTRATIGRAPHY

Regular contributions of volcaniclastic sediments and tephra to the moat-fill succession over the last 5 m.y. from the Erebus Volcanic Complex will greatly aid the development of a high-resolution chronostratigraphy. We anticipate being able to develop an age model for the cored record based on radiometric dating of tephra (e.g. fission track and Ar/Ar), biostratigraphy (primarily diatoms, but other microfossil groups such as marine palynomorphs, foraminifera and radiolaria may be useful), paleomagnetic stratigraphy, and cyclostratigraphy. Other potentially useful tools will be strontium isotope dating of calcareous macrofossils (depending on preservation) and radiocarbon dating of the organic components for the uppermost part of the core.

Such a chronology will be critical if millennial-scale variations in ice shelf processes are to be compared with distal atmospheric ice core (e.g. EPICA) and oceanic deep marine records.

# 3. SCIENCE OPERATIONS PLAN

### 3.1 ON-ICE PROJECT MANAGEMENT STRUCTURE

The management structure for the On-Ice drilling phase of the MIS Project is outlined in a “wiring” diagram (Fig. 19). The project has two distinct, but inter-connected components: (a) The drilling operations team based at the MIS Project drill site and supported by Scott Base, Antarctica New Zealand; and (b) The Science Team based mostly at McMurdo Station and supported by Raytheon Polar Services Company (RPSC) and the National Science Foundation (NSF).

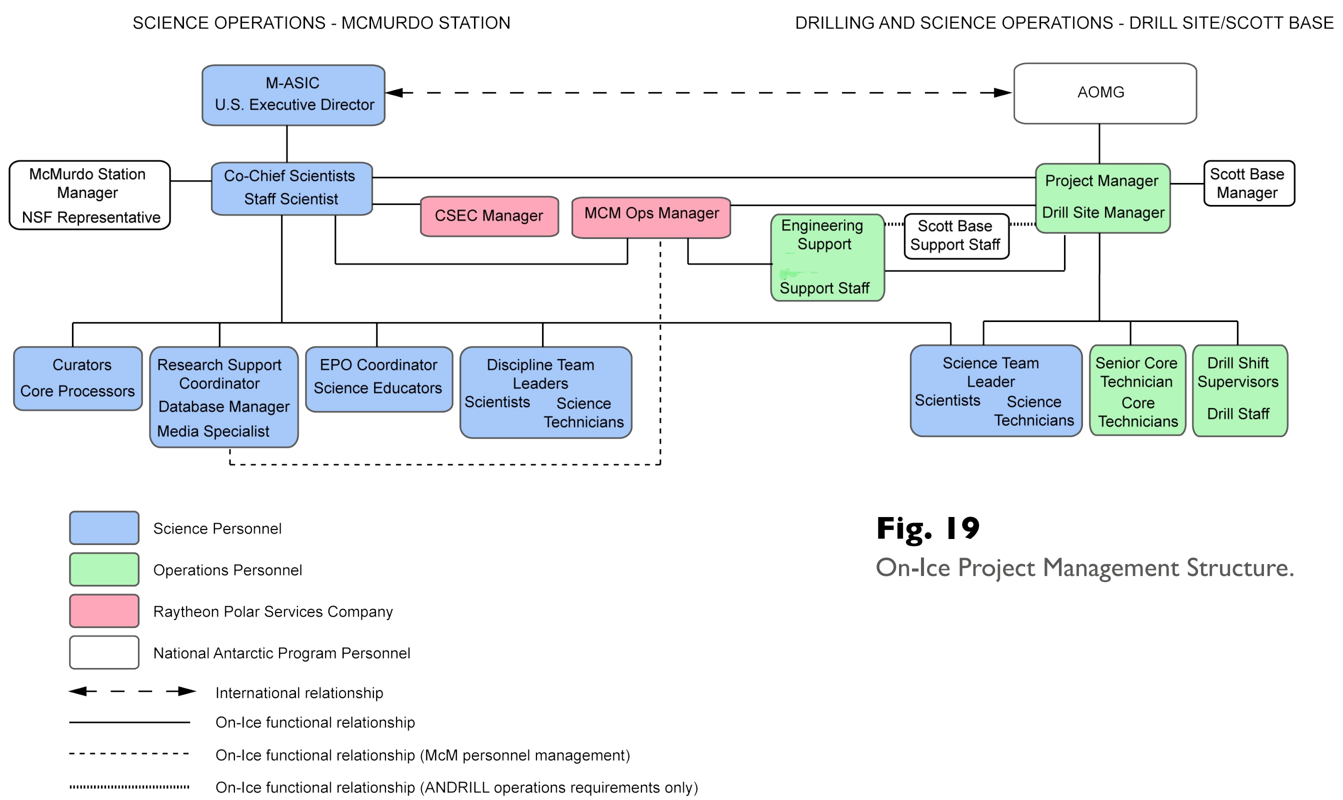



**Fig. 19**
On-Ice Project Management Structure.

### 3.1.1 Drilling Operations Management

Drilling operations are logistically supported through Scott Base. At the international level, the project is overseen by the ANDRILL Operations Management Group (AOMG).

The operations side of the Project employs a number of project staff. These include ANDRILL Project Manager (APM), Jim Cowie employed by Antarctica NZ, who has overall responsibility for On-Ice operations and financial control of the project budget. APM is the operator's (Antarctica New Zealand's) senior representative during drilling operations. The primary role of the APM is to provide overall project co-ordination between Scott Base logistics support, the drill site operation, the science operations at McMurdo Station and the AOMG. The APM will communicate with the Scott Base Manager, who is ultimately responsible for all On-Ice operations being conducted under the New Zealand Antarctic Program.

The Drill Site Manager (DSM), Alex Pyne is subcontracted by Antarctica NZ from the Antarctic Research Centre at Victoria University of Wellington, and has responsibility for MIS drillsite operations. The DSM reports to the APM and manages the drill site operation and laboratory core technicians. Each shift (day/night) will be managed by drill shift supervisors, Tony Kingan and Sam Woodford, who report to the DSM. Core handling, cutting, orienting, and packaging will be overseen by the Senior Core Technician, Cliff Atkins, who also reports directly to the DSM.

An Engineering Support Manager (ESM), Johnathan Leitch, employed by Antarctica NZ reports to the APM, and is responsible for the engineering requirements during site establishment and disestablishment and support during the drilling operation. The ESM communicates directly with the DSM over drill operations and engineering support requirements and if necessary the ESM will consult with the Scott Base Engineering Manager.

### 3.1.2 Science-Drilling Operations Interrelationships

Co-Chief Scientists (CCSs), Tim Naish - Victoria University-GNS Science and Ross Powell - Northern Illinois University are responsible for the overall management of the MIS science team and implementation of the science plan as outlined in this document, such that the scientific objectives of the project are achieved. This role requires a strong functional relationship between the CCSs, APM and DSM to ensure operations are effectively addressing scientific requirements.

It is anticipated that a CCS will visit the drill site and communicate with the APM on a daily basis. The CCS-APM relationship will also involve regular communication with Scott Base and McMurdo Station management over ANDRILL operational, scientific and media-outreach activities that may impact on the wider communities and National Programs.

The CCS-DSM relationship is important and involves effective communication and understanding of the scientific objectives of the program, so that the DSM and drilling supervisors can develop and maintain a drilling program that best achieves the scientific goals within drilling and operational constraints. Key science-related drilling decisions will be made through consultations between the CCS and DSM who will communicate on a daily basis about drilling progress and science issues. Drilling decisions may also involve advice from the Staff Scientist, Richard Levy and the Discipline Team Leaders. Safety-related drill site operation decisions are the sole responsibility of the DSM and these will be communicated directly to the APM and CCS.

The leader of the physical properties discipline team, Frank Niessen (FN), will be the head scientist at the drill site and will be responsible for daily science activities such as multi-sensor track scanning, core image scanning, microbiological sampling, and downhole logging activities. FN will report to the CCSs on science aspects, but is under the direct authority of the DSM with respect to drill site operations and safety issues.

The CCS, APM and DSM will meet twice weekly to assess progress and issues. At the international level, the project is overseen by the McMurdo ANDRILL Science Implementation Committee (M-ASIC).

### 3.1.3 Science Management

The Staff Scientist (SS), employed by the ANDRILL Science Management Office (SMO), University of Nebraska-Lincoln, reports to the CCSs and is responsible for coordinating and supporting the science operation at Crary Science and Engineering Center (CSEC) and the drill site. The SS will often communicate directly with the DSM over science support at the drill site and core handling issues. Discipline Team Leaders (DTLs: Larry Krissek, Frank Niessen, Massimo Pompilio, Reed Scherer, Gary Wilson,) report to the CCSs through the SS. A Data Manager (DM: Josh Reed), Head Curator (HC: Matt Olney), and a Research Support Coordinator (RSC: Laura Lacy) all report to the SS and provide support for the science team. The RSC will have regular interactions with RSPC and NSF personnel. CCSs and SS will interact regularly with the CSEC Manager. An Education and Public Outreach Coordinator (EPOC: John Jackson) will manage a team of educators (ARISE Program) and other media outreach activities, and will report directly to SS. The CCSs, SS, DTLs, HC, DM, RSC and the EPOC will comprise an executive management team that meets daily to ensure the scientific and EPO goals of the project are on track and to discuss and develop strategies to resolve issues.

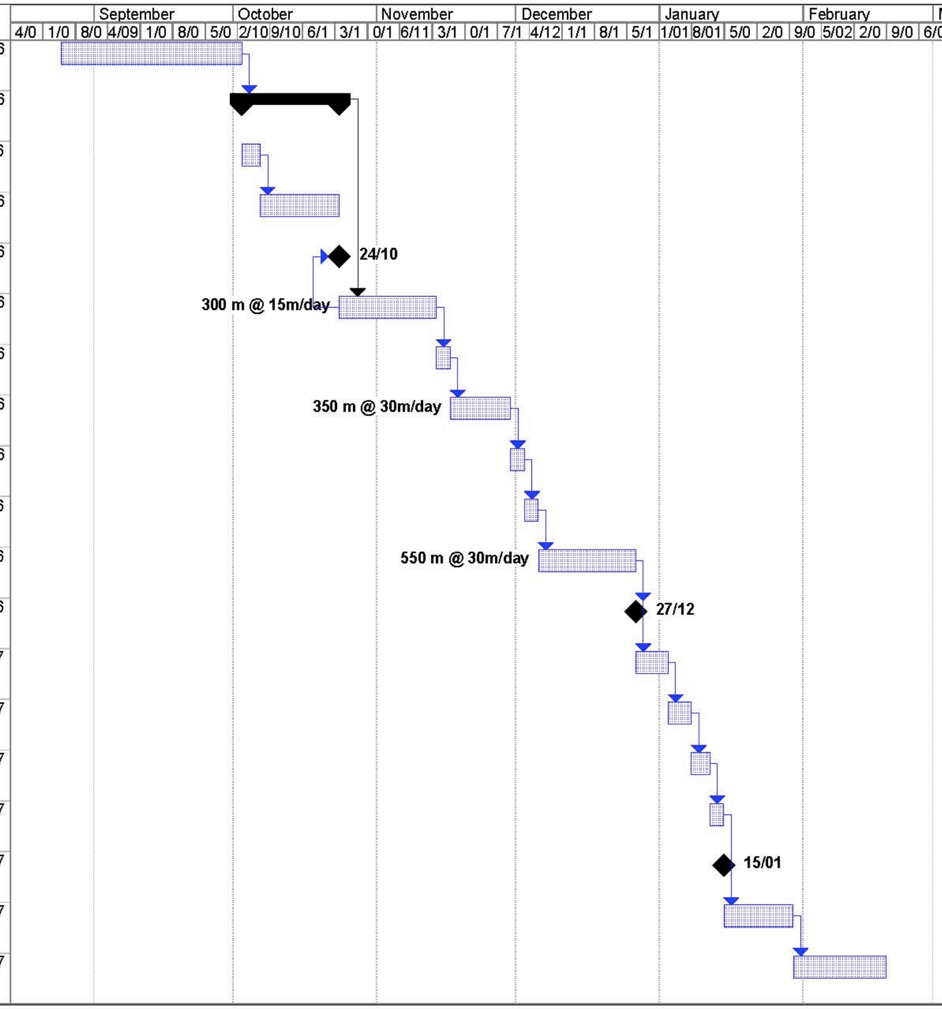
The executive management team will meet daily at 8:30 a.m. The entire CSEC science team will meet daily at 9:30 a.m. for a morning briefing until about 10:00 a.m. Immediately following the briefing, the lead day-shift sedimentologist will present a description of the core logged during the previous night by the sedimentology night-shift team. A core tour that highlights aspects of the stratigraphy may be presented using Corelyzer (see section 3.5.3.2) and discussed at this meeting. The core tour is expected to finish around 11:00 a.m. Samples are then selected for core characterization. In the afternoon one of the CCSs will visit the drill site. Sedimentology night-shift team will operate between 10:00 p.m. and 10:00 a.m. The day shift lead sedimentologist will overlap with the sedimentology team between 8:00 and 9:00 a.m. to be briefed on the evening's description. The curatorial and XRF core scanning teams will run both day and night shifts. All shifts overlap with the 9:30 -10:00 a.m. science team meeting.

## 3.2 DRILLING OPERATIONS AND SCIENTIFIC RESEARCH FACILITIES

The operational activity plan and time line for the MIS Project is presented in figure 20.

Drilling and science operations will occur at three primary locations, the drill site, Scott Base and McMurdo Station. The drill site is situated on the Ross Ice Shelf approximately 9 km southeast of Scott Base (Fig. 21A). Drill site facilities comprise three distinct units: drill rig and platform, day shelter, and lab (Fig. 21B). Scott Base will house the drilling operations management team, drillers and support personnel. All scientists, science support personnel, ARISE educators and other outreach personnel will live at McMurdo Station. Several members of the Science Team will travel to the drill site to work in the drill site laboratory. All other STMs will work in one or more of the following facilities at McMurdo Station: Crary Science and Engineering Center (CSEC), Core Storage Facility (CSF), Antarctic Research Facility Mobile Laboratory Van (ARF-MLV), and RAC-Tent Scanning Facility (RTSF) (Fig. 22).

| ID | | Task Name | Duration | Start | Finish |
|---|---|---|---|---|---|
| 1 | | Setup phase 1(Winfly) | 39 days | Fri 25/08/06 | Tue 3/10/06 |
| 2 | | Setup phase 2 | 21 days | Tue 3/10/06 | Tue 24/10/06 |
| 3 | | SB/Orientation | 4 days | Tue 3/10/06 | Sat 7/10/06 |
| 4 | | Setup incl SR installation | 17 days | Sat 7/10/06 | Tue 24/10/06 |
| 5 | | First core | 0 days | Tue 24/10/06 | Tue 24/10/06 |
| 6 | | Soft sediment coring | 21 days | Tue 24/10/06 | Tue 14/11/06 |
| 7 | | Casing | 3 days | Tue 14/11/06 | Fri 17/11/06 |
| 8 | | HQ coring | 13 days | Fri 17/11/06 | Thu 30/11/06 |
| 9 | | Downhole logging (incl new mud) | 3 days | Thu 30/11/06 | Sun 3/12/06 |
| 10 | | Casing | 3 days | Sun 3/12/06 | Wed 6/12/06 |
| 11 | | NQ coring | 21 days | Wed 6/12/06 | Wed 27/12/06 |
| 12 | | Last core | 0 days | Wed 27/12/06 | Wed 27/12/06 |
| 13 | | Downhole logging (incl new mud) | 7 days | Wed 27/12/06 | Wed 3/01/07 |
| 14 | | Casing Cutting, Plug & Abandon | 5 days | Wed 3/01/07 | Mon 8/01/07 |
| 15 | | Sea Riser Recovery | 4 days | Mon 8/01/07 | Fri 12/01/07 |
| 16 | | Contingency | 3 days | Fri 12/01/07 | Mon 15/01/07 |
| 17 | | Deadline for end of DS ops | 0 days | Mon 15/01/07 | Mon 15/01/07 |
| 18 | | Decomm & repositioning | 15 days | Mon 15/01/07 | Tue 30/01/07 |
| 19 | | Prep for SMS & ship offload | 20 days | Tue 30/01/07 | Mon 19/02/07 |




Project: MIS Timeline v1.1 01Aug06
Date: Tue 1/08/06

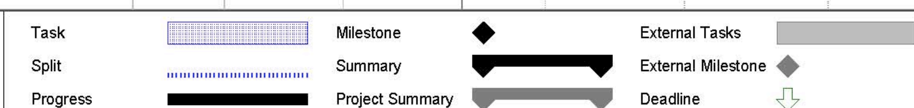



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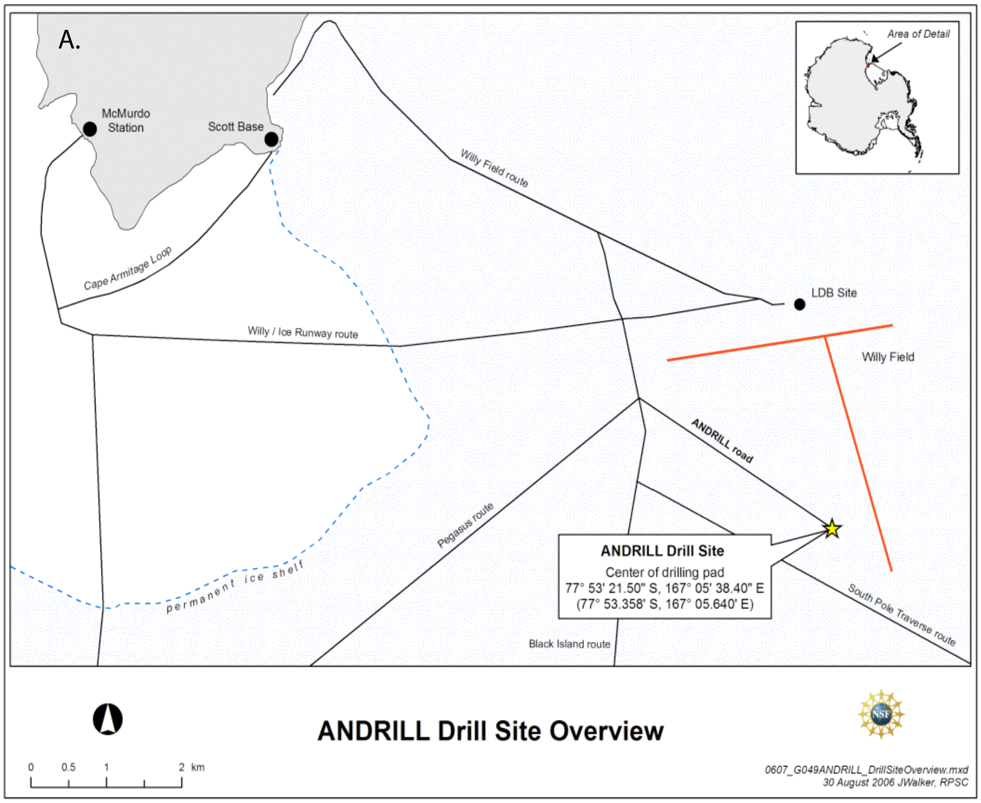
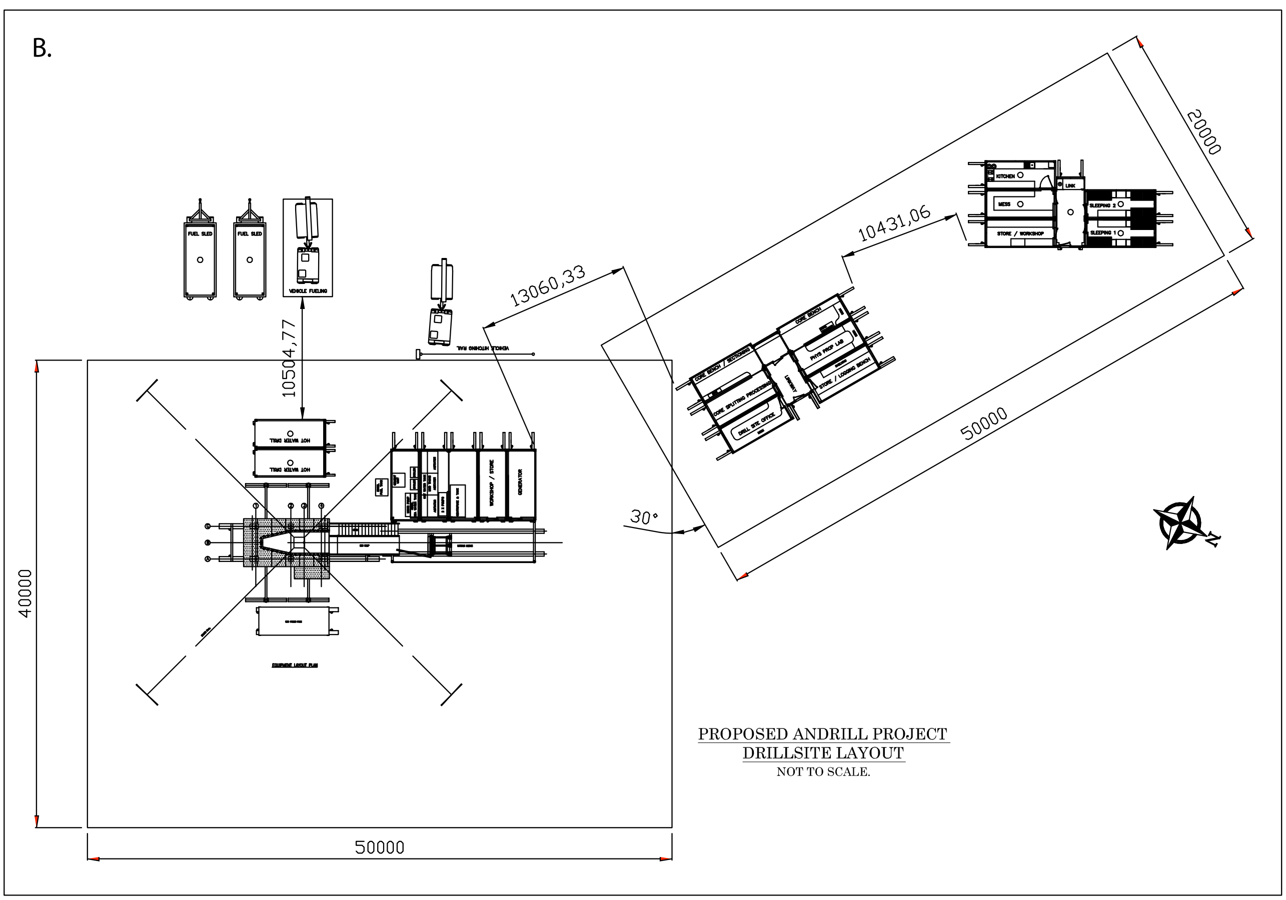
**Fig. 20** Timeline for the on-ice operational phase of the MIS Project.

**Fig. 21**
A. Regional map of the drill site and surrounding infrastructure.
B. Drill site layout.



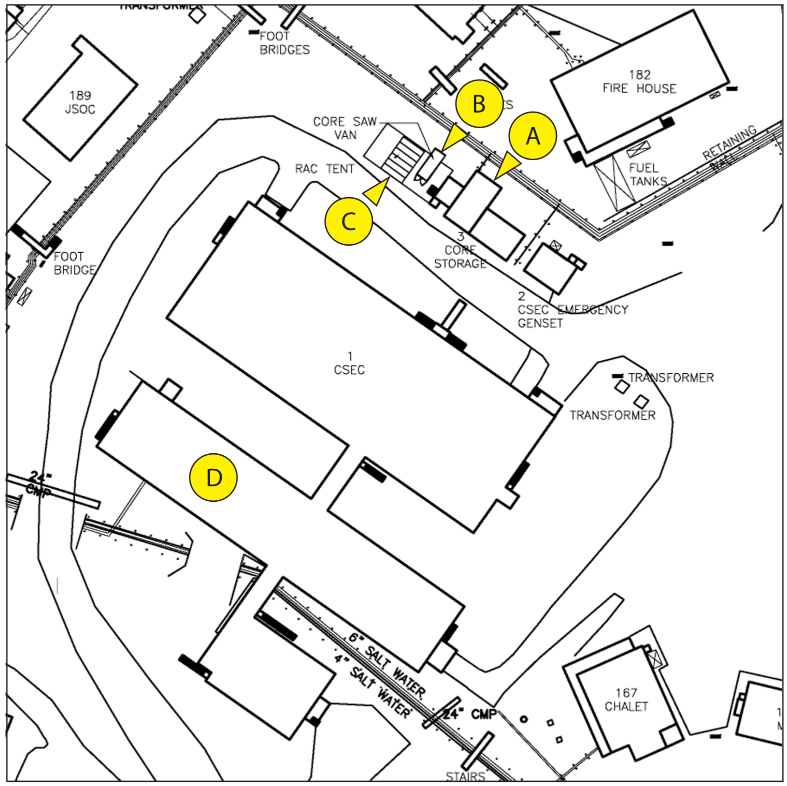



**Fig. 22**
Primary Research locations at McMurdo Station: A. Core Storage Facility (CSF), B. Antarctic Research Facility Mobile Laboratory Van (MLV), C. RAC-Tent Scanning Facility (RTSF), D. Crary Engineering and Science Center – Phase II (CSEC-II).

## 3.3 CORE MANAGEMENT AND SCIENTIFIC WORKFLOW

### 3.3.1 Core Workflow Diagram

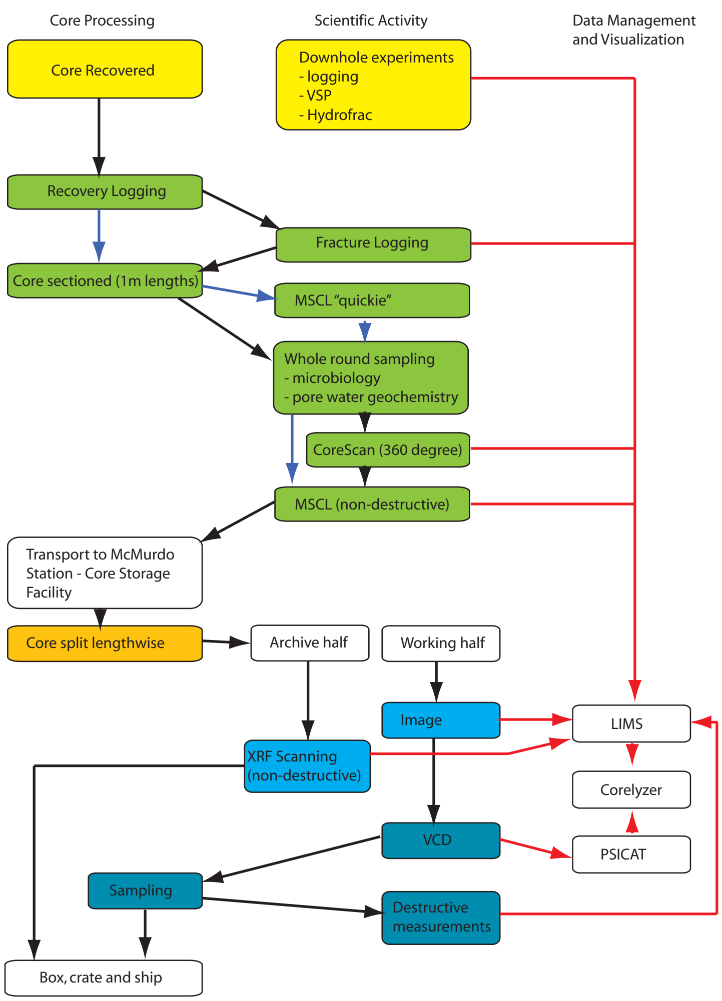



**Fig. 23**
Diagram outlining stages in core processing and associated scientific activities. Black arrows indicate core flow for lithified core. Blue arrows indicate modified core flow for soft sediments in liners. Different colored boxes distinguish the location at which an activity occurs: drill rig – yellow, drill site laboratory – green, ARF-MLV – orange, RTSF – light blue, CSEC – dark blue.

### 3.3.2 Drill Site (Rig and Lab)

Activities at the drill site will take place at two primary locations: drill rig and platform and the laboratory "complex" (fig. 21B). The drill site laboratory complex comprises a series of interconnected modified shipping containers (fig. 24).

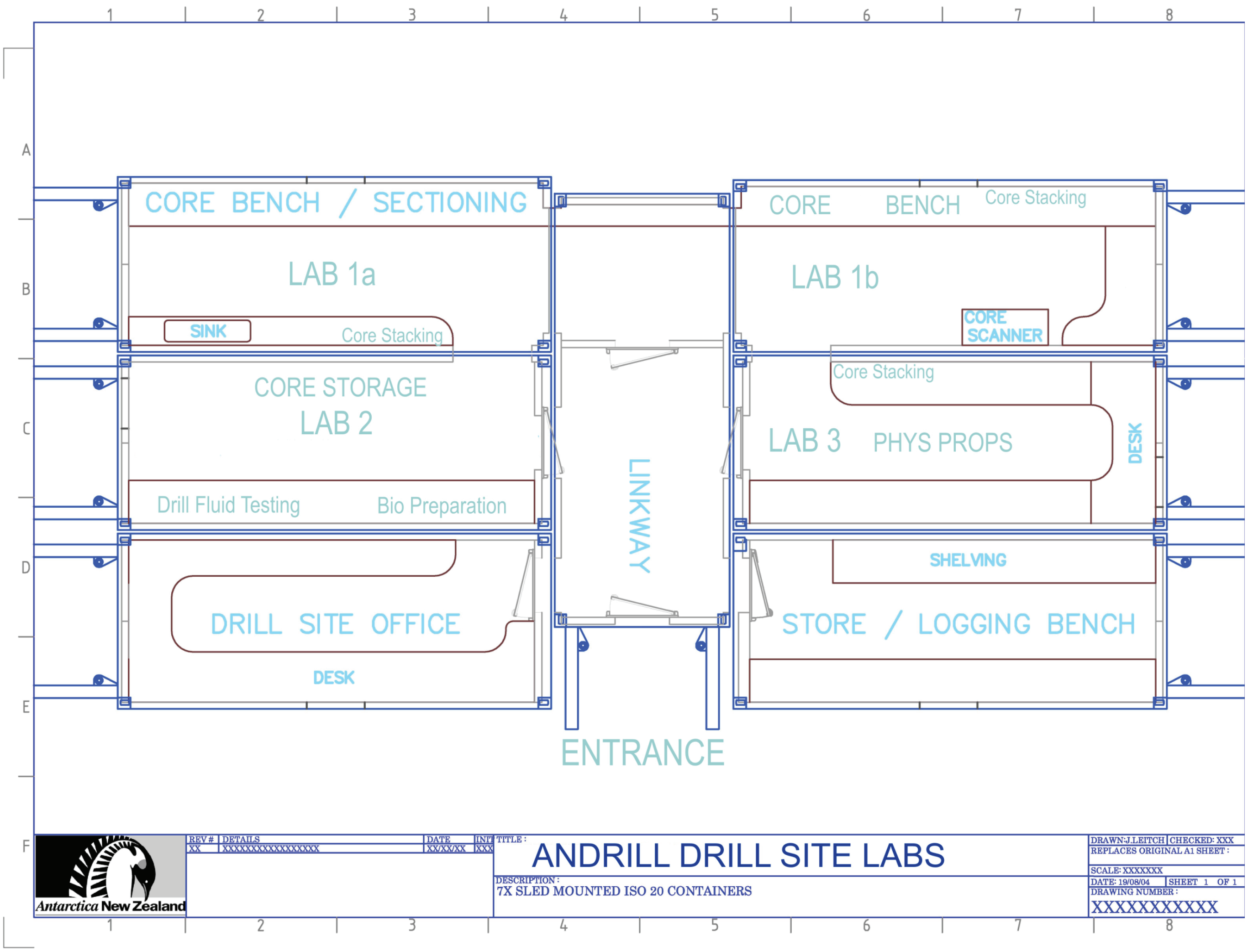



**Fig. 24**
Drill site laboratory "complex."

Tasks to be undertaken at the drill site, personnel responsible for the tasks and locations for activities are summarized in Table 1 below for both soft-sediment coring and rock coring.

## Table 1

Tasks to be undertaken at the drillsite, personnel responsible for the tasks and locations for activities are summarized in Table 1 below for both soft sediment coring and "hard rock" coring.
CT: Core Technician
CSMG: Core Structure Measurement Group
MSTG: Multi-Sensor Track Measurements Group
MPWG: Microbiology Porewater Geochemistry Group

*Soft-Sediment Coring PQ and HQ - Recovered in core liner*

| Step | Task | Linked Task | Responsible | Location |
|---|---|---|---|---|
| 1 | Recovery in liner. Liner and catcher transfer to core lab | Core orientation tool, liner scribe, measure angle? | Driller/ CT | Catwalk & Lab 1 |
| 2 | Establish drill run depth | Recovery Log | CT | Lab 1a |
| 3 | Confirm soft sediment | If hard rock - transfer to splits and follow hard rock procedures @ step 4 | CT/CSMG | Lab 1a |
| 4 | Cut liner in 1 m lengths | | CT | Lab 1a |
| 5 | Cap and label liner (special cut-outs) | Top depth | CT | Lab 1a |
| 6 | Stack 1 m liner | | CT | Lab 3 |
| 7 | Physical Properties (fast) | Confirm recovered intervals on recovery log | MSTG/CT | Lab 3 |
| 8 | Microbiological sampling | Slice of lined core taken | CT/MPWG | Lab 1b, Lab 2 |
| 9 | Physical Properties (slow) | | MSTG | Lab 3 |
| 10 | Stack 1 m liner | | MSTG | Lab 1a |
| 11 | Core sampling in liner - capped | Core refrigerated for transport | MPWG | Lab 1a & Lab 2 |
| 12 | Recap 1 m liner | Label T & B depths | CT | Lab 1a |
| 13 | Box core | Label & record transport core box # on recovery log | CT | Lab 1a |
| 14 | Core box storage | | CT | Lab 2 |
| 15 | Core box transport | Core transport record | CT | Lab 2 |

*“Hard Rock” recoevery in Steel Splits (PQ3, HQ3 & NQ3)*

| Step | Task | Linked Task | Responsible | Location |
|---|---|---|---|---|
| 1 | Recovery in steel splits. Splits and catcher box transfer to core lab | Core orientation tool, liner scribe, measure angle? | Driller/ CT | Catwalk & Lab 1 |
| 2 | Establish drill run depth | Recovery log.<br>Press out catcher core | CT | Lab 1a |
| 3 | | | | |
| 4 | Check & fit previous core runs | Record on core recovery log | CT (CSMG) | Lab 1a bench |
| 5 | Draw red & blue scribe lines (slotted splits & roll core) | | CT (CSMG) | Lab 1a bench |
| 6 | Fracture logging | Record depths top/bottom & dip/dip direction each fracture | CSMG | Lab 1 bench |
| 7 | Transfer to core carriers | Record carrier ID – recovery log | CT | Lab 1a bench |
| 8 | Core cut in 1 m lengths | Stack for core scanning | CT | Lab 1b stack |
| 9 | Microbiological sampling | | CT/MPWG | Lab 1b, Lab 2 |
| 10 | Fracture observations | Measure surface features, photograph | CSMG | Lab 1b |
| 11 | Whole-core scanning | Scan records – spreadsheet, Backups | CSMG | Lab 1b |
| 12 | Stack 1 m liner | | MSTG | Lab 3 |
| 13 | Physical properties (slow) | | MSTG | Lab 3 |
| 14 | Stack 1 m liner | | MSTG | Lab 1a |
| 15 | Core sampling | Removed core marker & record on recovery log | CT | Lab 1a & Lab 2 |
| 16 | PVC splits, lay-flat & seal. Box core | Label & record transport core box # on recovery log | CT | Lab 1a |
| 17 | Core box Storage | | CT | Lab 2 |
| 18 | Core box transport | Core transport record | CT | Lab 2 |

### 3.3.3 Transport to McMurdo Station

Drill-site staff will transport whole core (contained in insulated aluminum boxes) via tracked vehicle (Hägglund) to the sea-ice transition near Scott Base. Curatorial staff will transfer core boxes to a pick-up truck and transport the core to the Core Storage Facility (CSF) at McMurdo Station.

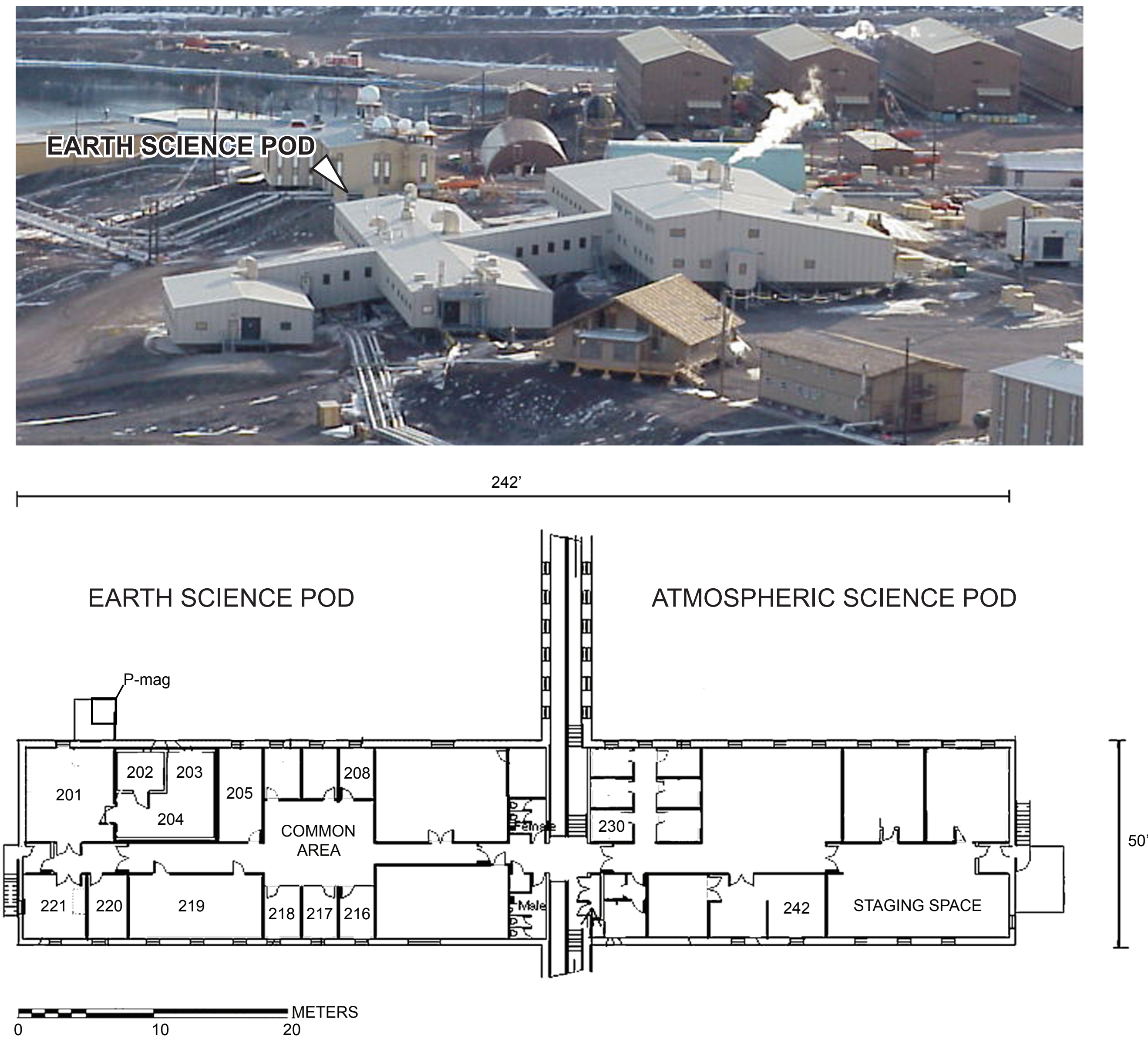



**Fig. 25**

CSEC Phase II – Earth Science and Atmospheric Science Pods. Space is allocated in the following way: 201 – Core Logging and Curation, 202-204 – Storage and Extra Work Space, 205 – Sedimentology, 208 – Curators and Data Management, 209 – Science Team Common Area, 216 – Physical Properties, 217 – Co-Chief Scientists, 218 – Science Management, 219 – Micropaleontology Prep, Macropaleontology, Microbiology, PW Geochemistry, 220 – Thin Section Prep, 221 – Petrology, Geochemistry, and Sedimentology, 230 – Paleomag, 242 – Micropaleontology.

Notes:

i. Core will be secured within the carrying cases to prevent movement and the cases will be placed inside an enclosed, heated trailer to protect the core from freezing.
ii. Eight to ten carrying cases (24 to 40 m of core) will be transported at least once per 24 hrs along with the core catcher samples and all related paperwork.
iii. Empty core boxes will be returned to the drill site for re-use.

**3.3.4 McMurdo Station**

Core management at McMurdo Station will occur at four primary locations: i) Core Storage Facility (CSF), ii) Antarctic Research Facility Mobile Laboratory Van (MLV), iii) RAC-tent Scanning Facility (RTSF), and iv) Crary Science and Engineering Center (CSEC), Room 201 (Fig. 23). Scientific activities at the CSEC will occur in allocated laboratory and office space (Fig. 25).

**3.3.4.1** Core Storage Facility

Temperature in the CSF will be maintained between 2 and 5° C (35 and 41° F). Humidity will be augmented by the use of humidifiers to maintain the highest possible level of humidity. The door shall be secured with a padlock when not in use. Only the two Curators, Co-Chief Scientists, and the CSEC Laboratory Manager will have keys to access the Facility.

Note: Core processing at McMurdo Station may well lag behind the acquisition of core at the drill site by one or two days. If this is the case, incoming core from the drill site will be stored in the CSF while the backlog of core is processed.

**3.3.4.2** ARF Mobile Laboratory Van: Core Splitting into Archive and Working Halves

i. Core will be carried from the CSF to the MLV located adjacent to the loading dock of the facility to be split.
ii. Liner for each 1 m section of soft-sediment will be cut longitudinally using a double razor-blade apparatus built into the core splitter. Whole core will then be cut into an archive and working half using a wire.
iii. Each 1 m section of lithified whole core will be cut longitudinally into an archive half and a working half using a rotary diamond saw.
iv. The archive and working halves (for both soft and lithified core) will each be placed into labeled split-core liners and then into separate standard industry wax-cardboard core boxes (3 m per box for PQ size core, 4 m per box for HQ size core, and 5 m per box for NQ-sized core).
v. The core liners will be labeled with the following information: meters below sea floor (mbsf), an "UP" arrow, and any other important information.
vi. In addition, separators, with mbsf depth written on them, will be placed at one-meter intervals within the core liner and all voids within the core will be filled with foam.
vii. The end of the cardboard core box will be labeled with the appropriate core information: Box #, meters below sea floor (mbsf), and either "archive" or "working".

**3.3.4.3** RAC-Tent Scanning Facility (RTSF): Core Imaging and XRF scanning

i. Immediately after splitting, the Archive and Working halves of the core will be carried from the MLV to the adjacent RAC-Tent Shelter.
ii. The Archive Half will be scanned with an AVAATECH XRF scanner and Minolta Spectrophotometer.

iii. Upon completion of XRF scanning the Archive Half of the core will be returned to the CSEC-CSF and unpacked and stored on the metal racks.

iv. The Working Half will be digitally imaged with a GEOTEK core scan camera at a standard resolution of 600 dpi (and additionally at 1200 dpi for features of interest).

v. When the digital imaging is finished the Working Half will be packaged in vinyl insulated carrying bags or alternative carrying case and transferred to the CSEC Room 201 where it will be laid out for logging and sampling.

**3.3.4.4** CSEC Room 201: Core Logging and Destructive Sampling

A core laboratory will be set up in Room 201 in the CSEC. The floor, benches, and all equipment in the room will be thoroughly cleaned prior to the core arrival at the laboratory and at the end of each splitting/viewing/sampling session to minimize potential for contamination of core. The temperature of Room 201 will be maintained at 18°C. The room will contain about 10 m of bench space covered with an easily cleaned surface. High-intensity halogen lighting will augment the fluorescent lighting to enhance viewing of core.

**Core Logging**

Sedimentologists will log core as it arrives from the RAC-Tent and is laid out on the workbenches. During the last two hours of the logging shift (~ 7:30 a.m. to 9:30 a.m. each day) the core loggers will provide the day shift sedimentologists with a short briefing and tour of the displayed core. Relevant features of the logged section will then be summarized at a morning meeting of the entire science team, and the core made available for inspection and sample flagging.

**Core Sampling**

Core catcher samples: The core catcher samples will be further sub-sampled by the curators immediately upon receipt from the drill site. The average volume of each sub-sample will vary depending on the intended use (e.g. diatom analyses, foraminifera analyses, etc).

Selecting additional high-priority samples: On-Ice sampling will be kept to a minimum, with samples primarily taken for ephemeral property studies, critical age dating refinement, or other investigations that are necessary to properly characterize the core for the purposes of the On-Ice and Initial Reports. Investigators will select high-priority samples by placing disposable sample “flags” (a toothpick with an adhesive label wrapped around it) at relevant positions alongside the core. Paleomagnetic investigators will mark their samples by placing 4 x 7 mm slips of paper over their requested intervals.

Disputed Sample Intervals: Overlapping sample requests will be resolved through discussions with the STMs involved, the curators, and the ANDRILL Sample Committee. Sample Committee will comprise the CCSs, SS, Head Curator (HC), and DTLs. Additional sample requests may be submitted during drilling as a consequence of an unanticipated discovery. These requests will be considered by the Sample Committee.

**Sample Data Entry**

The curators will enter the sample interval data into a relational database. These data include investigators name, core number, box number, sample interval (mbsf), sample volume (cubic centimeter), date, and comments. The comments section will include type of sample (e.g. sediment, fossil, or clast) and the discipline and type of analysis to be performed on each sample (e.g. petrology-thin section or paleontology-diatoms). Sample and coring information will be accessible through the web site of the Antarctic Research Facility of Florida State University in Tallahassee.

**General Sampling**

Common laboratory spatulas, small scoops, plastic tubes, etc., will be used to remove samples from unlithified core. A diamond saw will be used to cut the more lithified material, as well as large clasts. All of these tools are to be cleaned prior to the beginning of the sampling session and between the sampling of different intervals. At no time will any tool be used more than once before it is cleaned. Voids left in the core following extraction of the samples will be filled with cut foam blocks to stabilize the core.

Upon completion of sampling, each 1 m section will be wrapped in plastic wrap (to help retard desiccation) and replaced in the correct core box. The cores will then be returned to the CSEC-CSF.

**Paleomagnetic Sampling**

Paleomagnetists will conduct their own sampling. To avoid contamination of the core, orientated, coherent sections will be removed from the core box, placed on a carrying tray, and taken to the paleomagnetic sampling lab (a separate building located on the loading dock of CSEC Room 201). A hollow, thin kerf, diamond drill will be used to remove the sample and the remaining core section will be replaced in the core box in the proper orientation.

**Core Shipment To Florida State University**

The core will be re-examined in the CSF prior to packaging for shipment to the core repository at Florida State University. Additional foam blocking will be added where needed and the core misted with filtered water again before the core-box lids are taped into place. Core boxes will be placed into specially constructed wooden boxes that contain nine separate compartments holding four boxes each. Containers will be marked with arrows pointing to the upright position and with signs designating the correct temperature for transport (4°C/40°F). Shipping crates will be transported in a refrigerated container via the cargo ship Greenwave to Lyttleton and then on to California where they will be off-loaded and transported overland via refrigerated truck to Florida.

### 3.3.5 Florida State University - Antarctic Research Facility (FSU-ARF)

Core will be maintained at the FSU-ARF following standard curatorial policy and procedures that are outlined on the Facilities web site (http://www.arf.fsu.edu).

## 3.4 COMMUNICATIONS

RPSC will provide Internet and radio telephone communication capability at the drill site. The primary methods of communication between Scott Base, CSEC at McMurdo Station and the drill site will be telephone and email. VHF radios will be available to Science Management Staff at the CSEC. These radios will be programmed to receive and transmit on USAP is Mt Aurora and Mac Ops Repeaters and the New Zealand Crater Hill repeater.

Note also that CSEC and Drill Site Management personnel will be able to utilize *WhiteBoard* Live Chat sessions as required.

## 3.5 DATA MANAGEMENT

### 3.5.1 Management Policy and Data Workflow

All data produced during the drilling phase of the MIS Project will be submitted by each STM or DTL to ANDRILL's central database (see LIMS discussion below). These data will be shared among all STMs (On- and Off-Ice). If an individual member of the Science Team or group of STMs wishes to use another STMs data they must employ ethical practices including, at a minimum, notification to said STM and appropriate acknowledgment.

Access to raw materials and data generated during the ANDRILL MIS Project is restricted to STMs for a moratorium period that begins when first core comes out of the ground and extends 18 months beyond the Post-Drilling Core Workshop held in April 2007.

### 3.5.2 Short-Term Data Storage and Management (On-Ice)

ANDRILL will use Labware LIMS (Laboratory Information Management System) to collect and manage all data generated On-Ice in a central location (Oracle Database). This system has been configured for ANDRILL through a collaborative partnership with the Integrated Ocean Drilling Program (IODP) – JOI Alliance at Texas A&M University. The LIMS associates individual data files and images with the specific sections of core from which the data were generated. The LIMS will allow easy tracking of all data and its associated "sample".

Individual STMs are unlikely to interact with the LIMS directly but will access data via the Corelyzer and PSICAT visualization tools (see section 3.5.3). However, if desired (or required) all data and images in LIMS will be accessible to project participants via a web interface. Note that access to data through LIMS is restricted to MIS Project STMs for the duration of the moratorium period.

Each STM will submit data (on a daily basis where possible) to the ANDRILL SMO. STMs can submit their data via a secure personal data folder in the ANDRILL *Whiteboard* or can hand the data to SMO staff on a data storage disc (i.e. DVD, CD, thumb drive). Josh Reed (ANDRILL Data Manager) is responsible for data entry into LIMS.

A copy of the LIMS and Oracle database will be sent from McMurdo Station to Christchurch New Zealand on external hard drives via military aircraft and onto Otago University via courier as often as possible (schedule will vary). These data will be uploaded to a server and will be copied or transferred to the LIMS hosted and maintained by IODP at Texas A&M University. Off-Ice STMs will be able to access the data using web services.

### 3.5.3 Visual Core Description (VCD) and Data Visualization Applications

**3.5.3.1** Paleontological Stratigraphic Interval Construction and Analysis Tool (PSICAT)

PSICAT is a stand-alone Java-based graphical editing tool developed by CHRONOS for creating and viewing stratigraphic diagrams (barrel sheets) produced during VCD activities.

What sets PSICAT apart from other commercially available drawing programs (e.g. Adobe Illustrator and Corel Draw) is that it captures the underlying data behind the core log diagram instead of just a vector image. Capturing actual VCD data has many advantages, for example:

(a) data can be quickly and easily accessed by a large group of people;
(b) data can be managed by the user in real-time (e.g. dynamic scaling, data filtering, compositing other data into the diagram, etc);
(c) users can query the database to enhance scientific analysis (e.g. view all sections that contain ash layers and diatom appearance/extinction events);
(d) data can be used by other programs like the PSICAT plugin for Corelyzer (see below).

Members of the MIS Project core logging team will use PSICAT to create VCD logs. The VCD data captured with PSICAT will be uploaded to a central database regularly so that all project participants can keep up to date with the logging process and current core description. Access to the central database will be restricted to STMs during the moratorium period. All STMs will be able to download PSICAT and the ANDRILL extensions to PSICAT and view the data from the central database.

Core log diagrams will also be available to view next to high-resolution core images in Corelyzer (see below) via a PSICAT plugin.

**3.5.3.2** CoreWall Suite and Corelyzer

CoreWall Suite is a new state-of-the-art data visualization software package developed at the Electronic Visualization Laboratory at the University of Illinois at Chicago. The suite includes Corelyzer, Workflow Database, CoreClip, and Core Navigator. ANDRILL will utilize the Corelyzer component of the CoreWall Suite during the MIS Project. Corelyzer is a core-data visualization application that runs on Windows and Macintosh operating systems. Corelyzer is designed to allow integration and visualization of a suite of data obtained from core analyses. During the drilling phase of the ANDRILL MIS Project, STMs will be able to view the following data using Corelyzer:

- High-resolution whole and split core images
- MSCL data
- Annotations and comments
- PSICAT core log diagrams

These data will be stored in the LIMS database. ANDRILL will utilize two 2 x 30” panel Corelyzer units during its On-Ice operations. One unit will be located in CSEC 201 and one in the common work area. Corelyzer software can also be downloaded onto personal computers. We recommend that STMs store core image files on external hard drives to avoid filling the internal hard drives on personal computers.

**3.6 PERSONNEL MANAGEMENT**

A Guide to Participation in the ANDRILL MIS Project (ANDRILL Contribution 6 http://andrill.org/sciencesupport) provides information for On-Ice involvement in the project. Participants are encouraged to refer to this document. Laura Lacy (ANDRILL Research Support Coordinator) is the primary point of contact for STMs with respect to personnel management issues. The following provides additional information specifically regarding what you might expect as you transition from your home institution to Christchurch and onto Antarctica.

### 3.6.1 Deployment Schedule and Management

**Deployment and Redeployment**

Designated STMs were contacted by the ANDRILL SMO to coordinate science needs, travel itineraries and to record STMs' passport numbers for a travel database.

All travel itineraries and ticketing for U.S. Participants to Christchurch, New Zealand will be provided through the U.S. Raytheon Polar Services Company (RPSC) office; all Non-US Participant travel to Christchurch should be arranged through respective national Antarctic science or funding agencies (the SMO recommends that all German, Italian and New Zealand participants contact their respective National Representatives to obtain information or direction regarding appropriate travel procedures). Once in Christchurch, all travel to the ice will be arranged through RSPC.

Accommodations while in Christchurch will be arranged through RSPC based on information you provided to RSPC and the SMO.

For all participants, once you arrive in Christchurch you will be met by a RSPC employee and Laura Lacy. At this time you will be assigned times or appointments with the US Antarctic Program's (USAP) Clothing Distribution Center (CDC) and IT support for computer checks. Please be aware of the dates and times you have been assigned. Read information handed to you and ask questions. Laura will be available for assistance as needed. You'll be able to contact her at either the USAP office or by telephone (number to be supplied before your arrival to Christchurch).

Following the airport briefing, you will board shuttles, which will take you to your assigned hotels. During Check-in, hotel staff will instruct you on what to expect when your deployment day arrives and procedures for check-out. Hotels will be notified by RSPC in Christchurch whether your flight is available or not (delays may be possible due to weather or other issues), and will arrange for shuttles to pick you up at assigned times at your hotel. Do NOT make arrangements for shuttle pick-up unless specifically told to do so.

On day of deployment, you will meet other grantees and personnel headed to the ice. Wear your ECW gear as instructed. You will check in your checked luggage; be weighed with your gear and hand-carry items; and clear security for travel. Once you have cleared security, you will watch a video on your first 48 hours on the ice. This video will instruct you on what to expect once you arrive in McMurdo.

Once you arrive on the ice you will be met by shuttles and RSPC personnel. You will then be transported to McMurdo Station and met by Leslie Blank, RPSC McMurdo Operations Manager for ANDRILL. Leslie will assist you in obtaining your keys to housing, walking you through and acquainting you with McMurdo Station. She will also assist you in obtaining your luggage as it becomes available for pick-up (Note: you will not have access to your checked luggage until several hours after arrival); additionally, if you shipped cargo, she will be able to direct you where you need to go and who you should speak with to claim. A brief ANDRILL meeting and orientation will be scheduled shortly after your arrival. This meeting is mandatory; do not miss it. Richard Levy will also be available in the SMO office, housed in the CSEC to assist you as needed. All information you need will be delivered at assigned meetings and posted on the virtual *WhiteBoard*. Do not miss meetings and check the *WhiteBoard* frequently.

**Re-deployment**

On-Ice STMs are expected to be on the ice mid-October through December 2006 and the first week of January 2007. It is expected that the MIS field season will be completed in 10 weeks; however, it is possible that drilling

and science operations may take longer. (Please be prepared to remain in Antarctica through the holiday season (s)). STMs will be notified by the CCSs as to whether or not they are required to stay longer than the anticipated re-deployment dates.

The departure travel or re-deployment process will begin upon successful completion of all obligations to the MIS Project, as determined by the CCSs. All departure travel from Antarctica to Christchurch will be arranged through Laura Lacy, following CCS notification or endorsement. This rule will apply during the entire field season.

Specific re-deployment information and directions will be provided upon arrival to McMurdo Station during your ANDRILL orientation. In general, the RSPC travel office will ask you to provide information with regards to expected departure (as determined by CCSs or SS); any leisure travel you may want booked on your way home (for U.S. participants only. RSPC's travel office can make bookings, but you'll be required to make payment as directed); and general return ticketing services from McMurdo Station to Christchurch and home destination. Travel arrangements will also include hotel reservations in Christchurch. Most STMs will be required to stay at least one night in Christchurch before heading home. The RSPC travel office will assist non-US participants in return ticketing from the ice to Christchurch and in securing hotel reservations for their stay while in Christchurch; however, return ticketing from Christchurch to home destinations needs to be arranged through one's respective national funding agencies.

RSPC will contact Laura with a manifest and seek approval or changes before you are contacted with re-deployment instruction and confirmation. After you have been contacted by either RSPC or Laura, and know you are manifested to leave, you will see travel manifest postings throughout McMurdo Station. Please check these announcements to ensure you have been listed and are manifested to leave. Note: weather conditions and the number of "grantees" leaving the ice can cause delays in your departure. You can only leave the ice if you name appears on the manifest list. Just because you have been told you are leaving on a specific date, does not necessarily mean you will leave on that date. You will leave only if cleared to do so and your name appears on a manifest list.

Please contact the SMO if there are any questions and refer to the MIS Participation Guide for further information.

#### 3.6.2 Housing

On-Ice housing will be arranged through the SMO and provided by the U.S. Antarctic Program (USAP). All STMs will be housed at McMurdo Station in the 201 Building. Housing is dormitory-style and requires roommate pairings. While every effort will be made to match persons on day shift to persons on evening shift, allowing for alternating use of rooms, it is more than likely that some day shift members will be roomed together given the overall Science Team numbers and expected division of shift duties. In addition, there is a slight chance that MIS team members may be paired with a roommate or roommates of another Science Event or an RSPC employee.

More information on housing can be found in the MIS Participation Guide.

#### 3.6.3 Field Safety Training

All STMs will participate in an orientation in-brief following arrival at McMurdo Station. Basic safety and survival information will be included in this initial orientation. STMs working at the drill site will be required to participate in a drill site safety orientation presented by ANDRILL Operations Staff. Any STM who wishes to travel off station must adhere to USAP field safety protocol, rules, and regulations. If you wish to participate in ANDRILL field trips that require travel beyond marked trails you must (at a minimum) have completed an overnight field-training

course (taught by RPSC Field Safety Training personnel) within the last five years. If you have completed the course within the last five years you will be required to take a refresher course (does not require an overnight “camping” experience) prior to departing for the field.

### 3.6.4 Daily Meetings

Daily meetings will be held to ensure that STMs are kept informed regarding scientific and social activities. These meetings will be held each morning at 9:30 a.m. prior to the core tour. STMs will also be able to track progress using the purpose designed web-based *WhiteBoard* (see section 5.2 for details).

### 3.6.5 Field Trips

STMs will be offered at least one opportunity to participate in a field trip to examine regional geologic features that have influenced deposition and past environmental conditions at the MIS Project drill site. Members will sign-up for a trip once the team arrives at McMurdo Station.

# 4. SCIENTIFIC PLAN

## 4.1 SCIENCE ROLES AND RESPONSIBILITIES DURING AND POST-DRILLING

The main task of the drilling phase and the months leading up to the Post-Drilling Core Workshop (post-drilling phase) of the project is the characterization of the core and the strata from which it has been recovered. The main task of the Post-Drilling Core Workshop is to focus on more detailed studies on intervals of the core that hold special interest. This chapter outlines the scientific approach of each of the discipline teams during drilling and post-drilling phases.

The roles and responsibilities of the individual scientists in the MIS Project Science Team are summarized in Table 2 (drilling) and Table 3 (post-drilling). Sample requests for both On-Ice and post-drilling phases that have been approved by the Co-Chiefs and the M-ASIC are also shown in Tables 2 & 3. Note that new sample requests can be submitted during drilling to the Sampling Committee (Section 3.3.4). Also new sampling requests can be made at the Post-Drilling Core Workshop.

**Table 2**

Roles and responsibilities of the individual scientists in the MIS science team – core characterization (pre-core workshop).

***See pgs 118-130***

**Table 3**

Roles and responsibilities of the individual scientists in the MIS science team – science documentation (post-core workshop).

***See pgs 131-139***

## 4.2 DRILL SITE SCIENCE ACTIVITIES

### 4.2.1 Overview of data acquisition and scientific objectives

Several members of the MIS Project Science Team will conduct their routine scientific work at the drill site in the purpose built lab facility (Fig. 24). This group of scientists and technicians will reside at McMurdo Station and 'commute' to the drill site via shuttle van and tracked vehicle. The science shifts will coincide with the Drilling Operation shifts. The drill site science team includes physical properties disciplines - borehole, multi-sensor track and structural analysis team (here referred to as the "Physical Properties Discipline Team"). For operational reasons, the drill site scientific team also includes a microbiologist because sampling of fresh and uncontaminated sediments and rocks from the cores has to be performed at the drill site and thus becomes part of the technical/ scientific core-flow procedure in the drill site laboratory.

For scientific reasons, the Physical Properties Discipline Team further includes shear-strength measurements carried out in CSEC by the XRF-Scanner team (section 4.3.1) on split cores. Shear-strength measurements are included here because they are proposed by the multi-sensor track group.

All these disciplines perform On-Ice and Off-Ice science activities. While all On-Ice scientists continue with data processing and interpretation during the Off-Ice period of the project, there are additional scientists with Off-Ice roles only. Overall Discipline Team Leader (DTL) for drill site science work and Off-Ice science contributions of the Physical Properties Discipline Team is Frank Nissen.

Four 'groups' will carry out scientific activities at the drill site lab: Core Structure Measurements Group (CSMG), Microbiology and Porewater Geochemistry Group (MPWG), Multi-Sensor Track Group (MSTG), and Downhole Measurements Group (DMG). The different data sets obtained by these groups are summarized in Table 4.

**Table 4**

Summary of drill-site measurements.

| measurements | in drillhole | continuous-core |
|---|---|---|
| <u>physical properties</u>: velocity, density, mag susc, resistivity | X | X |
| <u>physical properties</u>: natural gamma, neutron, temperature | X | |
| <u>imaging</u>: dipmeter, televiewer, core scan | X | X |
| <u>structure</u>: fracture pattern | X | X |
| vertical seismic profile | X | |
| walk-away vertical seismic profile | X | |
| hydrofracture | X | |

The scientific objectives of the Geophysics/Structure disciplines (MSTG, DMG, CSMG) with respect to sedimentology and stratigraphy as well as structure and tectonics are summarized as follows:

**4.2.1.1** Stratigraphic objectives

- Seismic-borehole and core correlation and synthetic seismogram
- Log- and MST-based physical properties proxies for sequence stratigraphic calibration and cycle stratigraphy. Identification and quantitative characterization of subtle lithologic patterns and affinities (e.g., cluster and factor analysis, fining-upward patterns, particle size proxies)
- Measurement of sedimentary dip patterns
- Understanding compaction relationships, their patterns and their controls

**4.2.1.2** Structure & tectonics objectives

- Intraplate stress: direction & magnitude: *in situ* stress tensor from induced fractures (borehole hydrofracture experiment)
- Fracture pattern and paleostress history: rift faulting history from core faults and links to regional seismic profiles
- Uplift and tilting history
- History and pattern of regional heat and fluid flow
- Backstripping for subsidence history

**4.2.2 Structural Analysis, Whole-Core Scanning, and Core Orientation**

The On-Ice Core Structure Measurements Group (CSMG) consists of two fracture logging scientists, Terry Wilson (TW) and Tim Paulsen (TP), and two technicians, Andreas Läufer (AL) and Cristina Millan (CM). TW and TP share the primary responsibilities for oversight of On- and Off-Ice core structural measurements and will make decisions on scientific priorities jointly. AL and CM will provide technical support (see below) and will contribute to the core

fracture studies. TP and TW will share primary responsibilities for core-based structural logging, core fracture photography, and interpretation of structural data. AL in a secondary role, will assist Paulsen and Wilson in analyzing fracture patterns using whole-core imagery to compare results with core-based fracture measurements. CM will contribute to the microstructural characterization of core fractures. All CSMG members will be responsible for the initial unpacking and checkout of the core fracture logging gear and final preparation for winter storage.

TW will provide oversight of the CoreScan® whole-core image acquisition for the ANDRILL project. AL and CM will be responsible for Corescan®'s initial unpacking, set up and checkout and for running and troubleshooting (if any) the CoreScan® to capture whole-core digital imagery. They will prepare whole-core segments for scanning, make decisions on which core intervals can be scanned, and will be responsible for keeping CoreScan® logs and archiving whole-core imagery on DVD. They will be the primary links between the CSMG and ANDRILL's data management system, providing whole-core scan data for incorporation into the Corelyzer data visualization system.

Most of the On-Ice CSMG work will take place at the drill site science lab. Two-member teams of the CSMG will work on alternate 12-hour shifts throughout drilling operations. Workload for the CSMG will be consistent and intensive, consisting of the following steps (note that the following workflow will only be carried out on lithified core): The drill-site core-logging technicians (not part of the CSMG) will fit together core pieces and will carefully and accurately draw red and blue scribe lines along the length of each core run. Members of the CSMG will supervise the technicians and help troubleshoot this process. TW and TP will define intact core intervals, within which there had been no internal relative rotation of the core during drilling or coring.

After the core has been scribed, TW and TP will assign depths in meters below sea floor (mbsf) to the top and bottom of each fracture. Depths to fracture top and bottom will be recorded to the nearest centimeter. The dip and dip direction of each fracture will be measured with respect to an arbitrary 'north' defined by the red line scribed on the core.

Core will then be cut into 1 m segments by the drill site core-logging technicians. TW and TP will then measure and photograph fracture features. They will systematically examine the core surface and, where open, the individual fracture surfaces to constrain fracture mode of origin. They will also record any bedding offsets, crosscutting or abutting relations between fractures, type of fracture fill, and type and orientation of any surface fractographic features.

After photography and surface examination, the whole core surface will be cleaned by the scanning technicians and then each 1 m length (or subsection) of whole core will be scanned using the CoreScan® instrument, except where the integrity of the core will not permit handling.

Throughout the scanning process, AL and CM will be tabulating whole-core scan records of the depths of individual scans and segments that could not be scanned. They will also back up digital imagery as needed. After whole-core scanning, the scanning technicians will transport the whole core to the multi-sensor core logger (MSCL) for analysis.

The CSMG will also need to observe the slabbed-core at CSEC, in order to add microstructural observations and select appropriate samples for thin section study. This viewing will occur at the end of each night shift.

All members of the CSMG will be responsible for initial data processing and analysis, and writing the On-Ice and Initial Reports. AL and CM will supervise transport of the CoreScan® and structural measurement equipment from the drill site to McMurdo Station, where they will prepare the equipment for winter storage.

### 4.2.3 Microbiology and Porewater Geochemistry (Sampling)

Once core is recovered it must be sampled quickly so as to not significantly impact the microbial community and/or alter porewater geochemistry. Core processors will cut one-two whole round samples at the designated section in the core. One whole round sample is for microbiological studies and will be transferred to a vertical clean bench so that around 100 – 500 g of sample can be placed aseptically into a sterile whirl-pak bag. The whirl-pak bag is then placed inside of an airtight tri-laminated bag with oxygen scrubbing packets inside, is vacuum-sealed and frozen. The sample is then transferred to the CSEC for further processing (see also section 4.3.5). The other whole round sample is for porewater geochemistry studies. If the whole round sample is in core liner, the liner will be capped and the sample placed into a refrigerator. If the whole round sample is not in core liner it will be transferred into an airtight bag and placed into a refrigerator. Porewater samples must be transported to the CSEC within two hours of initial recovery for further processing.

### 4.2.4 Multi-Sensor-Track Measurements

The On-Ice Multi-Sensor Track Measurements Group (MSTG) consists of one logging scientist, Frank Niessen (FN), and two technicians, Andrea Catalina Gebhardt (AG) and Diana Magens (DM). DM will maintain scientific involvement in the Off-Ice phase of the project as part of her PhD program. Members of the MSTG will ensure that a continuous (24 hour) whole core logging operation occurs. The work plan will include data processing, storage and transfer into the ANDRILL data management system at the CSEC. Note: all three members of the MSTG are employees of the Alfred Wegener Institute for Polar and Marine Research, which also owns the MST equipment.

FN is responsible for supervising the MSTG, for proper system calibration and initial data processing to a level that is usable by other groups working on ice. Here it is anticipated to process magnetic susceptibility and porosity data so that they can be displayed on the Corelyzer. Also wet bulk density data will be used to identify horizons in the core, which might have been overconsolidated by grounded ice, as guidance for shear-stress measurements. During the drilling phase, high-resolution measurements of p-wave velocities will be converted into a cumulative 2-way travel-time log for the entire core combined with an acoustic impedance record calculated from velocity and density data. This log can be directly compared with the seismic profiles from the MIS Project drill site. Daily updates of the travel-time log will provide useful information to the CCSs on whether or not an important drilling target (reflector) has been reached.

AG is responsible for the technical supervision of the MST system, set-up of drill-site laboratory data network, logging and data acquisition during the day shift, and overall MST data storage and back-ups.

DM will assist FN during the night shift with logging, data acquisition and initial data processing. DM will also assist AG with assembling and dismantling of the MST at the beginning and end of the drilling phase.

In addition, the technician of the XRF-Scanner team at CSEC (see Chapter 5a) will carry out shear strength measurements on split cores (soft sediments only) at selected depth intervals based on density data obtained by the MST group at the drill site.

Workload for the MSTG and CMSG will be relatively constant. Depending on the drilling operation there are the following phases:

- between arrival On-Ice and the first core available for logging, the MSTG will unpack the equipment, run tests and calibrations and get the core-flow facilities (core carrier) in place.
- during the drilling phases (PQ, HQ, NQ) the team will work 24 hours in two shifts of 12 hours (a night and a day shift).
- during the drilling pauses (bore-hole logging phases), major maintenance on the MST will be carried out at the drillsite combined with re-adjustments of the system to smaller core diameter and different state of consolidation of the core material followed by system re-calibration.
- after the drilling phase and until departure from the ice, AG and DM will be responsible for packing the MST and final data storage. FN will join the CSEC team for final preparation of the MST data for the On-Ice Report.

#### 4.2.5 Downhole Measurements

The On-Ice downhole measurements group (DMG) consists of two logging scientists, Roger Morin (RM) and Trevor Williams (TWi), the VSP/seismic scientist, Stuart Henrys (SH), and three technicians Erich Scholz (ES), Travis Crosby (TC) and Dhiresh Hansaraj (DH). There are also two Off-Ice scientists, Richard Jarrard (RJ) and Michelle Kominz (MK). The three On-Ice scientists are equal partners, but have a clearly defined division of primary responsibilities. RM and TWi will make decisions on logging-tool scientific priorities jointly.

RM has borrowed (from USGS) or has leased the majority of the logging tools and is responsible for their initial unpacking and checkout (with technician help), leadership of logging data acquisition (including decisions on which tools can be safely run and over what intervals), initial data processing, troubleshooting, and final preparation for return shipping. Logging data acquisition is too lengthy, however, for RM to run all of the tools, so TWi, ES, and TC will assist him. RM's On-Ice scientific analysis responsibilities will include fluid flow, heat flow, structure/stress/fractures (in collaboration with the structure group), and identification of optimum hydrofracture locations (in collaboration with TWi).

TWi will assist RM in logging operations, and he will take the lead in sedimentological interpretation of the logs. He will be the main scientific link between the DMG and the sedimentologists and geochemists and will be responsible for export of logging data to ANDRILL's data management system.

SH is the lead scientist for the vertical seismic profile (VSP) and walkaway-seismic experiment. SH will work with his MSc student Dhiresh Hansaraj (DH) and Alex Pyne (AP) to determine overall VSP/walkaway design and placement of shots. AP will be primarily responsible for supervision of drilling shot holes, placing of charges, and firing of shots. SH will supervise testing by TC of the downhole hydrophone string and geophone and uphole Bison data acquisition equipment. DH will assist SH with the VSP experiment and seismic-borehole correlations. SH will supervise the VSP/walkaway experiment, working with AP's firing crew and TC's data acquisition. SH has primary scientific responsibility for analysis of these data and for establishing the link between seismic-reflection time and well depth, using not only these data but also the sonic log (with RM) and multisensor-track velocities (with FN).

Within the DMG, ES is primarily responsible for the hydrofracture experiment, under the overall hydrofracture supervision of TW (Core Structure Measurements Group). This responsibility will involve initial equipment unpacking and checkout, setup of the winch, operation of the hydrofracture equipment at the rig site, troubleshooting (if any), and final preparation for storage between seasons. ES will also assist in logging operations, as he is the most experienced with technical aspects of logging operations.

TC is primarily responsible for the data acquisition aspects of the VSP (and walkaway-seismic) experiment, under the supervision of SH. On a time-available basis, TC will also assist ES with the hydrofracture equipment and RM with the well logging.

**Workload for the DMG will be highly variable, consisting of the following phases:**
Between arrival On-Ice and the conclusion of HQ drilling: Priority is on testing equipment, and workload will be generally light (unless major problems are encountered). After the equipment has been transported to a container at the drill-site, it will be unpacked and tested to confirm that it is operational; this is expected to involve a relatively short stay at the drill-site, mainly by the technicians and RM. A few shot holes for the check-shot experiment may be drilled.

**Immediately after HQ drilling:**
This is the ~2.2 day first downhole measurements period, for measuring the HQ portion of the hole (~ the top 500 m). Work by the DMG will be continuous, and all of the On-Ice DMG are likely to remain at the drill site for most or all of this period. The measurement suite probably will consist of the following: caliper, T/resistivity, magnetic susceptibility/inclinometer, sonic, televiewer, neutron porosity, density, natural gamma, dipmeter, and induction. No hydrofrac will be undertaken on the HQ hole, and the VSP will be confined to a brief check-shot experiment to establish location of the bottom of the hole within the seismic section and to test VSP equipment. If insufficient time is available for all of these downhole measurements, the following are considered to be lower priority: VSP check-shot and induction.

**Between the first logging and conclusion of NQ drilling:**
The DMG scientists will concentrate on data analysis at CSEC: data quality control and editing, reprocessing, display, initial interpretation, collaboration with other groups concerning interpretation, and export of data to LIMS and Corelyzer. Workload will be heavy for the logging scientists, moderate for the VSP scientist, but light for the technicians, unless equipment troubleshooting is required. Drilling of the VSP/walkaway shot holes will occur during this period.

**Immediately after NQ drilling:**
This is the ~4.4 day second downhole measurements period, for measuring the NQ portion of the hole (~ the bottom half of the hole). Work by the DMG will be continuous, and all of the On-Ice DMG are likely to remain at the drill site for most of this period. The logging tool suite will be the same as that run previously in the HQ hole. Following logging, the VSP, hydrofracture, and walkaway experiments will be undertaken. If insufficient time is available for all of these downhole measurements, the following are considered to be lower priority: walkaway seismic and induction.

**After the second logging:**
Workload will continue to be intensive. The three scientists will have only a few days for data processing and analysis, plus writing their On-Ice Report section. The two technicians will need to supervise transport of equipment from the drill site to McMurdo Station, where they will prepare the winch and hydrofrac equipment for over-winter storage. With RM, the techs will clean up and pack the logging equipment for shipment back to the U.S.

## 4.3 McMURDO STATION SCIENCE ACTIVITIES

### 4.3.1 Split Core Scanning/XRF/Reflectance/Shear Strength

The elemental composition of the archive half of the split cores will be analyzed with a XRF core scanner at a high downcore resolution (approx. 2 to 5 cm, depending on drilling speed) and a spot size of 1 cm. Elements between Al and U could be detected with average detection limits ranging from 5 ppm (Sr) to 0.2% (Al), and results will be available shortly after the measurement. If time allows a second run with smaller spot size or different resolution could be undertaken and may provide a homogeneity factor for the drilled sediments (matrix to clast ratio). After calibration with standards and geochemical analyses the relative counts per second (cps) could be changed to quantitative values in later Off-Ice studies. The XRF core scanner has been used in previous studies for rapid quantification of the relative proportions of terrigenous and biogenic fluxes (Adegbie, et al., 2003; Helmke et al., 2005) and detection of early diagenesis (Funk et al., 2004; Reitz et al., 2004). This method can be used to indicate anoxic porewater conditions and could be combined with the magnetic susceptibility measurements made by FN with XRF element concentrations (Fe, Mn, Ti). Results may indicate periods of high organic production under open marine conditions and oxidation of organic carbon in the sediment. Variations of other elements like Ca, Ba, Sr, V, Cu, Ni, Zn may indicate biogenic activity. Variations in Fe, Ti, Mg may relate to various volcanic events. Variations in Al, Si, K, Fe, Mg, and Ti may indicate fluctuations in terrestrial input. Previous XRF core scanner measurements made by FN on the short cores taken below the shelf ice in Windless Bight show that downcore element variations are detectable and correlate to physical properties. For interpretation of high resolution downcore element distribution normalization by ratio calculations will be done. Cluster and principal component analyses of the data can provide proxies for changes in sediment origin and setting e.g. changing ice flow conditions, RIS grounding and calving line variations, sea ice occurrence, and marine productivity. The downcore element distribution pattern will be available as additional parameter for core correlations or composite section construction and will provide clues for individual sampling in addition to environmental interpretation.

The XRF core scanner was manufactured by AvaaTech Analytical X-Ray Technology and is owned by the Alfred Wegener Institute for Polar and Marine Research. Employees of this Institute will run the instrument On-Ice. Gerhard Kuhn (GK) is the scientist responsible for the XRF core scanner work. He will take measurements during day shifts and process data compilation. Donata Helling (DHe) will work during night shift and, in addition to sample measurements, will do the technical maintenance of the XRF scanner, calibration measurements and data backup. She will maintain scientific involvement in the MIS Project Off-Ice phase as part of her PhD program.

Color reflectance will be measured by GK and DHe on the archive half with a Minolta CM-2002 Spectrophotometer at approximately 2 cm intervals or corresponding to color changes. Wavelength range is 400 to 700 nm in steps of 10 nm. Raw data and some common color models will be assembled.

Shear strength measurements will be collected on soft sediment cores using a Pilcon hand held shear vane. In general, sampling intervals will be every meter but actual locations will be driven by density data derived from MST measurements obtained by FN. GK is responsible for obtaining the shear strength measurements but will work with the curators and members of the core logging team to identify the appropriate procedures and best practice as drilling commences.

ARISE Participants Alexander Siegmund and LuAnn Dahlman will each spend one month working with members of this Discipline Team.

#### 4.3.2 Sedimentology/Stratigraphy

**4.3.2.1** Overview

The primary role of the sedimentology/stratigraphy team during the drilling phase of the MIS project is description of the core and compilation of core logs, which serve as the official record of the drillcore. Sedimentological/ stratigraphic investigations are divided among: (a) a night shift (10:00 p.m. to 10:00 a.m.) team, which will construct the primary core log, and (b) a day shift (8:00 a.m. to 8:00 p.m.) team, which will (i) reconfirm the core description, (ii) develop summary logs and initial interpretations, (iii) communicate additions and modifications to the core log to the night shift and the rest of the science party, and (iv) provide information summaries at daily meetings to scientists from other discipline groups prior to core inspection sessions.

The day-shift sedimentologists are Lionel Carter (LC) and Robert McKay (RMc). RMc will be primarily responsible for examining smear slides and thin sections taken through the core and providing summary descriptions to the night shift sedimentologists for incorporation into the core logs. LC will be lead sedimentologist during the day and will lead the core tour, check the stratigraphic descriptions, work on interpretations, and integrate with other discipline teams in order that they understand the nature of the recovered core. Greg Browne will replace Lionel Carter in late November. The night shift will comprise Larry Krissek (LK, lead core description), Gavin Dunbar (GD, core description and facies), Ellen Cowan (EC, core description, glacial- and micro-facies), and Thom Wilch (TWc, core description, volcaniclastic sediments and tephra). Franco Talarico (FT) will also join the night-shift for quantitative assessment of clast composition.

The aims of the core characterization are twofold: (1) to provide a detailed and comprehensive description of the core that can be interpreted in terms of the paleoenvironmental history of the area, and (2) to provide a summary description of the core that can used by the rest of the science team. The primary mechanism for recording this description will be the graphic core logs developed digitally in PSICAT (section 4.3.2.2). These logs will include a graphic representation of lithology (with particle-size as the main determinant, since particulate sedimentary and volcanic rocks are anticipated to be the likely principal drilling targets). Other rock types, such as igneous flows and intrusions, will also be recorded on the graphic log. The log will also include symbols that provide details of lithology, physical sedimentary structures, deformational structures, biogenic structures, fossils, color, extent of bioturbation, and strata contacts over a given interval. Additional information may be added as textual comments. The detailed core logs will be used to develop sedimentological and stratigraphic interpretations of the core for inclusion in the On-Ice and Initial Reports. Generalized versions of the core logs, which summarize major stratigraphic trends and the locations of important marker beds (such as volcanic ash layers), will serve as the template upon which other scientific groups will present and interpret their results.

ARISE Participants Vanessa Miller and Julian Thomson will each spend one month working with members of this Discipline Team.

**4.3.2.2** Procedures and Protocols

**Core description and construction of core logs**

Compilation of core logs will utilize the new software package PSICAT, developed by Josh Reed (CHRONOS – Iowa State University), with standardized classifications, particle size scales, fill patterns, and symbols. Lithologies

**KEY TO BIOTURBATION INTENSITY**

| BI | Characteristics | Mudstone Facies | Sandstone Facies |
|---|---|---|---|
| 0 | Bioturbation absent | | |
| 1 | Sparse bioturbation, bedding distinct, few discrete traces | | |
| 2 | Uncommon bioturbation, bedding distinct, low trace density | | |
| 3 | Moderate bioturbation, bedding boundaries sharp, traces discrete, overlap rare | | |
| 4 | Common bioturbation, bedding boundaries indistinct, high trace density with overlap common | | |
| 5 | Abundant bioturbation, bedding completely disturbed (just visible) | | |
| 6 | Complete bioturbation, total biogenic homogenization of sediment | | |

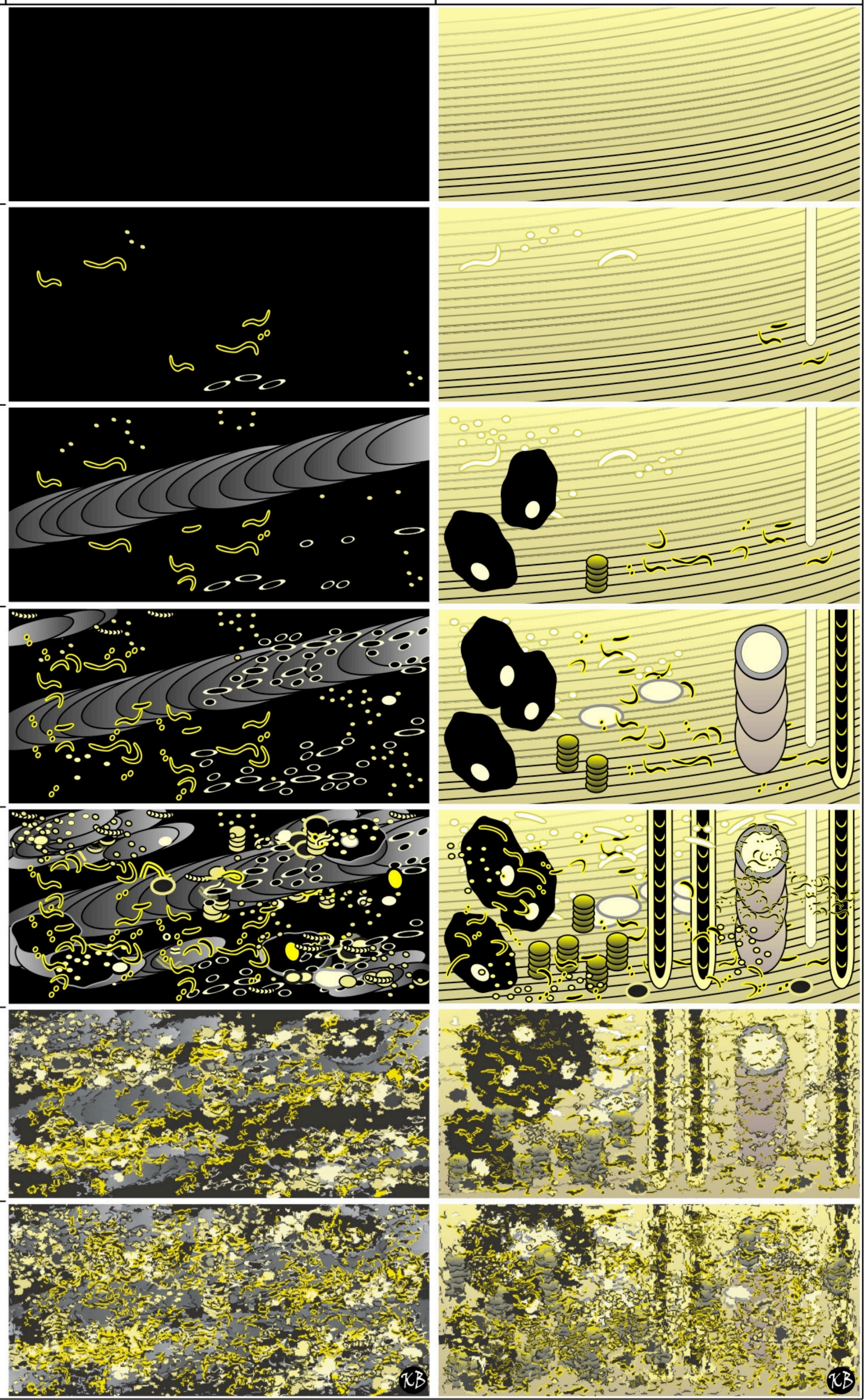


**Fig. 26**

Visual comparator for determining Bioturbation Index (from Bann et al., 2006 [submitted]).

and fill patterns are based on recommendations by the USGS, with minor modifications and additions from ODP/ IODP schemes; all lithologies and fill patterns used are defined within the pull-down menus of PSICAT. Symbols for physical and biogenic sedimentary structures, deformational structures, contained fossils, and bed contacts were derived from those used during the CRP, were modified based on the experience of ANDRILL STMs, and also are defined within the pull-down menus of PSICAT. The general intensity of bioturbation is indicated by a Bioturbation Index value between 0 (no disruption) and 6 (initial bedding completely destroyed) using the visual comparators of Bann et al. (2006 [submitted]) (Fig. 26), and is shown as a gray-scale bar on the PSICAT graphic log; discrete trace fossils are identified by specific symbols in the "Symbols" column of the PSICAT graphic log.

Core descriptions made by the night shift will be recorded directly into the PSICAT system. At least two members of the core logging team will observe the core together, and will dictate observations to a transcriber. The transcriber will enter the description data into PSICAT, and will query the core observers about any potential observations that have not been made yet for that interval of core. Both a Corelyzer display and a large-panel display of the PSICAT graphic column will be set up in the core description area (CSEC 201); these visualization tools will allow the transcriber and the team of core observers to readily cross-check between the core itself, the core description team, and the PSICAT graphic log as core description proceeds.

The distribution, composition, shape and other properties of gravel-sized clasts will be recorded into PSICAT by FT, who will work at the same time as, but independent of, the core description team. The clast data will be merged with the other core description data within PSICAT, so that stratigraphic profiles of clast abundance (number of clasts/10 cm of core length), clast size, and clast composition can be incorporated into the overall graphic column.

Because the core description in PSICAT is recorded as a digital file, the scale of the core log does not have to be specified at the start of core description. However, a paper copy of the log for each meter of core will be printed as soon as that interval has been described, to serve as a manual backup of all logs. This manual backup will be printed at a scale of 1 m per page. If time allows, a more generalized log, at a scale of one core box per page (3 or 4 m, depending on core diameter), will be generated in time for the core viewing by other STMs. The capability to combine multiple core log pages within PSICAT, and to produce logs at a variety of scales with definable levels of detail, will be particularly useful at the end of the drilling phase in the production of summary logs for the hole. For more information on PSICAT, see the Users Guide posted on the ANDRILL website (www.andrill.org).

The four individuals charged with compiling the core logs will have exclusive "write" access to the core description components of PSICAT during the drilling phase. Final versions of the detailed core logs, as well as updated generalized core logs, will be made available to the broader scientific party as quickly as possible via "read-only" access; the other discipline teams can use the generalized logs as a template upon which to enter additional information, such as biostratigraphic datums.

The original detailed core logs will be descriptive in nature. At appropriate intervals, lithostratigraphic units will be defined, taking into account large-scale, lithological stacking patterns. LC will lead this effort, in consultation with other members of the sedimentology/stratigraphy team, the CCSs, and other STMs. Interpretive information, such as sequence stratigraphic interpretations, will also be compiled at the end of the hole.

**Lithologic Classification Schemes**

Lithologic names for granular sediments and rocks will be assigned using the scheme illustrated in figure 27, which combines aspects of the classification systems used during the CRP and ODP Legs 185 and 188:

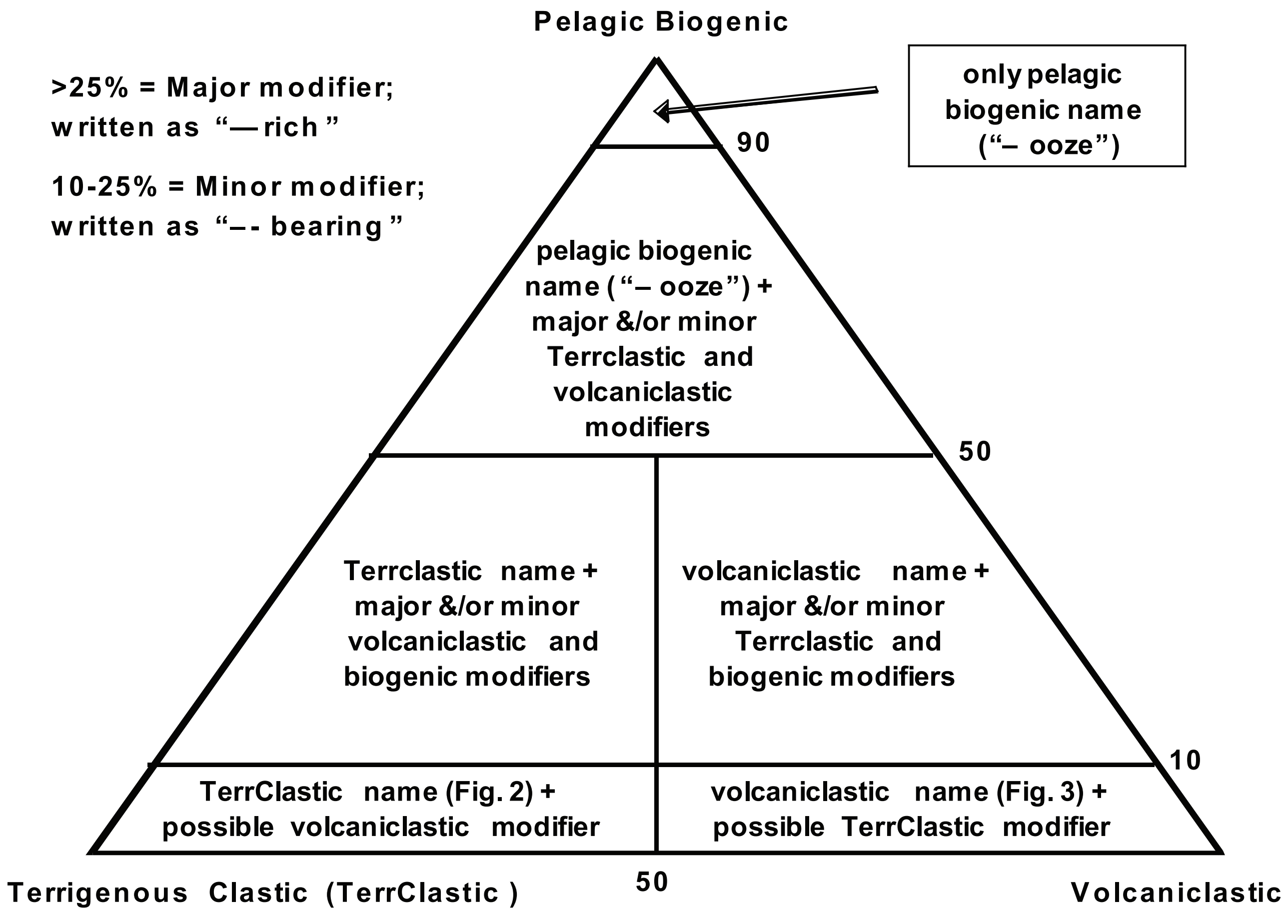



**Fig. 27**

ANDRILL MIS classification scheme for granular sediments that are mixtures of pelagic biogenic, volcaniclastic, and terrigenous clastic particles.

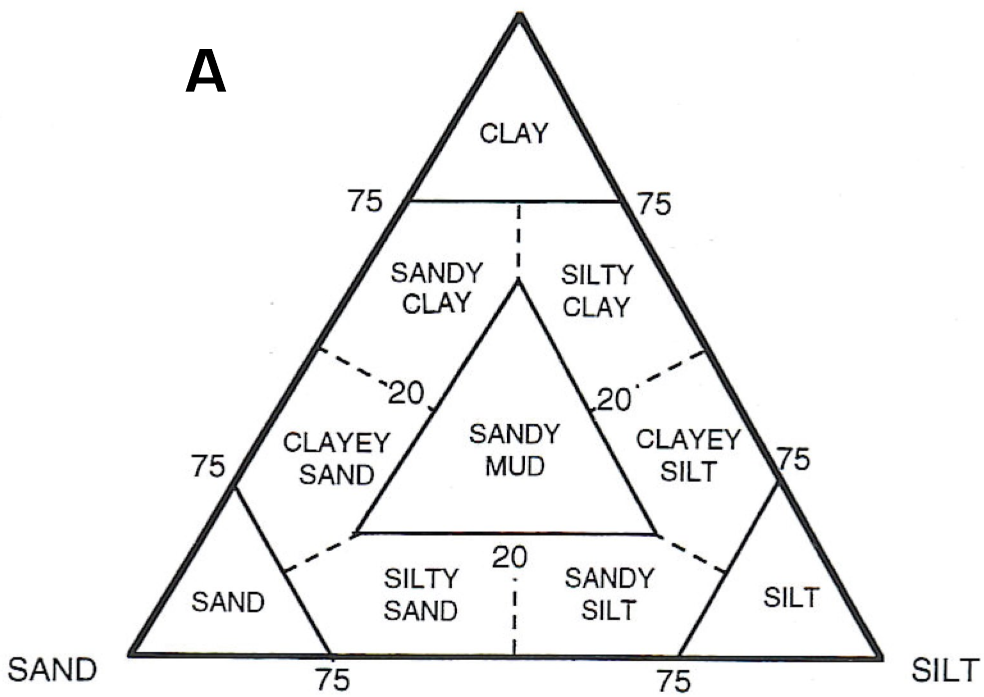
1) Principal name -- The principal lithologic name is assigned on the basis of the relative abundances of pelagic biogenic, volcaniclastic, and terrigenous clastic grains, as follows:

(a) The principal name of a sediment/rock with <50% pelagic biogenic grains and a terrigenous clastic:volcaniclastic ratio >1:1 is based on the grain size characteristics of the terrigenous clastic fraction.

i) If the sediment/rock contains no gravel, then the principal name is determined by the relative abundances of sand, silt, and clay (see Fig. 28a; after Mazzullo and Graham, 1988).

ii) If the sediment/rock contains terrigenous clastic gravel, then the principal name is determined by the abundance of gravel and the sand:mud ratio of the terrigenous clastic matrix (see Fig. 28b; after Moncrieff, 1989).

(b) The principal name of a sediment/rock with <50% pelagic biogenic grains and a terrigenous clastic:volcaniclastic ratio <1:1 is based on the grain size characteristics of the volcaniclastic fraction, following conventions described by Fisher (1961), Schmid (1981) and McPhie et al. (1993). Additional discussion and descriptions of volcaniclastic terminology can be found in Gillespie and Styles (1999).




**B**

| PERCENT SAND IN MATRIX | PERCENT GRAVEL (>2mm) IN WHOLE ROCK ESTIMATED FROM CORE | | | | | | PERCENT SAND IN MATRIX |
|---|---|---|---|---|---|---|---|
| | | *Trace - < 1%* | *1 - 5%* | *5 - 30%* | *30 - 80%* | *> 80%* | |
| 0–10 | FINE-GRAINED SEDIMENTS - See Figure 16 | MUDSTONE with dispersed clasts | MUDSTONE with common clasts | MUDSTONE with abundant clasts | Muddy CONGLOMERATE/ BRECCIA | CONGLOMERATE/ BRECCIA | 0–10 |
| 10–50 | | Sandy MUDSTONE with dispersed clasts | Clast-poor muddy DIAMICTITE | Clast-rich muddy DIAMICTITE | Sandy muddy CONGLOMERATE/ BRECCIA | | 10–50 |
| 50–90 | | Muddy SANDSTONE with dispersed clasts | Clast-poor sandy DIAMICTITE | Clast-rich sandy DIAMICTITE | Muddy sandy CONGLOMERATE/ BRECCIA | | 50–90 |
| 90– | | SANDSTONE with dispersed clasts | SANDSTONE with common clasts | SANDSTONE with abundant clasts | Sandy CONGLOMERATE/ BRECCIA | | 90– |

**Fig. 28**

Classification schemes for

(a) terrigenous clastic sediments (after Mazzulo and Graham, 1988) and

(b) poorly sorted terrigenous clastic sediments containing gravel (after Moncrieff, 1989).

i) The principal name of a volcaniclastic sediment/rock is based on texture, using a terminology similar to that applied to terrigenous clastic rocks but preceded by the modifier 'volcaniclastic' (see Fig. 29a). The term volcaniclastic is non-genetic and simply describes the rock composition rather than the mode of origin. In cases where the volcaniclastic rock/sediment origin can be determined, genetic terms (e.g. fine hyaloclastite) can be used as modifiers instead of volcaniclastic.

ii) In cases where pyroclastic material forms 75-100% of the sediment/rock, the principal name will be assigned using figure 29b.

**A**

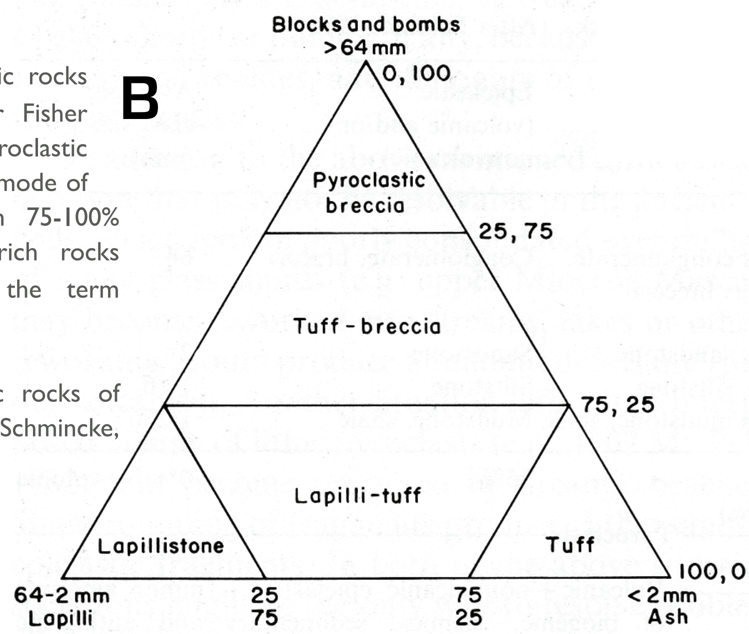
| Grain Size | Volcaniclastic Deposits | | Pyroclastic Deposits | | Autoclastic Deposits | |
|---|---|---|---|---|---|---|
| | Unconsolidated Sediment | Consolidated Rock | Unconsolidated Tephra | Consolidated pyroclastic rock | Hyaloclastite | Autobreccia |
| <$^{1}/_{16}$ mm | volcaniclastic mud | volcaniclastic mudstone | fine ash | fine tuff | fine hyaloclastite | ? |
| $^{1}/_{16}$-2 mm | volcaniclastic sand | volcaniclastic sandstone | coarse ash | coarse tuff | hyaloclastite sandstone | |
| 2-4 mm | volcaniclastic gravel | voclaniclastic conglomerate or breccia | lapilli tephra | lapillistone | granular hyaloclastite | granular autobreccia |
| 4-64 mm | | | | | hyaloclastite breccia | autoclastic breccia |
| >64mm | | | bomb or block tephra | agglomerate or pyroclastic breccia | coarse hyaloclastite breccia | coarse autoclastic breccia |

**Fig. 29**

(a) Nomenclature for volcaniclastic rocks (from McPhie et al., (1993), after Fisher (1961) and Schmid (1981)). Both pyroclastic and autoclastic rocks imply specific mode of origin. Pyroclastic rocks contain 75-100% pyroclastic material. Pyroclastic-rich rocks (25-75%) can be modified by the term 'tuffaceous', rather than pyroclastic,

(b) Nomenclature for pyroclastic rocks of mixed grain size (after Fisher and Schmincke, 1984).

**B**



(c) The principal name of a sediment/rock with >50% pelagic biogenic grains is “ooze”, modified by the most specific biogenic grain type that forms 50% or more of the sediment/rock. (e.g. if diatoms exceed 50%, then the sediment is a “diatom ooze”. However, if diatoms are 40% of the sediment and sponge spicules are 20%, then the sediment is a “siliceous ooze”).

2) Major and minor modifiers – major and minor modifiers can be applied to any of the principal granular sediment/rock names, and are listed before the principal name in order of decreasing abundance. The use of major and minor modifiers follows the scheme of ODP Leg 185:

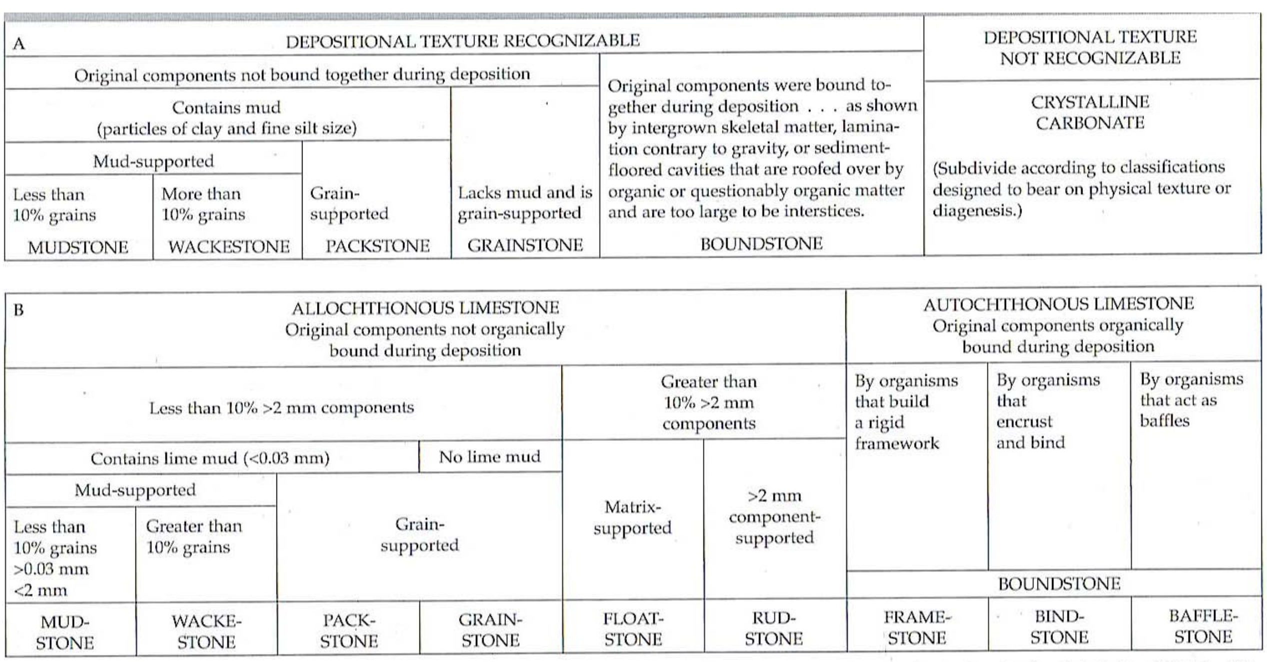
(a) Major modifiers are those components with abundances >25%, and are indicated by the suffix "-rich" (e.g., “diatom-rich”).

(b) Minor modifiers are those components with abundances of 10-25%, and are indicated by the suffix “-bearing” (e.g., “diatom-bearing”).

(c) If possible, modifiers are assigned on the basis of the most specific grain type (e.g., “silt-rich” or “silt-bearing”.) If necessary to exceed the 10% or 25% abundance thresholds, however, similar grain types can be grouped together (e.g., combine 5% diatoms and 5% sponge spicules to assign a modifier of “biosiliceous-bearing”).

(d) Authigenic components, if present, can be included as major or minor modifiers (e.g., “pyrite-bearing”), although the abundances of authigenic components do not play a role in determining the principal name of a granular sediment.

Lithologic names for non-pelagic limestones will be assigned using the Dunham classification scheme (see Fig. 30; from Boggs, 2006).



| A DEPOSITIONAL TEXTURE RECOGNIZABLE | | | | | DEPOSITIONAL TEXTURE NOT RECOGNIZABLE |
|---|---|---|---|---|---|
| Original components not bound together during deposition | | | | Original components were bound together during deposition . . . as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices. | CRYSTALLINE CARBONATE (Subdivide according to classifications designed to bear on physical texture or diagenesis.) |
| Contains mud (particles of clay and fine silt size) | | | Lacks mud and is grain-supported | | |
| Mud-supported | | Grain-supported | | | |
| Less than 10% grains | More than 10% grains | | | | |
| MUDSTONE | WACKESTONE | PACKSTONE | GRAINSTONE | BOUNDSTONE | |

| B ALLOCHTHONOUS LIMESTONE Original components not organically bound during deposition | | | | | | AUTOCHTHONOUS LIMESTONE Original components organically bound during deposition | | |
|---|---|---|---|---|---|---|---|---|
| Less than 10% >2 mm components | | | | Greater than 10% >2 mm components | | By organisms that build a rigid framework | By organisms that encrust and bind | By organisms that act as baffles |
| Contains lime mud (<0.03 mm) | | | No lime mud | Matrix-supported | >2 mm component-supported | | | |
| Mud-supported | | Grain-supported | | | | | | |
| Less than 10% grains >0.03 mm <2 mm | Greater than 10% grains | | | | | BOUNDSTONE | | |
| MUD-STONE | WACKE-STONE | PACK-STONE | GRAIN-STONE | FLOAT-STONE | RUD-STONE | FRAME-STONE | BIND-STONE | BAFFLE-STONE |

Source: A. After Dunham, R. J., 1962, Classification of carbonate rocks according to depositional textures, in Ham, W. E., ed., Classification of carbonate rocks: *Am. Assoc. Petroleum Geologists Mem.* 1. Table 1, p. 117,

**Fig. 30**

Dunham’s classification scheme for limestones, based on depositional texture (from Boggs, 2006).

## ANDRILL
### SMEAR SLIDE DESCRIPTION

Site__________ Hole__________ Core_________ Subbottom depth_______

Observer________________ Date____________

Sediment name____________________________________________________

Lithology________________ (dominant) __________________ (minor)

| **TEXTURE**: | % Sand | % Silt | % Clay | |
|---|---|---|---|---|
| Overall | ______ | ______ | ______ | (= 100%) |
| Terrigenous | ______ | ______ | ______ | (= 100%) |
| Biogenic | ______ | ______ | ______ | (= 100%) |

**COMPOSITION**: % Terrigenous________ % Biogenic__________ (= 100%)

Terrigenous (% total grains):

| | |
|---|---|
| Quartz | ______ |
| Feldspar | ______ |
| Rock fragments | ______ |
| Volcanic glass | ______ |
| Clay | ______ |
| Mica | ______ |
| Accessory Minerals | ______ |
| Others | ______ |

% Biogenic (% total grains):

| | | |
|---|---|---|
| Total siliceous | | ______ |
| Diatoms | ______ | |
| Radiolarians | ______ | |
| Spicules | ______ | |
| Silicoflagellates | ____ | |
| Total calcareous | | ______ |
| Foraminifera | ______ | |
| Nannofossils | ______ | |
| Plant debris | | ______ |
| Accessory components | | ______ |
| Others | | ______ |

**COMMENTS:**

**Fig. 31**
ANDRILL smear slide description form.

## ANDRILL

### THIN SECTION DESCRIPTION

Site__________ Hole__________ Core_________ Subbottom depth________

Observer________________ Date____________

Sediment name_____________________________________________________

Lithology________________ (dominant) __________________ (minor)

**TEXTURE**: Grain size (μm):

Max. ________

Min. ________

Mode(s)_________

Roundness_________

Sphericity _________

Sorting _________

**DETRITAL COMPOSITION** (% of total rock)

Quartz ______ (mono) ___________: poly ___________)

K-Feldspar ______

Plagioclase

Rock fragments ______ (types __________; ______________)

Muscovite ______

Biotite ______

Heavies ______

Opaques ______

Carbonates ______

Matrix ______ (types __________; ______________)

Others ______

**DIAGENETIC COMPONENTS** (% of total rock)

Cement ______ (types __________; ______________)

Other authigenic components ______________________________

**POROSITY** (% of total rock):

Primary ______

Secondary ______

**COMMENTS**

**Fig. 32**
ANDRILL thin section description form.

**Smear slide and thin section studies**

Smear slides should be taken at least every meter in the upper portion of the recovered core, with additional smear slides from lithologies of particular interest. An initial suite of smear slides will be made during primary core description by the night shift sedimentologists, and those smear slides will be scanned immediately in a reconnaissance fashion to assist in assigning lithologic names to the sampled intervals. Those smear slides, as well as any others taken later to more completely characterize the cored interval, will be analyzed in detail by RMc. Any modifications to the lithologic names assigned during the initial core description will be reported to the core description team, who will revise the core log within PSICAT.

Whenever possible, smear slides should be made by “smearing” on the underside of the cover slip, rather than on the glass slide; this produces smear slides that are more likely to be usable for micropaleontological analyses. Each smear slide that is made will be entered into the curation system, and ultimately will be archived at Florida State University. Each smear slide will be described using an ANDRILL SMEAR SLIDE DESCRIPTION form (see Fig. 31); the description form will be revised if required. Compositional data for each smear slide will be entered into an EXCEL spreadsheet, which will be downloaded daily into the ANDRILL MIS Project database.

Samples for thin sections will be taken from common lithologies and from intervals of particular interest in the more lithified portion of the core. The thin sections will be analyzed in detail by RMc; if necessary, TWc and other members of the Geochemistry/Petrology discipline team will assist in analyzing thin sections of volcaniclastic lithologies. Lithologic names derived from the thin section analyses will be reported to the core description team, who will make any necessary revisions to the appropriate intervals of the core log within PSICAT. Each thin section that is made will be entered into the curation system, and ultimately will be archived at Florida State University. Each thin section will be described using an ANDRILL THIN SECTION DESCRIPTION form (see Fig. 32) or an equivalent form for volcaniclastics, if needed. Compositional data for each thin section will be entered into an EXCEL spreadsheet, which will be downloaded daily into the ANDRILL MIS database.

**4.3.2.3** Roles and Tasks

Roles and tasks allocated to individual members of the On-Ice Science Sedimentology/Stratigraphy Discipline Team are as follows:

**Night Shift**

The four members of the sedimentology/stratigraphy core description group will work together. At least two of the four will observe the core and dictate observations, while one member transcribes the information into PSICAT. The fourth member of the team will either be observing the core or be cross-checking between the core image on Corelyzer, the core describers, and the developing core log in PSICAT. Team members will rotate between these tasks, while ensuring specific facies are being described by personnel with the most pertinent experience.

Specific areas of expertise and specific tasks include:

EC: core-logging, with emphasis on glacial sediments and facies analysis;

GD: core-logging, with specific emphasis on non-glacial facies analysis, stratigraphic stacking patterns, and sequence stratigraphy;

LK (Discipline Team Leader): core-logging, lead sedimentologist; assist in definition of lithostratigraphic units, compile sedimentology/stratigraphy section of the On-Ice and Initial Reports;

Josh Reed (JR): PSICAT support and training (will straddle shifts to provide input to both);
TW: core-logging, with specific emphasis on volcaniclastic sediments and tephrostratigraphy;
FT: will work independently during core-logging, with specific emphasis on clast characterization;
Matt Olney (MOl): curation;
Davide Persico (DP): core handling;
Kelly Jemison (KJ): core handling.

**Day Shift**
RMc: smear slides, petrography, facies analysis;
Lionel Carter (LC): day shift lead sedimentologist; check core descriptions, develop integrated facies scheme and stratigraphic interpretation, coordinate production of summary logs;
Matt Curren (MC): curation;
Steve Petrushak (SP): core handling;
Charlene King (CK): core handling.

It is anticipated that the night and day shifts will overlap each morning. Night-shift is scheduled from 10 PM to 10 AM. Day shift sedimentologists will work from 8 AM to PM. The entire sedimentology/stratigraphy team will meet at 8-9 AM for an update on recent progress and to review the previous night's logging. At the 9.00 AM science team meeting, LK will present a summary of the core log developed during the previous evening. From 10-11 AM, LC will run core tours. The latter two activities will benefit from the ability to view core images on Corelyzer in the ANDRILL common area (CSEC 209).

**4.3.2.4** Research interests of On-Ice Science Team Members

Members of the Sedimentology/Stratigraphy group will also collect data for their specific research projects during the course of the core characterization phase. A summary of projects proposed by participants is provided below.

RMc: Grain size analysis and detailed textural characterization of lithofacies;
LC: Core description and interpretation with emphasis on oceanography (e.g. ice shelf/ water mass variability) recorded by marine intervals;
EC: Description of glacial facies; microfabric analysis of diamicts using large-area thin sections; surface microtextures of quartz grains from sandy diamicts;
GD: Particle size analysis and facies analysis in collaboration with RM, EC and LC; trace/major elements in biogenic silica (e.g. Fe) by LA ICPMS on individual siliceous tests from selected marine intervals to track ice shelf-sea ice dynamics;
LK: Lithostratigraphic description/interpretation; bulk mineralogy of fine-grained intervals;
TWc: Volcaniclastic lithofacies and mode of emplacement; combined volcanic/glacial history; Ar/Ar dating.

### 4.3.3 Paleonotology

**4.3.3.1** Overview

Fossils provide a key tool for interpreting Antarctic sediments. Microfossils occur in diverse lithologies and comprise a full range in fossil concentration from rich siliceous oozes and bioclastic carbonates to diamictons, ashes, and sandstones virtually devoid of microfossils. Hemipelagic sediments typically contain common or abundant fossil material whereas most glacial diamictons contain microfossils in low abundance. Microfossils may be *in situ* and well preserved or reworked, diagenetically altered, or mechanically degraded. Fossils occurring in Antarctic sediments include siliceous groups, strongly dominated by diatoms, but also including silicoflagellates, ebridians, endoskelletal dinoflagellates, chrysophyte cysts, radiolarians, sponge spicules, and, occasionally, plant phytoliths reworked from terrestrial deposits. Calcareous microfossils are generally rare in Late Cenozoic Antarctic sediments but may include planktonic and benthic foraminifera. Agglutinated forams generally dominate over calcareous benthic forams. Other calcareous plankton include thoracosphaera (calcareous dinoflagellates) and may include rare coccoliths. Calcareous benthic macrofossils may be locally abundant and diverse, dominated by molluscs (mostly bivalves and gastropods) or bryozoans, and including echinoderms, cnidarians, barnacles, and other groups. Organic walled microfossils are less abundant in late Cenozoic Antarctic sediments than in Paleogene deposits, but occurrences include dinoflagellates, foram linings, and other groups, including diverse displaced and reworked terrestrial palynomorphs. Reworked microfossils from older strata may be abundant, especially in association with glacially influenced sediments. These may comprise all of the above groups, most notably diatoms and marine and terrestrial palynomorphs.

Initial study of diatoms, foraminifera, macrofossils, and organic-walled microfossils will be characterized On-Ice during drilling, and will continue into the post-drilling phase. Calcareous nannofossils will be investigated exclusively during the post-drilling phase, although their occurrences will be noted during routine diatom analysis.

Fossils provide five distinct sets of valuable information:

(a) Biostratigraphic age determination (during and post-drilling);

(b) Paleoenvironmental interpretation based on ecological constraints of the living organisms (and their ancestors) (during and post-drilling);

(c) Assessment of reworking by analysis of stratigraphically mixed fossil assemblages (during and post-drilling);

(d) Interpretation of sedimentologic and glacial processes by mechanical degradation by either normal load compaction or by subglacial shearing (during and post-drilling);

(e) Geochemical and geochronological signals carried in skeletal and organic remains (e.g., radio and stable isotopes, trace elements, etc.) (post-drilling).

Biostratigraphy is the most critical paleontologic application for analysis during drilling. Each fossil group has a unique biostratigraphic signature, but diatoms provide, by far, the most detailed and well calibrated biostratigraphic record for the Antarctic nearshore zone. Fossil age picks will be integrated into the chronostratigraphic scheme and will be calibrated to the Berggren et al., (1995) time scale (section 4.3.6). Mike Hannah will serve as the chief paleontologic database manager on ice. The diatom age model generated by Rosemary Cody, Richard Levy, and David Harwood using the CONOP method for the Southern Ocean diatom species will be used as an additional reference to enhance age resolution.

Diverse information may be rapidly generated from fossil analysis to aid the interpretation of depositional environments. Fossil assemblages can be used to confidently establish, for example: (a) the influence of sea ice, (b) constraints on water paleo-depth, based on the presence/absence of certain benthic taxa, (c) the incursion of pelagic water masses, (d) insights into water temperatures, (e) paleoproductivity (f) influx of terrestrial surface waters, by the occurrence of non-marine microfossils, notably diatoms, (g) a gauge of sediment reworking and mixing by the occurrence of older, displaced taxa, and (h) an evaluation of subglacial shearing by the diatom fragmentation index established by Scherer et al. (2004), which aids in distinguishing glacial marine sediments from subglacial till.

Fossil data will help guide facies interpretations and, depending upon sediment accumulation rates and core recovery, will be integrated into spectral models of Milankovitch and sub-Milankovitch cyclostratigraphy (post-drilling analyses by Linda Hinnov). On-Ice description and interpretation of biogenic sedimentary structures (ichnofossils) and macrofossil degradation will be advanced in the post-drilling phase by Molly Miller, in collaboration with Marco Taviani (On-Ice). Assessment of diatom abundance will be compared with opal data, produced by Fulvia Aghib, and diagenetic analyses. Most geochemical analyses of fossil materials will be performed at home institutions during the post-drilling time frame. Certain critical analyses, notably selection of fossil material for radiocarbon or for $^{87/86}Sr$ dating, conducted by Ian Graham, may be initiated during the drilling phase.

ARISE Participants Betty Trummel and Vanessa Miller will each spend one month working with members of this Discipline Team.

**4.3.3.2** Diatoms and Other Siliceous Microfossils

Reed Scherer (RS), Charlotte Sjunneskog (CS), Diane Winter (DW), Paola Maffioli (PM) (all On-Ice)

Diatoms are ubiquitous unicellular, eukaryotic, microalgae that form a bivalved siliceous frustule. They are abundant in Antarctic waters and preserve well in Antarctic sediments. Diatom taxa are closely constrained by ecological conditions, and many lineages have high rates of evolution. These characteristics make diatoms the most important source of paleontologic information in Cenozoic aquatic sediments of Antarctica, and will be central to interpreting recovered ANDRILL sediments.

Diatoms are the primary paleontologic tool for biostratigraphy and paleoenvironmental reconstruction for the Antarctic. Virtually all sediments from Antarctica's marine basins include diatoms, though abundance and preservation may vary, respectively, from dominant and excellent, to rare and poor. Diatom fossils even occur in highly sheared subglacial sediment (Scherer et al., 1998; 2004). Core recovered from ANDRILL's MIS Project drill site will include primary glacial and marine sediments of ?late-Miocene to Pleistocene age, which will include abundant diatoms and diatom fragments. The overdeepened basin created by subsidence of the Ross Island volcanics provides a trap for sedimentary particles, including diatoms. Sediments to be recovered during the MIS Project will have been deposited under open marine conditions, when the Ross Ice Shelf was either absent or reduced relative to today, or beneath an ice shelf of modern or larger dimensions. Current water depths suggest that heavy grounding has been limited.

Diatoms will be analyzed during drilling by RS, CS, and DW, all of whom have parallel skill sets critical to On-Ice biostratigraphic and paleoenvironmental analysis, plus individual focus on specialized applications. Each diatomist will be responsible for directing individual post-drilling research, in addition to the overarching biostratigraphic and paleoenvironmental interpretations. Laboratory assistance during drilling will be provided by PM, but all diatomists will participate in sample preparation.

Diatom samples will be selected from fine-grained sediments. Several distinct approaches will be employed at the CSEC, including both rapid, high-density samples and selected interval samples for detailed analysis. Abundant smear slides will be prepared coincident with lithostratigraphic description of the core. Tiny toothpick samples will be taken for smear-slides, which are rapidly produced and provide an unadulterated observation of microfossils in the sediment, allowing accurate assessment of total microfossil abundance. Smear slides may be prepared at sample intervals down to millimeter scale, offering the possibility of microstratigraphic analysis of key intervals. Rapid production of these slides permits qualitative assessment of, literally, several thousand samples during the drilling season. The absence of chemical and mechanical degradation of the sample permits the assessment of absolute and relative abundance and preservation of diatom assemblages. Smear slides also permit assessment of material to guide interval sampling for diatoms and other microfossil groups, including nannofossils and palynomorphs.

Diatoms will be prepared at the CSEC using several distinct methods. Interval samples (2cc to 5cc) will be taken at approximately 20 cm intervals down-core, unless smear slide investigation calls for tighter or wider sample intervals. Samples will be processed for further analysis based on lithology, diatom abundance, and preservation. Diatom-rich hemipelagic sediments will be processed for biostratigraphy following methods commonly employed for shipboard diatom analysis (Scherer and Koc, 1998), and that employed by Scherer et al. (2000) from CRP 2/2A. Selected samples will be processed for true quantitative assessment of diatom abundance during drilling, following the method of Scherer (1994). This method is also preferred for paleoenvironmental analysis in the post-drilling period.

Most secondary biosiliceous groups will be analyzed routinely with the diatoms, because sample preparation and analysis utilize the same basic methodology. When important larger siliceous groups are encountered, notably radiolarians, subsequent processing will be performed in an attempt to concentrate these fossils for further analysis. Radiolarians will also be noted in foraminiferal preparations (Percy Strong). Furthermore, diatomists will note occurrences of calcareous nannofossils and palynomorphs in order to guide sampling and Off-Ice investigation of these microfossil groups.

Diatom biostratigraphy will follow established schemes developed during previous drilling/coring programs in the nearshore zone (CRP, CIROS, MSSTS, DVDP, piston cores) and the pelagic realm (ODP legs 114, 119, 120, 177, 178, 183, DSDP Leg 28, piston cores, etc). Biostratigraphic schemes and key first and last diatom and, secondarily, silicoflagellate and ebridian occurrence datums for the last 5 m.y., are summarized in Table 5.

Biostratigraphic study on ice will proceed following methods previously employed during On-Ice/shipboard participation in the CRP and Ocean Drilling Program (ODP) legs. Biostratigraphic ages will be established based on the most recent and complete datums from neritic and circumpolar pelagic high latitude records (Table 5). On-Ice biostratigraphy will be based mostly on qualitative and semi-quantitative data. High sediment accumulation

rates of diatom-rich intervals offer the opportunity to study patterns and rates of evolution in diatom lineages, which will further help refine biostratigraphy. This goal will be largely addressed in the post-drilling investigations.

Paleoenvironmental interpretation of ANDRILL cores will include the diverse opportunities offered by diatoms. Diatoms can be used to constrain, for example, (a) paleoproductivity (e.g., absolute abundance of bloom species such as *Chaetoceros*), (b) relative water temperature and habitats (e.g., pelagic vs neritic taxa, occurrence of subpolar taxa and warm vs. cold water morphotypes), (c) occurrence, extent and relative thickness of sea-ice environments, (d) constraining water depth (occurrence of marine benthic taxa), and (e) identification of pulses of terrigenous input by the occurrence of non-marine diatom taxa.

## Table 5

Key Antarctic diatom biostratigraphic datums and sources, late Miocene to present.

| | Diatom taxon | Revised age (Ma)b | Source (s) | Other reported ages/notes Zonal markers |
|---|---|---|---|---|
| LO | *Rouxia leventerae* | 0.14 | ZG | B+ |
| LCO | *Actinocyclus ingens* | 0.56–0.64 | ZG | B: 0.40–0.55a / RB: 0.3–2.0b / WI: 0.65b / ZG: 0.38b (LO) / WB: 0.66b / C, G, HM, GB: 0.66b (LCO) |
| LO | *Thalassiosira torokina* | 1.0 | B+ | WI: 1.76 |
| FO | *Thalassiosira antarctica* | 1.1 | S / B1+ | |
| LO | *Fragilariopsis barronii* | 1.2-1.5 | WB | WI: 1.095 / HM: 1.35b |
| LO | *Actinocyclus karstenii* | 1.63 | WI | HM: 1.7-2.8b |
| LO | *Proboscia barboi* | 1.7 | F / C / B | HM: 3.1a (local extinction) / RB: 1.6–4.2b / ZG: 1.82–1.85b |
| LO | *Thalassiosira inura* | 1.9 | HM / W | G: ~1.7a / RB: 2.0–3.1b / WI: 1.97b |
| LO | *Thalassiosira kolbei* | 1.8-2.0 | WB | HM: 1.87b |
| LO | *Thalassiosira vulnifica* | 2.3 | WI | WB: 2.1-2.5b / HM: 2.3b |
| LO | *Rouxia heteropolara* | 2.58 | G | HM: 2.61b |
| LO | *Thalassiosira insigna* | 2.6 | C / GB | G: 2.1–2.5a / F: 1.9–2.2a / B: 2.4–2.45a / RB: 1.8–4.6b / WI: 2.54–2.6b / ZG: 2.55–2.66b |
| LO | *Fragilariopsis interfrigidaria* | 2.7 | HM | C: 2.8a / G: 2.1–2.5a / B: 1.9–2.0a / RB: 1.8–3.3b / ZG: 2.58–2.96b / WI: 2.5-2.6b |
| FO | *Thalassiosira vulnifica* | 2.7-3.2 | WB | WI: 2.77-3.06b / HM: 3.17b / ZG: 3.26b |
| LO | *Nitzschia reinholdii* | 2.72 | ZG | RB: 2.5–4.6b / HM 3.4b |
| LO | *Fragilariopsis weaveri* | 2.8 | HM | ZG: 3.4-3.5b |
| LO | *Thalassiosira webbi* | 2.9 | HM | |
| LO | *Thalassiosira striata* | 2.9-3.35 | HM | WI: 2.77b |
| FO | *Actinocyclus actinochilus* | 3.1 | HM | RB: 2.2–3.2b |
| FO | *Fragilariopsis kerguelensis* | 3.2 | HM | C: 2.6a / B: 1.9–2.0a / RB: 1.2–3.2b / ZG: 2.04–2.34b |
| LO | *Thalassiosira complicata* | 3.25-3.45 | HM | |
| FO | *Fragilariopsis weaveri* | 3.35 | HM | |
| FO | *Thalassiosira webbi* | 3.4 | HM | |
| FO | *Thalassiosira insigna* | 3.42 | ZG | RB: 2.7–3.3b / HM: 3.4b / WI: 2.98b |
| FO | *Fragilariopsis ritscherii* | 3.58 | HM | |

| | | | | |
|---|---|---|---|---|
| FO | *Fragilariopsis praeinterfrigidaria* | 3.6 | WH | HM: 3.7b/ C: 2.8a / G: 3.6a / RB: 2.1–4.6b / WI: 3.88b |
| FO | *Fragilariopsis curta* | 3.7 | HM | |
| FO | *Fragilariopsis interfrigidaria* | 3.8 | G / B / HM / ZG | C: 4.0a / RB: 3.3–4.0b / WI: 2.67–3.9b |
| FO | *Thalassiosira kolbei* | 4.1 | HM | |
| FO | *Thalassiosira lentiginosa* | 4.2 | HM | WI: 3.75b |
| FO | *Fragilariopsis barronii* | 4.2-4.3 | WB | WI: 4.22b |
| FO | *Asteromphalus parvulus* | 4.48 | HM | |
| FO | *Thalassiosira fasciculata* | 4.48 | HM | WI: 4.22b |
| FO | *Thalassiosira striata* | 4.48 | HM | WI: 4.22b |
| FO | *Rouxia heteropolara* | 4.62 | G / HM | B: 3.8a / RB: 4.0–6.8b |
| FO | *Thalassiosira complicata* | 4.68 | HM | WI: 5.09b |
| FCO | *Thalassiosira inura* | 4.9 | G | B: 4.7–4.8a / RB: 4.5–9.0b WI: 5.56b (FO) / CG: 4.89b(FO) / ZG: ~4.9b / HM: 4.9(5.3)b (FO) |
| LO | *T. oliverana var. sparsa* | 4.9 | HM | |
| LO | *Denticulopsis simonsenii* | ~4.9 | CG | C: 4.4a (LO) / B: 6.3a (LCO) / G: 4.5a (LO) / G: 7.3a (LCO) / RB: 4.2–5.4b (LO) / B2+: 9.0b (LO) |
| FO | *Fragilariopsis praeinterfrigidaria* | 5.72 | WI | C: 4.3a / B: 4.3–4.6a / RB: 4.5–5.7b / G: 4.9b |
| LO | *Nitzschia donahuensis* | 5.8 | HM | |
| FO | *Thalassiosira oestrupii* | 6.1 | WI | RB: 4.3–5.1b / B:5.6–5.8b / HM: 5.6b |
| LO | *Denticulopsis delicata* | 6.2 | BW | |
| LO | *Hemidiscus ovalis* | 6.3 | HM | |
| LO | *Asteromphalus kennettii* | 6.4 | HM | |
| FO | *Thalassiosira oliverana* | 6.4 | HM | |
| FO | *Hemidiscus ovalis* | 7.65 | HM | |
| FO | *Nitzschia reinholdii* | 8.0 | B | HM: 6.4b |
| LO | *Denticulopsis ovata* | ~9.0 | HM | CG: 4.93b |
| FO | *Thalassiosira torokina* | 9.0 | HM | C: ~6.0a / G: ~7.7a / B: 7.7a / RB: 8.5–10.0b / WI: 8.8b |
| LCO | *Denticulopsis hustedtii* | 10.1 | YA | HM: 6.2b (includes D. simonsenii and D. vulgaris) |
| LCO | *Denticulopsis dimorpha* | 10.7 | HM | G: 9.8–9.9a / B: 9.9a / RB: 10.2–12.9b / YA: 9.2b (LO) |
| FO | *Denticulopsis dimorpha* | 12.7 | CG | G: 12.4a / RB: 11.1–13.0b / B, HM: 12.2b |
| FO | *Denticulopsis praedimorpha* | 12.9 | CG | B: 12.0–12.5a / HM: 12.8a / RB: 12.5–13.4b / /G: 12.82b |

B, Baldauf & Barron (1991); B1+, Bohaty et al. (1998); B2+, Bohaty et al. (2003); BW, Bohaty & Whitehead (unpubl. data); C, Ciesielski (1983); CG, Censarek & Gersonde (2002); F, Fenner (1991); G, Gersonde & Burckle (1990); GC, Gombos & Ciesielski (1983); HB, Harwood & Bohaty (2001); HM, Harwood & Maruyama (1992); M, McKelvey et al. (2001); RB, Ramsay & Baldauf (1999); S, Scherer (1991); S+, Scherer et al. (2000); WB, Whitehead & Bohaty (2003); WH, Winter & Harwood (1997); WI, Winter & Iwai (2002); YA, Yanagisawa & Akiba (1998); ZG, Zielinski & Gersonde (2002) data south of Subantarctic Front; a Berggren et al. (1985); b Berggren et al. (1995) / Cande & Kent (1995); c Foraminiferal data (McKelvey et al. 2001); FO, First Occurrence; FCO, First Common Occurrence; LO, Last Occurrence; LCO, Last Common Occurrence.

Other siliceous marine (e.g. silicoflagellates, ebridians, parmales, chrysophyte cysts, radiolarians) and non-marine (phytoliths, non-marine chrysophytes) microfossils provide additional paleoenvironmental information. Diatom microscopical analysis will be augmented by analysis of percent biosilica on key intervals. This will be performed entirely Off-Ice during the post-drilling phase.

Glacial diamicton is a dominant lithology in the Antarctic nearshore zone for sediments back to the late Eocene, yet these deposits are notoriously difficult to interpret. Reworked older diatom taxa in younger deposits are ubiquitous in Antarctic marine sediments and constitute a complicating factor for classical biostratigraphic application. However, the occurrence of mixed microfossil assemblages provides a new opportunity for interpreting glacial sedimentary processes by evaluating stratigraphic mixing (Sjunneskog and Scherer, 2005). Diatoms in glacial sediments can further direct interpretation of diamictons based on patterns of preservation. Laboratory analysis of diatom fragmentation under compaction and shearing, mimicking glacial or sediment overburden and basal shearing, respectively, allowed the development of an index of subglacial shearing, greatly aiding the interpretation of depositional conditions on the Antarctic continental shelf and beneath the West Antarctic Ice Sheet (Scherer et al., 2004). These new tools will enhance interpretation of ANDRILL sediments.

**4.3.3.3** Foraminifera

Percy Strong (PS, On-Ice), Martin Crundwell (MC, Off-Ice)

Foraminifera are microscopic (mostly <1 mm in size) protozoans that form a calcium carbonate test or one of cemented sand grains or other material (agglutinated). As a group, they occur in all marine planktic and benthic environments, spanning the entire range of salinities, temperatures, and depths. Each combination of these environments tends to have a characteristic association of foraminiferal taxa. Planktic, and to a lesser extent, benthic taxa are often useful for determining the geological age of strata.

Study of two surface sediment cores from beneath the McMurdo Ice Shelf (HWD Sites 1 & 2) (Barrett et al., 2005) has shown that the MIS core is likely to contain a good foraminiferal record, and this is supported by recovery of a rich Pleistocene fauna in the CRP-1 drillhole (Webb & Strong, 1998). In general, foraminiferal study is considered more likely to contribute to identification of major environmental change events than to biostratigraphic dating of the drilled sediments, due to poor representation of age-diagnostic planktic taxa at high latitudes. However, highest occurrence of the benthic foraminifer, *Ammoelphidiella,* approximates the Pleistocene/Pliocene boundary, and a few planktic bioevents may also be recognized.

Study of foraminifera On-Ice will be directed primarily at core characterization, and at preliminary identification of first-order paleoenvironmental changes. These changes could include calving-line transits and changes from polythermal to cold glaciation, both of which should have distinctive faunal signatures. Core characterization results would also serve to delineate critical sections of the core for future study.

Both “spot” and “fixed-interval” samples will be analyzed. Spot samples are selected for immediate examination from lithologies considered the most likely to be fossiliferous. Fixed-interval samples would be taken every five meters without regard to lithotype, and reserved mainly for later (Off-Ice) study. On-Ice examination would be on a time-available basis. Collection of fixed-interval samples would be contingent on sampling team workload and the interval could be varied as appropriate, based on the observed core.

Faunal study will focus on compiling faunal lists, and determining the relative abundances of major groups, i.e., planktic--calcareous benthic--agglutinated benthic. Weights of samples and resultant residue also would be recorded. A throughput of 3-5 samples per day is estimated. Results of this work would be presented in the On-Ice and Initial Reports, and would serve to identify the most productive avenues of further research.

Foraminiferal analysis will require relatively large samples, ca. 40 cc (c. 5 cm of quarter-core). Consequently, the sample interval will need to be fairly wide. We anticipate a sample interval of approximately every 5 m (or otherwise as appropriate). Fine and course (picked) residues will be available for petrographic, geochemical or other microfossil analysis.

PS and MC will continue with foram studies Off-Ice, assuming that suitable materials are recovered, Off-Ice studies by PS will include further taxonomic description, quantitative faunal analyses, and integration of fauna with facies and sequence architecture. If abundant and suitable taxa are found then collaborations with geochemists for stable carbon and oxygen isotope and Mg/Ca analyses are anticipated. Also material will be made available for strontium dating of the cored interval, especially where mollusks are lacking.

Work Off-Ice by MC will include primary quantitative study and will focus on counts of major foraminiferal groups (i.e., planktic, calcareous benthic, and agglutinated benthic) standardized by weight "BIOLOGS" and thorough picks of residues to identify important environmental and age indicators to detail the stratigraphic distribution of taxa, interpret depositional environments, and develop a robust chronostratigraphic framework – important prerequisites for understanding the Plio-Pleistocene history of the Ross Ice Shelf.

The BIOLOG approach to foraminiferal biostratigraphy distinguishes between productivity and sedimentary signals, identifies expanded and condensed sections, and provides estimates of relative rates of sedimentation that can be used in conjunction with similar data, from other fossil groups. Results are used to characterize sedimentary facies and refine core chronology by interpolating ages more precisely between dated horizons (biostratigraphic datum levels, tephra horizons, magnetostratigraphic reversals, and geochemical datum levels) identified during the initial core characterization and post core characterization phases of the MIS Project. This work complements that of the On-Ice team. Core characterization results will also provide accurate stratigraphic distribution and preservation data for foraminifera, especially calcareous taxa, the availability of which will have a significant bearing on future geochemical proxy studies.

Fixed-interval samples for study (Off-Ice team) would be taken every 2-4 m without regard to lithology, in order to establish a BIOLOG framework for spot samples examined by PS (On-Ice), from lithologies considered most likely to be fossiliferous. Collection of fixed-interval samples could be varied as appropriate based on the observed core and sampling team workload. A throughput of 6-10 samples per day is estimated. The initial results of this work would be presented in daily/weekly reports and in the On-Ice and Initial Reports, and would serve to identify the most productive avenues of further research.

Assuming that suitable materials are recovered, Off-Ice studies will include further taxonomic description, quantitative faunal analyses, and integration of fauna with facies and sequence architecture.

**4.3.3.4** Acid Insoluble/Organic-Walled Microfossils

Mike Hannah (MH, On Ice), Erica Crouch (ECr, Off-Ice), Ian Raine (IR, Off-Ice)

Acid insoluble remains of microscopic marine flora and fauna includes dinoflagellate cysts, acritarchs, prasinophyte algae and zooplankton, including egg cases. Terrestrial palynomorphs include spores and pollen. Although a taxonomically variable group, palynomorphs have proved useful for biostratigraphic and environmental studies at various high latitude sites including the CRP and ODP drilling in Prydz Bay.

Based on previous drilling and work on sea floor samples the MIS Project core is likely to contain a good record of marine palynomorphs. We expect to see assemblages containing a diverse set of fossil groups including fossil dinoflagellate cysts, prasinophyte algae, acritarchs and zooplankton. Experience gained from the CRP and work on sediments from Prydz Bay has shown that marine palynomorphs are likely to be recovered from a wide variety of lithofacies, even where other fossil groups are absent.

A good record of fossil dinoflagellate cysts could contribute significantly to the biostratigraphy. In post Miocene sediments, comparisons with New Zealand and ODP sites could add to the age model. Should Miocene sediments equivalent to the upper part of Cape Roberts be encountered then the entire marine palynomorph assemblage will be critical to our understanding of the age of the section.

Our understanding of the environmental significance of fossil marine palynomorphs has increased significantly since the CRP, mainly through comparisons with modern Arctic assemblages and analysis of the palynomorph content of modern sea floor sediments from Prydz Bay. We expect to see changes in water masses and ice cover reflected in shifts in the overall Marine Palynomorph assemblage. We expect to document any large scale assemblage changes and interpret them during the drilling phase.

The combination of simultaneous study On-Ice and Off-Ice studies at home institutions (see below) is aimed firstly at core characterization, and the documentation of large scale changes in palynomorph assemblages. These assemblage variations will be interpreted in terms of water-mass and climate changes. It is expected that changes in water circulation, ice cover, and temperature should produce distinctive floral signatures. Spot samples are required. These should be taken on average every 5 meters in fine-grained lithologies.

Off-Ice studies will include further taxonomic description, quantitative faunal analyses leading to a detailed paleoenvironmental interpretation for the site. Changes in assemblages will be correlated with facies and sequence architecture. A dinocyst biostratigraphy has been suggested for the Cape Roberts sequence, and this will be important should we encounter similar age material.

No palynological processing is planned on the ice. All samples will be sent back to New Zealand where Geological and Nuclear Sciences (GNS) staff will process them. Some of the resulting slides will be returned to Antarctica for examination by MH. The remainder will be examined in New Zealand by EC/IR.

#### **4.3.3.5** Macropaleontology

Marco Taviani (MT)

Macrofossils are small to large metazoans (mostly > 1 mm in size) many of which are equipped with a calcium carbonate skeleton. As a group, they are ubiquitous in the marine realm and are well represented in the Antarctic region. Macrofossils have proven to be an excellent group to reconstruct past environments and may have biostratigraphic significance. At times macrofossils are valuable material for dating purposes ($^{14}C$, U/Th, amino-acid etc.). Finally they may serve as archives to unravel past salinities, temperatures, nutrients etc. by decoding geochemical signals within their mineralized skeletons.

Experience gained through the CRP lends support to the hypothesis that core recovered during the MIS Project may contain a significant macrofossil record (Taviani and Beu, 2003). In particular, a biogenic-carbonate unit in CRP-1 was almost completely made up by benthic and, subordinately, planktic fossils (Cape Roberts Science Team, 1998; Taviani and Claps, 1998), including a substantial amount of molluscs, bryozoans and other metazoan groups (Taviani et al., 1998). In general, macropaleontological studies may contribute to an independent reconstruction of past marine environments and, to a lesser degree, their age (Taviani and Beu, 2003). They will also provide the most suitable material for radiometric dating, as well as for geochemical studies whose importance should not be neglected for high-resolution climatic assessment (Taviani and Zahn, 1998; Taviani et al., 2006).

Study On-Ice will be directed primarily at core characterization, to provide first-hand environmental data and to assist sedimentological reconstructions. Faunal study will focus on compiling faunal lists and on selecting the most promising material for subsequent dating and/or geochemical studies. Results of this work will be presented in the On-Ice and Initial Reports*,* and will serve to identify the most productive avenues of further research.

All core sections containing macrofossils will likely be sampled. Initial work will focus on taxonomic evaluation. Secondary efforts will include paleoenvironmental assessment, biostratigraphy, dating, and geochemical studies. Environmental information provided by macrofossils will be made available to the sedimentologists. At times, layers that are potentially but not obviously macrofossiliferous may be considered for spot samples. To help identify these layers, MT will examine coarse sample residues provided by other members of the MIS Paleontology Team.

Sediment encased within mollusc and other shell cavities often exhibit unusually fine preservation of other microfossils, due to reduced thoroughflow of porewaters. Care will be taken to remove matrix sediments for further analysis without destroying important macrofossil material. Many macrofossils potentially contain paleoceanographic (isotopic, trace elemental) or geochronological ($^{87}Sr/^{86}Sr$ dating) tracers. Samples for these geochemical studies will be recovered during drilling, but these analyses will predominantly be performed during post drilling research.

Off-Ice follow-up research will include a) taxonomic composition of Antarctic mollusc and coral faunas and related evolutionary and biogeographic implications in the late Cenozoic of the Southern Ocean; b) reconstruction of former environments based upon macrofossils; and c) evaluation of past water mass attributes through geochemical signals that are encoded within pristine carbonate exoskeletons (Taviani et al., 2006). Refined

taxonomic work on the different macrofossil groups will likely require cooperation with various specialists not yet identified in the MIS Project Scientific Team.

Molly Miller will work with MT to compile information about biogenic structures, taphonomy, and fossil species to reconstruct pictures of the benthic communities at different times, and relate these to modern communities. MM is particularly interested in: a) biogenic structures - what animals are producing them and the distribution of those animals today; b) the relationship between soft-bodied, primarily infaunal animals, and those that are sessile and/or have hard parts; and c) what happens to skeletal parts after death, including ophioroid and asteroid plates, sponge spicules, and isopod skeletons. She will relate her taphonomic experiments to the lithostratigraphic record in the core.

Main requirements for macropaleontological work are a workbench and sink with H/C water for sample preparation, and a desk for microscope work. Equipment provided through ANDRILL would include binocular microscope with lights, camera and adaptor, desktop PC, wet sieves, hotplate and drying oven. MT will supply small tools to prepare fossils. There are no major safety issues related to the sample preparation and examination of macrofossils.

Likely collaborators include sedimentologists, biostratigraphers and geochemists working on carbonate shell. It is anticipated that Mollusca might represent a prominent group and the cooperation with other experts as anticipated. Studies of bioturbation and fossil degradation will be in collaboration with MM (Off-Ice), following protocols established by Miller and Smail (1997) and Bottjer and Droser (1994).

#### 4.3.4 Geochemistry/Petrology

During the On-Ice activity, the Geochemistry/Petrology Discipline Team will focus mainly on compositional and textural characterization of coarse glacigenic sediments and on the description and characterization of volcaniclastic layers and tephra. Finer sediments (< 2 mm) will be described from a textural and lithological point of view by Sedimentology-Stratigraphy team members, while the XRF core scanner will provide high-resolution relative element concentrations on the split core surface (section 4.3.1). Further detailed studies by both teams are planned Off-Ice. Pore fluid sampling and analysis will be performed On-Ice by Stefan Vogel with support from Chieh Peng (section 4.3.5).

The terrigenous component of sediments cored at the MIS site are derived from either the Transantarctic Mountains (TAM) located to southwest and west of Ross Island, or the Late Cenozoic volcanoes forming the McMurdo Volcanic Group, including Ross Island to the north and White Island to the south. The TAM comprise a basement of Late Precambrian- Early Paleozoic metasediments and granitoids overlain by Devonian quartz sandstones and Permian-Triassic coal-bearing strata of the Beacon Supergroup, followed by Jurassic Ferrar Dolerite and Kirkpatrick basalts of tholeiitic affinity. McMurdo volcanoes surrounding the MIS Project drill site show distinctive age, eruptive styles and alkalic magma compositions. Older volcanoes (Mt. Discovery, Minna Bluff, Black and White Islands, Mt. Terror, Mt. Bird, and Hut Point Peninsula) are all basaltic shields (Kyle, 1990) fed by magma belonging to the DVDP lineage (mineral assemblage made of feldspar, olivine and kaersutite) defined by Kyle (1981), whereas products of the younger Mt. Erebus strato-volcano are more evolved and are mainly anorthoclase-phonolites.

An *in situ* macroscopic analysis and log of all clasts from granule to boulder grain class in the MIS Project core will be carried out Franco Talarico (FT). Shape and surface features will be described, followed by sampling and petrographic examination of thin sections of selected basement clasts (about 10-15 per 100 m). This will help discriminate between different lithologies and improve lithological determinations and attribution. Preliminary data processing will include summaries of size, shape and relative abundances all major lithologies. These data will provide constraints on quantitative provenance models.

On-Ice investigations of volcaniclastic layers will be aimed at recovering information on composition, grading, internal sedimentary structures, grain size, internal organization and geometry. These data are crucial for reconstructing the mode of emplacement and post-depositional history of the deposits. Textures of volcanic deposits (McPhie et al., 1993) reflect both processes related to eruption and emplacement and also successive modification by both syn-volcanic and post-volcanic processes. It will be important to determine whether volcanic layers are undisturbed pyroclastic or autoclastic deposits (primary deposits), or are related to resedimentation coeval with, or independent of, eruptions. The role of weathering, erosion and reworking of primary volcanic deposits will be assessed. This distinction is important for dating and possible correlation with other volcanic deposits in the area, for the reconstruction of the magmatic evolution of volcanoes, and for an assessment of magma production rate.

Structures, internal organizations, and geometry of volcaniclastic layers will mainly be described and characterized by Thom Wilch (TWc) (Sedimentology/Stratigraphy Discipline Team) during the core logging activity. Preliminary compositional analysis and petrographic and textural characterization, will be undertaken by Phil Kyle (PK) and Massimo Pompilio (MP) in CSEC based on thin section and smear-slide examination, microscopic observation of clast morphology and sieving. Samples will also be sent to Off-Ice labs for preliminary analyses for chemistry and chronology of critical volcanic layers (whole-rock, minerals and/or glass). PK and TWc will be primarily responsible for the selection of up to 10 samples for argon dating to be sent to Bill Mackintosh's lab at New Mexico Tech. MP will select an initial suite of samples for geochemical characterization to be sent Ricardo Vannucci's lab in Pavia.

Any significant volcanic units in the core and, in particular. all recognizable primary tephra layers, lava flows or subvolcanic bodies will be sampled (50 cc) for textural and petrological investigation. Large clasts of volcanic rocks will be also sampled systematically through the core, up to a maximum of about 100 samples between 100-500 grams in size. In case of thick and monotonous tephra succession a reasonable representative number of samples (e.g. 2-3 per meter), will be collected.

ARISE Participants Matteo Cattadori and Julian Thomson will each spend one month working with members of this Discipline Team.

### 4.3.5 Microbiology and Porewater Geochemistry

**4.3.5.1** Overview

Kevin Mandernack (KM) will characterize microbial life and microbial processes in the sediment core recovered at the MIS Project drill site. For KM the upper 20 m is the most essential part of the core. Desired sampling intervals are continuous sampling (0.1 m) in the upper 1 m, 25 cm from 1 to 2 m, 50 cm from 2 to 5 m, and 1 m sampling intervals from 5 to 20 m. Sampling intervals between 10 m and 100 m should be 20 m and sampling intervals below 100 m should be 30m at minimum.

KM will conduct both bacterial lipid analyses and DNA analysis. It is expected that gradients in microbial life and geochemistry of porewaters is greatest in the upper 1 m, and decreases with depth. For study of diffusion processes over the time scale of the most recent deglaciation to the last glacial cycle the upper ~20 m are of most interest.

Slawek Tulaczyk (ST) will model evolution of porewater and sea/subglacial water history at the MIS Project drill site based on constraint from vertical distribution of porewater chemistry in the MIS Project core. For this work ST requires acquisition of porewater at high sampling intervals (0.1 to 1 m) in the top 1 to 10 m, and at greater sampling intervals (10 to 100 m) in the remainder of the core. ST is especially interested in determining stable isotope composition of porewater as well as chlorinity and sulfate concentration. In addition to this minimum analytical work, routine porewater measurements should satisfy IODP standards and include measurements of pH, alkalinity, major cation, anion and trace element (see Gieskes et al. 1991, for range of analytical work conducted on ODP legs).

Stefan Vogel (SV) has proposed to decipher climatic and environmental changes and ice sheet evolution from a carbonate stratigraphy. SV's work is divided into (a) obtaining a continuous carbonate stratigraphy along the MIS Project core, and (b) investigating diagenetic processes influencing the stratigraphic record. The proposed work includes routine measurements of inorganic and organic carbon in bulk sediment (On-Ice), isotopic composition and geochemical analysis including major and trace element composition of bulk carbonate, carbonate nodules and pebble coatings (Off-Ice), study of physical and structural characteristics of individual carbonate deposits using petrographic microscope and SEM (Off-Ice); and, in collaboration with ST's stable isotope work, collection and measurement of the geochemical composition of porewater fluids (On- and Off-Ice).

ARISE Participants LuAnn Dahlman and Betty Trummel will each spend one month working with members of this Discipline Team.

**4.3.5.2** Guidelines for Sampling and Processing

**Gravity Cores**

We anticipate recovering several short (<1.5 m) cores in early October prior to deployment of the sea-riser using a gravity-coring device provided by the Alfred Wegener Institute (AWI). The primary objective of this coring phase of the MIS Project is to obtain core for microbiological and porewater geochemistry studies. If only one core is successfully recovered then continuous samples from this core will be provided to KM and SV. Sample sizes required for microbiological analyses are: 0-0.5 m (55 g), and 0.5-1.5 m (105 g). Whole round samples will be

collected using the following possible methods: (a) whole round samples are sliced off with a knife as core is extruded using the AWI extrusion device and samples are bagged, (b) core liner is cut with a liner cutter, sediment is sliced through with a knife or wire, and the lined whole round sections are capped and sealed.

If more than one core is recovered whole core sections may be capped and preserved for stratigraphic analyses. Additional sections may be capped and sampled for porewater using rhizon sampling equipment.

**Primary ANDRILL Core**

During “primary” ANDRILL core recovery, a maximum of one sample may be allowed from the upper 10 m (contingent on CCS approval). Sampling intervals between 10 m and 100 m should be 10 m and sampling intervals below 100 m should be 30 m minimum. In the event that redeployment of the ANDRILL system is possible, following completion of the primary hole, continuous sampling (0.1 m) in the upper 1 m, 25 cm from 1 to 2 m, 50 cm from 2 to 5 m, and 1 m sampling intervals from 5  to 10 m is desired.

Microbiological samples will be taken at the drill site (see section 4.2.3). KM requires both sediment sample for microbial analyses and access to key porewater data. Porewater data must be collected from samples adjacent to those collected for microbial analysis. Sample sizes required for microbiological analyses are: 5-20 m (105 g), below 20 m (10 g). Note that KM is primarily interested in “soft” sediment and is unable to conduct his work once core becomes lithified. Required whole round sample size (core length) for porewater analysis is dependent on porosity and core diameter. For example, a 6 cm whole core disk is required for core with 50% porosity and a 16 cm whole core disk is required for core with 20% porosity. For soft-sediment cores (in liners), it is recommended that a lower porosity value be assumed and a 16-20 cm slice obtained.

Time critical work includes the extraction and processing of porewater samples and the sub-sampling of sediment for biological work. Microbiological samples should be collected within 1 hour of core retrieval. Access to the MIS Project core at the drill site is required for microbiological sediment sampling, but not porewater sampling. Microbiological sampling of soft-sediment will be undertaken after a low-resolution MST core scan has been conducted to establish core continuity and ensure a complete suite of physical properties is collected. This will occur within 0.5-1 hr of the core barrel arriving at the rig floor. One meter lined lengths deemed appropriate for whole core porewater samples will be placed in a sealed temperature controlled container for “fast-track” transport to the CSF at McMurdo Station where samples will be taken immediately by the curators in consultation with a CCS. Suitable sections of the lithified core will also be identified at the drill site by the core technician and put in a sealed temperature controlled container for transport to McMurdo and subsequent sampling. Again the sample will be taken under the supervision of a CCS. Access to the drill site, and activities at the drill site will be arranged between the DSM and a CCS. It should be noted that sampling might require working flexible shifts, being flexible in terms of the daily drilling operation and possibly sleeping at the drill site camp. Sample selection criteria for sampling both lined and lithified cores will be agreed jointly between the head core technician and a CCS. In general the core sampling will follow the following principals: (a) no sampling of lithological contacts; (b) samples will be taken in the center of “thickish” lithologically homogenous units; (c) in the case of porewater samples these should be taken as much as possible from “thickish” diamicts; and (d) when possible, porewater samples from lined intervals will be taken after liner has been removed.

### 4.3.6 Chronostratigraphy and Geochronology

A robust age model for the MIS Projectcore will rely on the integration of several data sets; biostratigraphy (diatoms, foraminifers, nannofossils, palynomorphs), chronostratigraphy (paleomagnetism, cyclostratigraphy, $^{87}Sr/^{86}Sr$), and radiometric ($^{40}Ar/^{39}Ar$, ITPFT) or cosmogenic dating methods ($^{10}Be/^{26}Al$, PSL). While drilling is underway, however, initial age model development will rely mainly on biostratigraphy and the remainder of the On-Ice task will be the careful selection of specific samples for subsequent analysis. Additional information may be available from the Sedimentology/Stratigraphy Discipline Team through the recognition of disconformities and/or unconformities in the stratigraphic succession.

#### **4.3.6.1** Immediate On-Ice Age Model

As age relevant data becomes available in collaboration with the Paleontology and Sedimentology Discipline Teams, a working age model will be compiled and refined to assist the CCSs in progress and target assessment. The primary task will be to identify age ranges for stratigraphic subdivisions of the cored succession. The recognition of breaks in deposition/preservation will require combined sedimentologic and biostratigraphic/ chronostratigraphic information with primary emphasis, initially on biostratigraphic occurrence datums and zones. Results will be presented as an age-depth plot showing constraining datums, range of possible age and, where possible, error margins.

**Biostratigraphy – On-Ice Procedures & Sampling**
Outlined in Section 4.3.3

**Paleomagnetism – On-Ice Procedures & Sampling**
On-Ice sampling will be conducted by Gary Wilson and Fabio Florindo, with technical support from Christian Ohneiser.

Oriented standard discrete paleomagnetic samples (8 cc plastic cubes or 11 cc drilled cylinders depending on core consistency) will be collected, where possible from fine-grained undisturbed horizons at 1-2 m intervals. Samples will be collected from the working half of the MIS core and oriented with respect to up-core direction and with respect to the core orientation scribe line. Paired sampled (separated by a few cm stratigraphically) will be collected from varying lithofacies every 10-20 m down core for a pilot study to assess the most suitable demagnetization technique for routine treatment of the remaining samples.

Samples will be collected by: a) pressing plastic cubes into the split face of the working half of the core and the up-core direction marked and angle between the split face and core orientation scribe line recorded; or b) by drilling into the face-down working half of the core and the up-core direction marked and angle between the core orientation scribe line and the center line of the sample recorded. Once collected, samples will be put into plastic bags with the core depth/sample label on them and stored in a mu-metal shield.

NRM will be measured on each sample using a Molspin minispin magnetometer and high and low frequency magnetic susceptibility measured using a Bartington MS2 meter. Samples will then be shipped to New Zealand in mu-metal boxes and polarity determined using the 2G cryogenic magnetometer in the shielded room at the Otago

University Paleomagnetism Laboratory. Pilot samples will first be demagnetised using both thermal and AF methods and the remainder of samples demagnetised using the appropriate method. Data will be returned to the On-Ice paleomagnetism team as it becomes available for incorporation into the On-Ice chronostratigraphy report. Following the drilling season, discrete samples will be transported to the respective paleomagnetic laboratories at the Isituto Nazionale di Geofisica e Vulcanologia, Rome (INGV), and Otago University, Dunedin, New Zealand.

*NB – exposure of the core to magnetic fields associated with ferrous materials should be minimized, especially for extended periods (such as during core transport or storage).*

ARISE Participants Julian Thomson and Matteo Cattadori will each spend one month working with members of this Discipline Team.

**$^{40}Ar/^{39}Ar$ – On-Ice Sampling**

At least ten samples will be selected from the MIS Project core for $^{40}Ar/^{39}Ar$ analysis. Sample interval will be dependent upon the occurrence of suitable material, however, a broad distribution of samples is preferred to provide the best overall geochronological constraints for the core. The ideal material is silicic volcanic ash containing abundant potassium feldspar phenocrysts. Typically a few tens of grams of ash would be required to produce enough potassium feldspar mineral separate to yield precise and accurate age data. If silicic volcanic ash is not encountered, other potential dating materials include intermediate or basaltic lava, volcanic ash or clasts of reworked volcanic material. In most cases, a few grams of material should be sufficient for $^{40}Ar/^{39}Ar$ analyses.

**Photon-Stimulated-Luminescence (PSL) – On-Ice Sampling**

Three core characterization samples will be extracted from the upper part of the MIS core (<200 kyr). Sixty ml and 15 ml samples will be collected in a controlled light environment by a designated and suitably trained technician. Samples will be extracted from the centre of the working half of the core from sandy (60-300 microns) horizons with potential eolian influence in sand transport. Proximity to horizons with reliable alternative age data (such as tephra, polarity reversals, or well constrained biostratigraphic indicators) is desirable at this initial core characterization stage.

*NB – Sample material should not be exposed to x-rays*

**$^{87}Sr/^{86}Sr$ – On-Ice Sampling**

Where *in-situ* unaltered calcitic shell material is identified in the working core half by the On-Ice macro paleontologist, it will be retrieved for $^{87}Sr/^{86}Sr$ analysis.

**4.3.6.2** Immediate Post-Drilling Analyses

**Paleomagnetism – Polarity Stratigraphy**

Once discrete sample demagentisation has been completed at Dunedin and Rome labs, the resulting magnetic polarity record will be subdivided into magnetozones, where magnetozones are defined as intervals with multiple, consecutive samples with inclinations that are distinctly different from neighboring intervals and with clearly defined normal or reversed polarity. Magnetozone boundaries are generally placed at the midpoint between successive samples of opposite polarity or at a lithological contact or visual disconformity that separates such samples. Magnetozones will be labelled progressively downcore according to polarity.

**$^{40}Ar/^{39}Ar$ - Analysis**

$^{40}Ar/^{39}Ar$ studies will be conducted in the New Mexico Geochronological Research Laboratory (NMGRL). On return to NMGRL, samples will be characterized to assess suitability for dating using the Cameca SX-100 electron microprobe at New Mexico Tech and mineral separates prepared for irradiation. Argon analyses will be undertaken using the MAP-215-50 mass spectrometer at NMGRL and results should be available in time for the Post-Drilling Core Workshop at Florida State University.

**Photon-Stimulated-Luminescence (PSL) - Analysis**

Once core characterization samples are returned to the laboratory 'darkroom' in Reno, NV any daylight-exposed outer surfaces of the samples will be prepared for elemental (U, Th, K) analyses. The daylight-shielded fraction will be treated in the darkroom with HCl acid to destroy carbonates, then dried for sieving into sand fractions in the range 100-300 um diameters. Fractions smaller and larger than this approximate range will be archived. Following magnetic separation, the non-magnetic fraction will be HF-acid treated to destroy any feldspars (Aitken, 1998). Selected grain-size subfractions of probable quartz (at least a few hundred mg are required) will be prepared for single-grain photon-stimulated luminescence (PSL) dating analyses (e.g., Boetter-Jensen et al., 2003) using automated, scanning-laser PSL instrument systems made in Denmark (Boetter-Jensen et al., 2003).

**$^{87}Sr/^{86}Sr$ – Analysis**

$^{87}Sr/^{86}Sr$ analyses will be carried out at a reputable TIMS or LAMS system, probably at VIEPS (Melbourne, Australia) either collaboratively or semi-commercially. High precision data ($<=0.0022\%$ $2\sigma$) will be compared with the LOWESS smoothed 'look-up' tables of McArthur et al. (2001) to yield ages with a theoretical resolution of ±0.2-0.3 Ma for most segments of the Cenozoic paleo-seawater curve.

**4.3.6.3** Preliminary Age Model

Once immediate Off-Ice analyses are completed, the chronostratigraphic data is likely to include biostratigraphic data (FO, LO, range and zone picks for diatoms, foraminifera, nannofossils & palynomorphs), magnetic polarity data, radiometric ages ($^{40}Ar/^{39}Ar$ and $^{87}Sr/^{86}Sr$) and environmental information (e.g. depositional cyclicity). Limitations on the data sets will include the need to correlate with another timescale, environmental controls, reworking or formational versus depositional ages. We will hold a workshop immediately preceding the Post-Drilling Core Workshop at FSU to integrate the data sets and discuss errors and limitations and standardize approach. Where possible we will employ a graphic correlation process (such as CONOP) to link into databases to optimize the age model and highlight intervals where data coverage is temporally limited. Magnetic polarity and cyclostratigraphy will be employed where possible to refine the chronology of specific intervals.

**4.3.6.4** Ongoing Chronostratigraphic Work (Off-Ice)

The Chronostratigraphy Discipline Team will undertake more detailed sampling and focus on specific intervals of need following compilation of the initial age model for the Initial Report and Post-Drilling Core Workshop.

Beyond more detail and focused sampling depending on need, new tasks that are planned for the Off-Ice phase of the MIS Project include the following: (a) Isothermal Plateau Fission Track (ITPFT) analysis will be attempted on the glass phases of the ash (where silicic volcanic ash does not contain potassium feldspar phenocrysts,)

Success of this technique depends on optimal glass shard size (> 250 microns), low vesicularity, and absence of microlitic and/or detrital grains; (b) Paleointensity & secular variation studies to increase the resolution of the age model and global model of paleointensity and secular variation in the Brunhes Normal Chron (last 780 ka); (c) Detailed environmental magnetic measurements to help define erosion, transport and depositional process models and cyclicity; (d) Cosmogenic isotope analysis ($^{10}Be$ & $^{26}Al$) to determine burial ages for the cored sediment as well as linkages to landscape erosion.

Specific sample requirements and approaches will be addressed once the core recovery record and material is obtained.

**4.3.6.5** Composite Standard Event Database

Application of a newly developed high-resolution Composite Standard Database (CSD) provides a powerful tool to help meet ANDRILL's science objectives. Integration of new stratigraphic data developed by the MIS Project Science Team into the CSD will allow us to: (a) evaluate new data and provide real-time feedback to project scientists both on and off the ice, (b) develop an integrated age – depth model for each core, (c) identify condensed intervals and unconformities to aid sequence stratigraphic interpretation and tie cores to the regional seismic network, (d) develop correlation models for local, regional, and global reference sections.

Compilation of the database was achieved using CONOP-9, an automated multidimensional graphic correlation tool (Sadler, 2001, 2004) that operates under constrained optimization (Kemple et al., 1995). The composite standard database (CSD) currently includes first and last appearance datums for over 95 Miocene-Recent diatom taxa. The age of the CSD has been calibrated using 52 paleomagnetic reversal datums and 2 ashes (Cody, 2006).

As new stratigraphic data become available during the ANDRILL MIS Project, they can be incorporated into the CSD simply by adding a new section file to the CONOP-9 program and running a new correlation analysis.

Adding new stratigraphic data to the CSD through CONOP-9 can allow a stratigrapher to:
(a) Evaluate new data (e.g. identify incomplete ranges and possible reworking in the ANDRILL core).
(b) Develop an age – depth model for each new section (core).
(c) Develop correlation models for local, regional, and global reference sections.
(d) Increase the reliability and biogeographic coverage of the database.

Richard Levy, James Crampton, Rosemary Cody, and David Harwood (in collaboration with members of the Chronostratigraphy and Paleontology Teams) will integrate new stratigraphic data gathered from the MIS Project core into the CSD. The CSD and CONOP-9 provide an effective and efficient mechanism to quickly integrate and evaluate multiple stratigraphic data sets. Data that could be incorporated include biostratigraphic (with a focus on first and last occurrence datums of marine diatoms), magnetostratigraphic, chemostratigraphic, and dated volcaniclastic events (fall tephra and pyroclastic flows).

Age control for the ANDRILL cores will likely initially come from an integrated diatom biostratigraphy and magnetostratigraphy. Other fossil data will be collected by members of the MIS Project Science Team and could be incorporated into an age model if appropriate. Proximity of the MIS Project drill site to Ross Island and White

Island ensures that volcanic sediments (pyroclasts and fall tephra) will be prevalent in the core. Integration of highly precise ages derived from radiometric dating of the volcanic material will improve the accuracy of the CSD. Application of the CSD to the MIS Project core will help establish an age model that is based on a fully integrated regional dataset.

**Correlation of ANDRILL Cores to Regional and Global Records**

A robust and precise chronostratigraphic correlation tool is required to meet scientific objectives for the MIS Project. For example, paleoenvironmental records of important climatic events that characterize end-member climate states (e.g. Pliocene Climatic Optimum) will be examined at locations throughout the McMurdo Sound region where stratigraphic overlap between existing records and newly recovered ANDRILL records occurs (see figs. 6 and 7 in Harwood et al., 2005). Precise correlation of new records to existing drill core and outcrop (e.g. Dry Valley Drilling Project – 10, 11, and 15, CIROS-2, Prospect Mesa) will be critical if accurate paleogeographic reconstructions are to be established. Correlation of the MIS Project core to the regional seismic network will provide critical chronostratigraphic control for seismic sequences across the Victoria Land Basin and western Ross Sea. Stratigraphic age-depth models produced from CONOP analyses can precisely identify condensed sections and unconformities in the MIS Project core. These stratigraphic intervals can be correlated to regional unconformities and/or sequence boundaries identified in seismic lines.

One of the ultimate goals of the ANDRILL Program is to integrate local climatic and tectonic event history identified from locations proximal to the Antarctic continent (and the ice sheets that cover the continent) to global event histories. For example, one of the major goals of the MIS Project is to examine Ross Ice Shelf fluctuation and relate any variability to changes in thermohaline circulation expressed by variation in Pacific inflow interpreted from ODP cores along the eastern edge of New Zealand (Naish et al., 2005; Carter et al., 2004). This goal requires highly resolved and precise correlation to extra-Antarctic reference sections that can be achieved through refined chronostratigraphic age control provided by iterative development and application of the CSD.

**4.4 Dealing With the Unexpected**

If age intervals, lithologies and/or features are recovered in the MIS Project core that were not expected (not covered in this document) the following procedure will be followed. If the discovery is purely scientific without immediate health and safety implications then the sample committee (CCSs, DTLs, Curator's and SS), DSM and APM will meet and discuss how to deal with the discovery. This will involve a decision making process that addresses the following questions:

- How does the discovery affect the science plan and science priorities?
- Will the discovery lead to abandonment or repositioning of the hole (negative discovery)?
- Does taking advantage of the discovery impact on the science priorities agreed to by the science team (positive and negative discovery)?
- Does the pursuit of the discovery (for example drilling deeper) require a change to the drill plan (positive discovery)?
- Does the discovery (for example drilling deeper or drilling another hole) have budget implications?
- Does pursuit of the discovery have potential safety/risk implications?
- Does the pursuit of the discovery (for example drilling a terrestrial sequence) have implications for the expertise needed in The Science Team?

An amendment to both the science and operations plan will be made in consultation with AOMG and M-ASIC. This could involve abandoning drilling in a worst case scenario or could simply require a change in scientific procedures to allow additional analyses or a suite of samples to be taken.

## 4.5 OFF-ICE SCIENCE

### 4.5.1 Summary

Off-Ice science responsibilities are summarized in Table 2 and were compiled from original application proposals submitted by STMs. We have not gone into a lot of specific detail regarding Off-Ice science in this SLIP, as the direction for Off-Ice research will become clearer after drilling is completed and the Science Team has met at the Post-Drilling Core Workshop at FSU. All STMs will submit a one-page description prior to the core workshop explaining their plans and proposed collaborations for Off-Ice research (see 4.6)

## 4.6 POST-DRILLING SCIENCE ACTIVITIES

### 4.6.1 Revised Science Proposal

Following core recovery and prior to the Post-Drilling Core Workshop, STMs from ALL nations will be required to submit a modified research plan, based on the post-drilling project science plan (as revised by the CCSs), to request additional samples.

*Note:* US participants will submit proposals for additional funding. A panel convened by the Joint Oceanographic Institutions (JOI) will review these proposals. Additional samples will be distributed upon approval of supplemental funding.

### 4.6.2 Post-Drilling Workshop

A Post-Drilling Core Workshop will be held at Florida State University, Tallahassee, FL between May 1st and May 4th, 2007. Both On-Ice and Off-Ice STMs will attend (including ARISE Participants). Core material will be displayed during the workshop to allow both On-Ice and Off-Ice STMs to revisit the raw material. Results of the drilling and sample analysis to-date will be reviewed and further adjustments made to the science plan. Each member will submit papers or extended abstracts and figures/tables for distribution at the workshop and inclusion in the Initial Results Volume.

Workshop members will identify sample locations by noting appropriate positions on printed core images. The Sample Committee will review proposals for the science documentation phase that involve requests for additional samples. Approval of additional samples is contingent upon submission of a report for the Initial Reports Volume. Upon approval of the secondary sampling requests, the FSU curators will sample the cores and send the samples to the investigators. Sampling procedures will be similar to those outlined in section 3.3.4.4.

A workshop announcement with dates, accommodation and program will be sent out by the SMO in early March, 2007.

# 5. REPORTING AND PUBLICATION

## 5.1 PLANNING DOCUMENTS

The concept of ANDRILL advanced at an international workshop held at the University of Oxford in 2001, the results of which are reported in a comprehensive science workshop report (Harwood et al., 2002). The ANDRILL International Science Proposal (AISP) was written by proponents of drilling projects, members of National Steering Committees and the ANDRILL Science Committee (ASC) and submitted to National Antarctic Science Program Managers in June 2003. A formal review process led to the approval of two of the five proposed projects and the formation of the ANDRILL Operations Management Group (AOMG), which agreed through a formal Record of Understanding to coordinate operational support for the two approved projects. Science objectives and plans for the McMurdo Ice Shelf Project and the Southern McMurdo Sound Project are presented in the Scientific Prospectus documents (Naish et al., 2005; Harwood et al., 2005). STMs will find useful information in the document “Guide to Participation” in ANDRILL, which is complementary to the SLIP.

## 5.2 WEB-BASED REPORTING

The ANDRILL Science Team will utilize *WhiteBoard* on andrill.org to communicate during and following drilling. *WhiteBoard* is a virtual commons area developed by Megan Berg (ANDRILL Media specialist) in collaboration with Doug Fils at CHRONOS.

This virtual *WhiteBoard* uses an Open Source content management system called Plone that has been customized to meet ANDRILL’s needs. Certain components of *WhiteBoard* will act as a backend system, feeding content into andrill.org that will be automatically updated by scripts developed by CHRONOS that will run between McMurdo Station and Iowa State University.

Note: the system allows a user to designate access permissions to each file that they wish to upload. Only those users who have been granted access permission will see the particular file when they log in.

ANDRILL Science and Operations Management personnel will use *WhiteBoard* to create and circulate the following reports:

- Weekly Science Reports - Co-Chief Scientists. These reports will include a summary of scientific progress and results and will be circulated to an open audience.
- Daily Situation Reports – ANDRILL Project Manager (Jim Cowie). These reports summarize operational progress and are submitted to the Co-Chief Scientists on a daily basis. Circulation of these reports will be restricted to STMs and must be considered CONFIDENTIAL.

The *WhiteBoard* system also allows individual STMs to:

- Participate in ongoing forum discussions that will be updated so both On- and Off-Ice Team Members can interact;
- Transfer files to SMO data management personnel;
- Schedule a meeting;
- Participate in live chat discussions with other logged in members;

- Keep a personal webpage;
- Post announcements;
- Upload photos;
- Keep a journal or blog;
- Write articles (can be science reports, team updates, etc);
- Maintain a common calendar of events;
- View online Skype users (within respective networks);
- Allow Discipline Team Leaders to organize group discussions and invite other groups to join in if necessary.

In addition to *WhiteBoard* the ANDRILL web site will host a database of all ANDRILL related publications including reference lists, links to articles, and actual PDFs (where possible). STMs are required to notify the SMO regarding any ANDRILL related manuscript they have published so that these manuscripts can be incorporated into the publication database.

**5.3 ON-ICE REPORT**

The On-Ice Report will be a working document available on-line to the ANDRILL Science Team through http://andrill.org for access to data and written interval summaries. The On-Ice Report will include digital core images that can be viewed within Corelyzer and lithological logs produced by PSICAT.

Table 6 provides an outline of the contents of the On-Ice report and lists contributors responsible for certain sections. Presentation of data and descriptive summaries will be organized by scientific discipline. Discipline Team Leaders will have overall responsibility for compiling data from the On-Ice and Off-Ice scientists and writing summary reports that they will submit to the Staff Scientist for inclusion within the On-Ice Report. All scientists must complete their contributions to the On-Ice report while On-Ice. The On-Ice Report will provide essential information on the initial characterization of the core as a basis for guiding STMs as they prepare proposals for further analysis and sampling at the Post-Drilling Core Workshop. The On-Ice report has a similar structure to the Initial Science Report, but contains significantly less detail (Table 7). At the conclusion of the sample and data moratorium period, the On-Ice Report will be a useful resource for future investigators and will provide an archive of sample history.

**5.4 INITIAL SUMMARY PAPERS**

At the conclusion of the drilling period, and before the On-Ice Science Team departs Antarctica, the CCSs and SS will prepare summary papers that present the chief results of the initial studies. These manuscripts will bepublished in leading geoscience news journals such as Geotimes, EOS, etc. DTLs may report initial results within discipline-specific outlets.

**5.5 INITIAL REPORT**

The Initial Report is modeled on the CRP Initial Reports published in Terra Antartica (e.g. vol 7 No. 1 and 2 2000). The table of contents for the Initial Report and contributors is outlined in Table 7. It will represent an “up-scale” version of the On-Ice report and will build on contributions in the On-Ice report. The Initial Report will be organized

by research discipline, and will involve the full compilation of core characterization data with key tables, and figures. A summary and synthesis chapter will be added to present the first order age model, a stratigraphic synthesis with seismic correlation, and broad depositional and environmental assessment. Terra Antarctica Reports will publish the Initial Report as an ANDRILL Contribution. The date for final submission of contributions to the Initial report will be two weeks before the core workshop. The MIS Project Science Team, with lead authorship of "Co-Chief Scientists, Staff Scientist and MIS Project Science Team," will author the Initial Report. The initial report is intended to provide sufficient information to allow STMs to integrate data from other disciplines into their Scientific Results Volume publications. Note that authorship on the abstracts submitted to conferences during the core characterization period should include the MIS Project Science Team.

**Table 6**

Outline of the contents of the On-Ice report and contributors responsible for certain sections.

| **Sections (pages)** *153 pages total* | **Chapter co-ordinator** | **Contributors** |
|---|---|---|
| | | |
| **1.0 Introduction (10)** | Naish | Powell |
| 1.1 Background (5) | | |
| 1.2 Geological Setting (3) | | Henrys, Wilson |
| | | |
| **2.0 Operations summary (15)** | Levy | |
| 2.1 Project (5) | | Cowie |
| 2.2 Drillsite (5) | | Pyne |
| 2.3 Crary laboratory (5) | | Levy, Curren, Olney |
| | | |
| **3.0 Physical properties (18)** | Niessen | |
| 3.1 Downhole logs and summary (5) | | Morin, Williams |
| 3.2 Core physical properties logs and summary (5) | | Niessen |
| 3.3 Seismic-well correlation and summary (3) | | Henrys |
| 3.5 Core and borehole fracture studies (5) | | Wilson, T, Paulsen |
| | | |
| **4.0 Sedimentology & stratigraphy (30)** | Krissek | |
| 4.1 Lithostratigraphy and summary core logs 100m/p (15) | | Krissek, Carter, Dunbar, Cowan |
| 4.2 Tephrostratigraphy & volcaniclastics (5) | | Wilch, Kyle, Carter, McKay |
| 4.3 Preliminary facies scheme (5) | | Dunbar, Cowan |
| 4.4 Preliminary cyclostratigraphy (5) | | Carter, Naish |
| | | |
| **5.0 Biostratigraphy & paleontology (20)** | Scherer | |
| 5.1 Diatoms (5) | | Scherer, Sjunneskog, Winter, |
| 5.2 Foraminifera (3) | | Strong |
| 5.3 Palynology (3) | | Hannah, Raine |
| 5.4 Macropaleontology (3) | | Taviani |
| 5.5 Nannofossils (3) | | Wise, Villa |

| | | |
|---|---|---|
| 5.6 Microbiology (3) | | Mandernack |
| | | |
| **6.0 Petrology & geochemistry (22)** | Pompilio | |
| 6.1 Sedimentary petrology (5) | | McKay |
| 6.2 Igneous petrology (5) | | Kyle |
| 6.3 Clast petrology (5) | | Talarico |
| 6.4 Porewater geochemistry (2) | | Vogel |
| 6.5 XRF core profiles (5) | | Kuhn |
| | | |
| **7.0 Geochronology & chronostratigraphy (7)** | Wilson, G | |
| 7.1 Paleomagnetism (5) | | Wilson G, Florindo |
| 7.2 Potential for other geochronological tools (2) | | Wilson, Levy, Kyle |
| | | |
| **8.0 Summary & Synthesis (20)** | Naish, Powell | |
| 8.1 Preliminary age model (3) | | Wilson, Scherer |
| 8.3 Stratigraphic summary (5) | | Krissek, Carter |
| 8.4 Comments on depositional environments | | Dunbar, Cowan, Scherer |
| | | |
| **Appendices (4m/page core logs and scanned images, 300pages)** | Levy | Berg |

## Table 7

Outline of the contents of the Initial Report and contributors responsible for certain sections.

| **Sections (pages)** *280 pages total* | **Chapter co-ordinator** | **Contributors** |
|---|---|---|
| **Forward (1)** | Naish, Powell | |
| **Abstract (1)** | Naish, Powell | |
| | | |
| **1.0 Introduction (10)** | Naish | Powell |
| 1.1 Background (5) | | |
| 1.2 Geological Setting (3) | | Henrys, Wilson |
| | | |
| **2.0 Operations summary (15)** | Levy | |
| 2.1 Project (5) | | Cowie |
| 2.2 Drillsite (5) | | Pyne |
| 2.3 Crary laboratory(5) | | Levy, Curren, Olney |
| | | |
| **3.0 Physical properties (50)** | Niessen | |
| 3.1 Downhole logging (10) | | Morin, Williams |
| 3.2 Core physical properties (10) | | Niessen |
| 3.3 Vertical seismic profile (5) | | Henrys |
| 3.4 Core orientation (5) | | Wilson, T |

| | | |
|---|---|---|
| 3.5 Core fracture studies (10) | | Wilson, T, Paulsen |
| 3.6 Borehole fracture studies (10) | | Wilson, T, |
| | | |
| **4.0 Sedimentology & stratigraphy (48)** | Krissek | |
| 4.1 Core description and lithostratigraphy (16) | | Krissek, Carter |
| 4.2 Tephrostratigraphy & volcaniclastics (10) | | Wilch, Kyle, Carter |
| 4.3 Facies analysis (including microfacies) (10) | | Dunbar, Cowan |
| 4.4 Sequence stratigraphy and sedimentary cycles(8) | | Carter, Naish |
| 4.5 Deformation and diagenesis (6) | | Krissek, Cowan |
| | | |
| **5.0 Biostratigraphy & paleontology (53)** | Scherer | |
| 5.1 Diatoms (10) | | Scherer, Sjuuneskog, Winter, |
| 5.2 Foraminifera (10) | | Strong |
| 5.3 Palynology (10) | | Hannah, Raine |
| 5.4 Macropaleontology (10) | | Taviani |
| 5.5 Nannofossils (10) | | Wise, Villa |
| 5.6 Microbiology (3) | | Mandernack |
| | | |
| **6.0 Petrology & geochemistry (45)** | Pompilio | |
| 6.1 Sedimentary petrology (10) | | McKay |
| 6.2 Igneous petrology (10) | | Kyle |
| 6.3 Clast petrology (10) | | Talarico |
| 6.4 Porewater geochemistry (3) | | Vogel |
| 6.5 XRF core profiles (12) | | Kuhn |
| | | |
| **7.0 Geochronology & chronostratigraphy (37)** | Wilson, G | |
| 7.1 Paleomagnetism (10) | | Wilson G, Florindo |
| 7.2 Tephrochronology (Ar and ITPFT) (6) | | MackIntosh, Westgate |
| 7.3 Stontium chronology (6) | | Graham |
| 7.4 Cosmogenic isotope dating (6) | | Zondervan, Putkkonen |
| 7.5 Luminescence dating (6) | | Berger |
| 7.6 Potential for quantitative chronostratigraphic correlation (3) | | Levy, Crampton |
| | | |
| **8.0 Summary & Synthesis (20)** | Naish, Powell | |
| 8.1 Seismic-borehole correlation (5) | | Henrys, Hansaraj |
| 8.2 Age-depth model (5) | | Wilson, G, Scherer, MacKintosh |
| 8.3 Stratigraphic summary (5) | | Krissek, Carter |
| 8.4 Environmental & depositional history (5) | | Dunbar, Cowan |
| | | |
| **Appendices (4m/page core logs and scanned images)** | Krissek | Dunbar, Berg |

## 5.6 SYNTHESIS – KEY PAPERS

At the Post-Drilling Core Workshop a number of "key" outcomes of the drilling will be identified for high profile publications to Science, Geology and/or Nature. Titles and contributing authors will be agreed upon by the CCSs and DTLs. These papers may draw on a range of multidiscipline datasets that will become top priority for delivery during the science integration phase. CCSs will be authors of all key outcome papers. Lead authors will be those with the primary datasets and/or the overview and expertise to write the first draft. Contributing authors will be those with data sets or expertise of secondary importance.

STMs will inform CCSs and the SMO of abstract titles and presentations at scientific meetings that discuss MIS Project results and will submit copies of all publications to both CCSs (one copy each), the SMO (two copies) and the FSU Curator (two copies).

A standard acknowledgement statement to credit the support of various components of the ANDRILL effort will be available for inclusion in acknowledgement sections of publications, e.g. contributions from STMs, National Programs, Science Management Office, Operations Management Office, Drilling Support, Field Operations support, etc.

## 5.7 SCIENTIFIC RESULTS VOLUME(S)

The chief outlet for scientific contributions by the MIS Project Science Team will be the Scientific Reports Volume (s). These will comprise contributions from STMs and research teams with individual authored papers; "Science Team" authorship is not required. Several volumes may be appropriate to present the scientific output within specific disciplines. All papers may be presented as one volume dedicated to the MIS Project.

The CCSs and/or DTLs will contact publishers to secure appropriate vehicles for publication of manuscripts and, in general, will act as volume editors (e.g. Palaeo$^3$, Paleoceanography, Marine Geology, Global Planetary Change). To help the CCSs in attracting interest of publishers and to coordinate scientific production, STMs will be asked to propose titles and authorship of contributions near the end of the drilling period. Titles may be modified and revised at the conclusion of the Post-Drilling Core Workshop. Inclusion of authors who are not currently members of the Science Team will require approval from CCSs. STMs may also publish papers on MIS Project materials within discipline-specific journals. CCSs must approve each manuscript to ensure that each paper satisfies STM responsibilities.

# 6. EDUCATION AND PUBLIC OUTREACH PLAN

## 6.1 MEDIA AND PRESS RELEASES

### 6.1.1 Media Policy

- The National Antarctic Programs will have joint media releases with regards to ANDRILL operations and drilling activities. Coordination of these releases will be by the Operations Management Office (OMO) within Antarctica New Zealand, which will work with the National Antarctic Programs to ensure that all parties are aware of media releases; will help tailor and coordinate the timing of releases; and will ensure that each release is cleared through each of the National Antarctic Program's clearance processes before issuance;
- The Science Management Office (SMO) at the University of Nebraska-Lincoln is the central office for coordination of media releases with regard to scientific outcomes;
- The OMO and SMO will share plans and releases with one another;
- The Point of Contact (PoC) at the OMO is Jim Cowie, Project Manager and/or Alison Whitaker. The PoCs for media issues at the SMO are John Jackson (JJ), Education and Outreach Coordinator and Tom Simons, Coordinator, Office of Communications at the University of Nebraska Communications;
- On-Ice visits to the ANDRILL drill site will cause no disruptions to the drilling activities. All visits to the drill site will occur during scheduled times; and visitors must be accompanied by a Co-Chief Scientist or designated official. (see additional discussion below);
- All science media activities while On-Ice are coordinated through the SMO;
- Co-Chief Scientists and a select pool of Science Team Members will be designated and identified as key contacts for the media. The pool should be comprised of scientists from all partner nations;
- A 36 hr moratorium period on releases will be honored to allow for translation (language) and simultaneous release with international partner presses;
- The OMO and SMO will distribute copies of press releases and other media to an agreed list of international program managers to facilitate the simultaneous release of news;
- All media releases dealing with ANDRILL should be forwarded to the SMO for archival/database purposes. Digital copies are preferred.

### 6.1.2 Key Information

- The following information should be included in all articles or discussions/interviews on ANDRILL (all of this information can be found in the ANDRILL media document [in preparation, expected to be available on-line October 2006]);
- ANDRILL is a multinational collaboration involving Germany, Italy, New Zealand, and the United States.
- Funding support for ANDRILL comes from the U.S. National Science Foundation, New Zealand Foundation of Research, Science, and Technology, Royal Society of New Zealand Marsden Fund, Antarctica New Zealand, the Italian National Program for Research in Antarctica - PRNA, the German Science Foundation, and the Alfred Wegener Institute for Polar and Marine Research Science;

- The overall science themes for the ANDRILL Program are (a) thresholds and stages in the development of the cryosphere; (b) climatic optima and ice sheet stability; (c) ice sheet modulation of global climate and sea-level; (d) origins and adaptations of polar biota; and (e) West Antarctic Rift (WAR) and uplift of Transantarctic Mountains (TAM);
- Specific MIS Project objectives are outlined in the MIS Scientific Prospectus document. (andrill.org/support);
- Amount of Science funding (national breakdown: U.S. 13 million USD; New Zealand 3 million USD; Italy ~1.5 to 2 million USD; Germany 500,000 USD; The total project, including logistics, has been funded internationally at $30 million USD;
- The operator for the ANDRILL Program is Antarctica New Zealand;
- For further information regarding science, contact Drs. Tim Naish (NZ) or Ross Powell (US) ANDRILL MIS Project Co-Chief Scientists; Dr. Richard Levy (Staff Scientist); or the ANDRILL Science Management Office (SMO) at the University of Nebraska-Lincoln. For operations, contact Mr. Jim Cowie or Ms. Alison Whitaker at the Operations Management Office (OMO) at Antarctica New Zealand.

### 6.1.3 Guidelines for Science Team Members

**ANDRILL Science Team Members are requested to:**

- Work within the media plan as developed by the Co-Chief Scientists, the OMO and the SMO;
- Stick to verifiable facts and general successes of the program. Defer to Co-Chief Scientists, Staff Scientist or operations personnel for questions that are outside initial scope of article/interview or deals with a perceived or actual disaster (be prepared to change direction of interview; decline comment; or cease interview if questions deal directly with a disaster, especially if there has been no announcement or comment from OMO, SMO, or Co-Chief Scientists);
- Ensure that all images or photos provided to the media by members of the Science Team include captions (if warranted) and relevant acknowledgments;
- Realize that you may have little control over the final product, so always make clear to the interviewer or reporter where s/he can access additional information (persons qualified to comment, literature available or resources located on the ANDRILL website).

### 6.1.4 Courtesy Requests for the Media

**Media involved with ANDRILL are requested to:**

***On-Ice***

- Seek participation through appropriate funding agencies or programs (National Science Foundation (NSF), Antarctica New Zealand, etc.);
- Coordinate with science management personnel and generally work with Co-Chief Scientists and designated pool of scientists for articles, interviews, etc;
- Visit the drill site or engage with drilling operations only during scheduled times. *Note that media must be accompanied by a Co-Chief Scientist, the Staff Scientist or other designated OMO/SMO personnel;*
- Total number of media persons allowed at the drill site at any given scheduled time will be identified by Jim Cowie on a case-by-case basis;

- Focus on science operations at McMurdo/Crary Lab, and draw upon the pool of scientists and science management personnel for information regarding the program, including updates on drilling activities, etc;
- As a courtesy, allow time for Science or Operation review and comment on articles and language translation activities.

***Off-Ice***

- Seek participation through appropriate national funding agencies, programs, or institutions;
- Coordinate with PoCs for science, operations, funding agencies (as warranted) and generally work with Co-Chief Scientists and designated pool of scientists for articles, interviews, etc;
- As a courtesy, allow time for Science or Operation review and comment of articles and language translation activities.

### 6.1.5 Resources Available from the SMO

The following items are available for download on the ANDRILL website (http://andrill.org)

- A Media Guide (available October 2006). Additional copies of the Media Guide will be produced and distributed to various national funding agencies and press before drilling commences in October 2006;
- 1-page pamphlet describing ANDRILL (available from SMO and on-line);
- Scientific Prospectus documents for the MIS and SMS Projects (available from SMO and on-line);
- Distribution list for media releases (which currently includes all National Program Directors and associated funding agencies; Members of the AOMG; Science Management Office; Operations Management Office; and others).

## 6.2 ARISE PROGRAM

### 6.2.1 Overview

ANDRILL has established a Research Immersion experience for Science Educators (ARISE) to facilitate development of mechanisms and materials to effectively connect ANDRILL with the public. The program will provide science educators with an inside view of ANDRILL, will engage them in authentic Antarctic geoscience, and will utilize their expertise in education to develop and implement innovative approaches to geoscience education and public outreach. Components of the program include: On- and Off-Ice research experience, an Antarctic geoscience course, and an educational working group.

**On-Ice Research Experience**

During each project a cohort of six science educators will join the ANDRILL science team at McMurdo Station in Antarctica. Each educator will become a member of a science discipline team and will be immersed in scientific investigation of the core and will accept all responsibilities that other STMs take on.

Participating science educators will gain insight into the nature of large multidisciplinary international science programs. Educators will experience authentic scientific inquiry as the discipline teams generate their data from the core, integrate their data and work together to develop and debate interpretations and establish a history of environmental and climatic change for this important part of the Earth.

**Off-Ice Research Experience**

ARISE participants will maintain communication and collaboration with discipline team members and will continue studying data and material collected on the ice. Core will be shipped back to the United States and the whole ANDRILL science team will reconvene at Florida State University to discuss initial findings, re-examine the core and sample for continued study of interesting sections and key intervals. Study of these newly sampled materials will continue for a year. The science team will meet again for final integration.

**Antarctic Geoscience Course**

Over 25 international scientists with a variety of expertise in Antarctic geoscience will meet in Antarctica to work on ANDRILL core at the Crary Science and Engineering laboratory at McMurdo Station. ANDRILL will utilize this unique convergence of geoscience experts from around the world to offer a comprehensive introductory Antarctic geoscience course. Many of the ANDRILL scientists will deliver lessons in their specific interest areas to both science educators participating in the ARISE program and the broader community through distance education modules. Several field trips are planned in the McMurdo Sound area. Credit for this course will be offered through the University of Nebraska – Lincoln.

**Education – Outreach Working Group**

A major task for ARISE participants is to develop innovative and effective education and outreach approaches based on knowledge gained during the research immersion experience. While in Antarctica, ARISE participants will meet on a regular basis to discuss and develop the EPO projects that they will complete and implement upon returning to their home institutions in their respective nations. Scientists and graduate students will be encouraged to join the working group to help develop on-going collaboration between ANDRILL scientists and educators.

### 6.2.2 Cohort for the MIS Project

**Matteo Cattadori – Rovereto, Trento – Italy**

Project Summary: Matteo will develop “smilla.it”, which will focus on developing inquiry-based learning activities using a variety of multi-media and ‘traditional’ teaching methods. Matteo’s activities will enable students to:

- Understand the importance of the Antarctica’s role in the global climatic system;
- Examine and understand our current concept of “global climate change” and compare the nature of climate evolution through natural and human influences;
- Develop an in-depth understanding of the patterns of Antarctic climate changes now and on the past;
- Learn that rocks and sediments contained climate change proxies;
- Examine, understand and practice several scientific techniques that allow researchers to uncover and interpret these climate proxies.

**LuAnn Dahlman – Mesa, Arizona – United States**

Project Summary: LuAnn is a professional developer of Earth and space science educational materials. She will contribute to raising public awareness about scientific drilling in Antarctica by producing and promoting print, hands-on, outdoor, and/or web-based learning activities. Materials that LuAnn will produce include:

- One or more chapters for the Earth Exploration Toolbook (http://serc.carelton.edu/eet);
- A GIS project that will allow teachers and students to explore spatial relationships among a range of Antarctic data layers;

- Hands-on and inquiry-based activities that will be incorporated into the Flexhibit™ component of the *IPY: Engaging Antarctica* Project;
- A multimedia journal to illustrate the experience of preparing for and participating in a science research project.

**Vanessa Miller – New York, New York – United States**

Project Summary: Vanessa teaches grades 4-6 at Central Park East 2 in New York City. Vanessa has developed a comprehensive plan to engage students from a cohort of collaborating schools in Antarctic geoscience. Students will work as scientists to understand that the Earth's environment is constantly changing and that Antarctica plays a significant role in our dynamic global system both today and in the past. Students from the cohort of schools will:

- Participate in local field trips to investigate buried secrets in their backyard;
- Collaborate with undergraduate students from Queens College, NYC;
- Create a collection of research materials including books, magazines, and video documentaries;
- Conduct interviews with ANDRILL Science Team Members;
- Communicate with ANDRILL participants through web logs on andrill.org;
- Engage in experimentation to explore impacts of environmental change;
- Host a museum to display findings in written and visual presentations.

**Alexander Siegmund – Heidelberg – Germany**

Project Summary: Alexander is a Professor in the Department of Geography at the University of Education in Heidelberg. Alexander plans to develop several collaborative projects with German Schools, newspapers and television to support ANDRILL Education and Outreach. One of the main emphases of Alexander's On-Ice work will be to connect with students involved in the GLOBE Project. He will also prepare reports for television magazines such as Morgenmagazin and Mittagsmagazin. Alexander's post-drilling Off-Ice efforts include preparing television reports for German television, preparation of publications that examine the didactical impact of ANDRILL related teaching and learning materials, and public presentations on climate history research, Antarctic scientific activities and didactical outcomes.

**Julian Thompson – Lower Hutt – New Zealand**

Project Summary: Juilan is an experienced teacher of Earth science and outdoor activities. Julian will utilize his ARISE experience to do the following:

- Create a network of national and international support to enhance development of EPO resources that are clearly linked to NZ National Curriculum and NCEA Standards;
- Collaborate with other ARISE participants to develop teaching resources such as texts, photos, diagrams and worksheets;
- Develop a comprehensive and practical understanding of ANDRILL science;
- Interview ANDRILL participants and collect video footage for an educational DVD.

**Betty Trummel, Crystal Lake, Illinois – United States**

Project Summary: Betty will conduct activities and develop materials to carry scientific research into the elementary classroom and provide an interactive and exciting learning environment for students. Specific goals include:

- Produce and publish a book titled *ABC's of ANDRILL and Antarctica*;
- Maintain an interactive on-line journal exchange through Project Iceberg at http://andrill.org/iceberg;
- Establish and maintain an international network of educators;
- Conduct research on impact of immersion experience on ARISE educators;
- Enhance the Ice Box resource trunk for educators;
- Engage in ongoing public presentations and polar education workshops to broadly disseminate information about ANDRILL and the scientific and educational knowledge generated by the Program.

## 6.3 PROJECT ICEBERG

Project Iceberg is the education and outreach clearing-house for the ANDRILL Program that is accessed through andrill.org/iceberg

All EPO projects associated with the ANDRILL Program will be linked through the Project Iceberg website. The site will provide access to educational resources and will be the central Internet location through which members of the public can communicate with scientists and educators involved in the ANDRILL Program.

## 6.4 AFFILIATED PROJECTS

Many media and education outreach organizations have projects that involve ANDRILL Science. Members of these affiliated projects will interact with members of the MIS Project Science Team at various stages both during and after drilling. John Jackson (JJ), ANDRILL EPO Coordinator, is the primary ANDRILL PoC for these projects. JJ will manage interaction between ANDRILL Science personnel and the media/education teams and will work to ensure all projects meet their goals.

**The following provides a brief overview of these affiliated EPO Projects:**

***Television New Zealand (TVNZ)***

A film crew from TVNZ will visit ANDRILL sites to collect footage for 15 minute current affairs broadcast on the *Sunday* program. They will operate out of Scott Base.

Anticipated event dates: November 30th to December 12th, 2006

***IPY: Engaging Antarctica – Nebraska Educational Television, WGBH-NOVA and UNL State Museum***

The goal of *IPY: Engaging Antarctica* is to increase public awareness of Antarctic geological research and discovery by complementing the excitement and interest generated by a documentary to be shown on PBS on the NOVA series in fall 2008 with a multi-faceted outreach effort. This documentary, Antarctica's Icy Secrets, will provide a geological perspective on how Antarctica continues to play a major role in affecting global climate by altering ocean currents and sea levels. Besides the NOVA documentary, the *IPY: Engaging Antarctica* project includes a companion NOVA website with a teacher guide and 24/7 access to the streamed program, a book for

educators, a curriculum book, and community outreach activities of interest to youth organizations, schools, libraries, and small museums. An innovative informal learning exhibit – one that blends standards- and inquiry-based learning with the latest information technologies – underpins *IPY: Engaging Antarctica* outreach activities. Coined the Flexhibit™, our low cost, high utility delivery paradigm is expected to revolutionize the way exhibits are traveled and distributed to community-based sites. *IPY: Engaging Antarctica* aligns strategically with the U.S. National Science Education Standards for grades 5–8 Content Standard D on the structure of the Earth System and Earth's history, Content Standard G on the history and nature of science, and Content Standard E on science and technology.

*IPY: Engaging Antarctica* will reach large and diverse audiences as a result of its unique "systems" approach to informal science learning, offering complementary television documentary, Flexhibit™, and web-based education focused on greater youth and adult understanding of the exciting geological research being conducted in Antarctica coinciding with the International Polar Year (IPY). The project team estimates the Flexhibit™ is likely to reach more than 288,500 youth and adults, 2,500 youth leaders, and additional numbers of students and teachers. Approximately 330,000 youth aged 18 and under watch NOVA on PBS each week, constituting 5 percent of NOVA's domestic audience. Households with annual incomes of less than $40,000 USD constitute 46 percent of NOVA's weekly audience. The project's multiple audiences and its use of integrated media materials offer opportunities to contribute to the knowledge base about how youth and adults understand geoscience and the interconnectivity of Earth Systems.

A film crew from NET and WGBH will visit Antarctica to collect video footage from the MIS and SMS Projects. They will operate out of McMurdo Station. Megan Berg will collect a variety of digital media (images and audio) for the Flexhibit™ component.

Anticipated event dates: November 30, to December 18, 2006 (dates for 2007 TBD).

***LEARNZ Virtual Field Trips***

LEARNZ (Heurisko) uses communications technologies as a basis for education and training (http://www.learnz.org.nz/). Their project in Antarctica will comprise development of a virtual field trip to allow students to explore, investigate, and immerse in the ANDRILL MIS Project. The target audience for this project includes 9-15 year old students. The field trip can be viewed at the following URL: http://andrill64.learnz.org.nz

In addition to the field trip, five LEARNZ ANDRILL newsletters will be sent to enrolled NZ schools. These newsletters can be viewed online at the following URL: http://mojo.epicentre.org.nz/cgi-bin/mojo/mojo.cgi?flavor=archive&list=andrill64

A crew from LEARNZ will collect a variety of media for their virtual field trip activity from a variety of ANDRILL work locations. They will operate out of Scott Base.

Anticipated event dates: November 13th to 21st, 2006

***IPY: Pole to Pole - A Collaborative Radio Series and Educational Clearinghouse***

In collaboration with four international polar research partners, Soundprint Media Center, Inc. (SMCI) will produce a landmark multi-part radio series: documentaries, short radio features, oral histories, an audio and educational clearinghouse, and related educational website on scientific research in the Polar regions. *IPY: Pole to Pole* will produce at least four documentaries per year, each approximately 30 minutes long, and 40-50 shorter features during the two-year International Polar Year (March 2007-2009). The international collaborators: SMCI, the Australian Broadcasting Co., the BBC World Service, Radio Deustche-Welle and Radio New Zealand will look at issues such as the influence of conditions in polar regions on global climatic conditions, how animals adapt to rapid environmental change, survival in extreme environments, and processes of change among native peoples in the Polar regions.

Two documentaries on the scientific activities and results of two drilling projects near both Poles will serve to demonstrate the connectedness of scientific research in the Polar Regions. Data from both these projects will be collected and used to understand changes in the bi-polar regions, including global changes in ocean currents and ice sheet dynamics. An additional story SMCI would like to pursue is model building, using these data, developed at the Antarctic Climate Evolution (ACE). Listeners can learn how comparison of data, and the collection of data from very long periods of time, can help us predict new changes in the climate.

SMCI and Radio New Zealand will collaborate to produce a documentary focusing on ANDRILL (ANtarctic Drilling), a U.S., New Zealand, German, and Italian collaborative research effort to drill deep into the floor of Antarctica's ocean, in McMurdo Sound. Scientists will start their drilling in October of 2006 with the MIS Project. In October 2007, scientists will return to retrieve cores during the SMS Project. Radio New Zealand plans to be on-site in October 2006, to cover the first drilling project (MIS). SMCI will cover the second drilling project (SMS) in 2007. Together, these producers will develop a documentary that traces this study of the role Antarctica played in past environmental change.

Veronika Meduna from Radio New Zealand will report on ANDRILL during the MIS Project. She will work out of Scott Base. In addition to her work with the *IPY: Pole to Pole* Project, Veronika will carry out live broadcasts from Antarctica.

Megan Berg will also collect audio material for the *IPY pole to pole* project.

Anticipated event dates: November 27th to December 12th, 2006 (dates for 2007 TBA)

**CNN Science and Technology**

CNN Senior Producer Kate Tobin and television crew will deploy to Antarctica as part of the NSF media program to capture and produce a series of television news articles that focus on ANDRILL Science and Technology. The CNN group is sponsored by NSF and will be based at McMurdo Station.

Anticipated event dates: November 16th to November 24th, 2006.

**William Mullen - Chicago Tribune**

William Mullen and a photographer will deploy to Antarctica as part of the NSF media program to develop a series of news articles for the Chicago Tribune that focus on ANDRILL Science and Technology. William is sponsored by NSF and will be based at McMurdo Station.

Anticipated event dates: TBD.

**Deborah Zabarenko - Reuters**

Deborah Zabarenko will deploy to Antarctica as part of the NSF media program to develop a series of news articles for Reuters news service that focus on ANDRILL Science and Technology. Deborah is sponsored by NSF and will be based at McMurdo Station.

Anticipated event dates: TBD.

## 9. REFERENCES

Adam, D.P., Bradbury, J.P. and Rieck H.J., Sarna-Wojcicki, A.M., 1990. Envirnmental changes in the Tule Lake basin, Siskiyou and Modoc Counties, California, from 3 to 2 million years before present. United States Geological Survey Bulletin, 1933: 1-13.

Aitken, M. J., 1998. *Introduction to Optical Dating*. Oxford University Press, Oxford: 262 pp.

Alley, R.B. and Bindschadler, R.A., 2001. The West Antarctic ice sheet; behavior and environment. AGU, Antarctic Research Series, 77: 296 pp.

ANDRILL International Science Proposal, 2003. ANDRILL: Investigating Antarctica's role in Cenozoic global environmental change. ANDRILL Contribution No. 2, ANDRILL Science Management Office, University of Nebraska- Lincoln, Lincoln, NE: 346 pp.

Bann, K.L., Fielding, C.R., MacEachern, J.A., and Tye, S.C., submitted. Sedimentology and ichnology of mixed wave- and storm-dominated deltaic deposits: examples from the Permian of Australia. In: Hampson, G.J., Dalrymple, R. and Burgess, P. (eds.). Advances in Shelf and Shoreline Stratigraphy, SEPM Spec. Publ.

Bannister, S. and Naish, T.R., 2002. ANDRILL site investigations, New Harbour and McMurdo Ice Shelf, Southern McMurdo Sound, Antarctica. Institute of Geological & Nuclear Sciences, Science Report 2002/01; 24 pp.

Bannister, S., 1993. Seismic investigation of the Victoria Land Basin under Ross Island. New Zealand Antarctic Programme 1992/93, Event K101. Institute of Geological & Nuclear Sciences, Science Report 93/14; 16 pp.

Barrett, P.J., Pyne, A.R. and B.L. Ward, 1983. Modern sedimentation in McMurdo Sound, Antarctica. In: Oliver, R.L., James, P.R. and Jago, J.B. (eds.). *Antarctic Earth Science*, Australian Academy of Science, Canberra; 550 554.

Barrett, P. J. (ed.). 1989. Antarctic Cenozoic history from CIROS-1 drillhole, McMurdo Sound. DSIR Bulletin, 245; 251 pp.

Barrett, P.J., Carter, L., Dunbar, G.B., Dunker, E., Giorgetti, G., Niessen, F., Nixdorf, U., Pyne, A.R., Riesselmann, C. and Robinson, N., 2005. Oceanography and sedimentation beneath the McMurdo/Ross Ice Shelf in Windless Bight: 1. School of Earth Sciences, Victoria University Research Report, 25; 92p.

Bartek, L.R. and Anderson, J.B., 1991. Facies distribution resulting from sedimentation under polar interglacial climatic conditions within a high-latitude marginal basin, McMurdo Sound, Antarctica. Geological Society of America, Special Paper, 261: 27-49.

Bartek, L.R., Henrys, S.A., Anderson, J.B. and Barrett, P.J., 1996. Seismic stratigraphy of McMurdo Sound, Antarctica; implications for glacially influenced early Cenozoic eustatic change? Marine Geology, 130: 79-98.

Beaudoin, B.C., ten Brink, U.S. and Stern, T.A., 1992. Characteristics and processing of seismic data collected on thick, floating ice: results from the Ross Ice Shelf, Antarctica. Geophysics, 57: 1359-1372.

Bentley C.R., 2004. Mass balance of the Antarctic Ice Sheet: observational aspects. In: Bamber, J.L. and Payne, A.J. (eds.). *Mass Balance of the Cryosphere*. Cambridge University Press, Cambridge, UK: 459-489.

Berggren, W. A., Kent, D. V., Flynn, J. J. and Van Couvering, J. A. 1985. Cenozoic geochronology. Geological Society of America Bulletin, 96: 1407–1418.

Berggren, W. A., Kent, D. V., Swisher, C. C. and Aubry, M. P. 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W. A., Kent, D. V., Aubry, M. P. and Hardenbol, J. A. (eds.). Geochronology, Time Scales and Global Stratigraphic Correlation. Society for Sedimentary Geology Special Publication 54: 129-212.

Bindschadler, R.A., King, M.A., Alley, R.B., Anandakrishnan, S. and Padman, L., 2003. Tidally controlled stick-slip discharge of a West Antarctic ice stream. Science, 301: 1087-1089.

Boggs, S., Jr., 2006. *Principles of Sedimentology and Stratigraphy*, 4th ed. Pearson Prentice-Hall: Upper Saddle River, N.J.

Bohaty, S. M., Scherer, R. P. and Harwood, D. M., 1998. Quaternary diatom biostratigraphy and palaeoenvironments of the CRP-1 drillcore, Ross Sea, Antarctica. Terra Antartica 5: 431–453.

Bohaty, S. M., Wise, S. W., Jr., Duncan, R. A., Moore, C. L. and Wallace, P. J., 2003. Neogene diatom biostratigraphy, tephra stratigraphy, and chronology of ODP Hole 1138A, Kerguelen Plateau. Proceedings of the Ocean Drilling Program, Scientific Results 183. <http://www-odp.Tamu.Edu/Publications/183_SR/016/016.htm>.

Bøtter-Jensen, L., McKeever, S.W.S. and Wintle, A.G., 2003. Optically Stimulated Luminescence Dosimetry. Elsevier, New York, 350 pp.

Bottjer, D.J. and Droser, M.L., 1994. The history of Phanerozoic bioturbation. In: Donovan, S.K. (ed.), The Palaeobiology of Trace Fossils, John Wiley and Sons: 155-176.

Bougamont, M., Tulaczyk, S. and Joughin, I., 2003. Response of subglacial sediments to basal freeze-on; 2, Application in numerical modeling of the recent stoppage of Ice Stream C, West Antarctica. J. Geophysical Research, B, 108: Art. No. 2223.

Brancolini, G., and others, 1995. Descriptive text for the seismic stratigraphic atlas of the Ross Sea, Antarctica. In: Cooper, A.K., Barker, P., and Brancolini, G., (eds.). *Geology and Seismic Stratigraphy of the Antarctic Margin*. AGU, Antarctic Research Series, 68: 271-286.

Broecker, W. S. and Denton, G. H., 1989. The role of ocean-atmosphere reorganizations in glacial cycles. Geochimica et Cosmochimica Acta, 53: 2465-2501.

Cande, S. C. and Kent, D. V. 1995. Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research, 100: 6093–6095.

Cape Roberts Science Team, 1998. Quaternary strata in CRP-1, Cape Roberts Project, Antarctica. Initial Report on CRP-1, Cape Roberts Project, Antarctica, Terra Antartica, 5 (1): 31-61.

Cape Roberts Science Team, 2000. Initial Report on CRP-3, Cape Roberts Project, Antarctica. Terra Antartica, 7.
Carter, L., Carter, R. M. and McCave, I. N., 2004. Evolution of the sedimentary system beneath the deep Pacific inflow off eastern New Zealand, Marine Geology, 205: 9-28.

Carter, L., Dunbar, G., McKay, R. and Naish, T.R., 2006. Oceanography and Sedimentation beneath the McMurdo/Ross Ice Shelf in Windless Bight: 2, School of Earth Sciences, Victoria University Research Report, 32: 26p.

Censarek, B. and Gersonde, R., 2002. Miocene diatom biostratigraphy at ODP Sites 689, 690, 1088, 1092 (Atlantic sector of the Southern Ocean). Marine Micropaleontology. 45: 225–268.

Ciesielski, P. F., 1983. The Neogene and Quaternary diatom biostratigraphy of subantarctic sediments, Deep Sea Drilling Project Leg 71. Initial Reports of the Deep Sea Drilling Project, 90: 635–665.

Clark, P. U. and D. Pollard, 1998. Origin of the middle Pleistocene transition by ice sheet erosion of regolith, Paleoceanography, 13: 1-9.

Clark, P.U., Pisias, N.G., Stocker, T.F. and Weaver, A.J., 2002. The role of the thermohaline circulation in abrupt climate change. Nature, 415: 863-869.

Cody, R.D., 2006. A new high-resolution Neogene chronostratigraphic model for the Southern Ocean: application of the constrained optimization method to diatom biostratigraphy. M.S. Thesis, University of Nebraska-Lincoln, Lincoln, NE, USA: 189 pp.

Conway, H., Hall, B.L., Denton, G.H., Gades, A.M. and Waddington, E.D., 1999. Past and future grounding-line retreat of the West Antarctic ice sheet. Science, 286: 280-283.

Cronin, T.M., Kitamura, A., Ikeya, N., Watanabe, M. and Kamiya, T. 1994. Late Pliocene climate change 3.4-2.3 Ma: Paleoceanographic record from the Yabuta Formation, Sea of Japan. Palaeogeography, Palaeoclimatology, Palaeoecology, 108: 437-455.

Cooper, A. K. and Davey, F.J., 1985. Episodic rifting of the Phanerozoic rocks of the Victoria Land Basin, western Ross Sea, Antarctica. Science, 229: 1085-1087.

Cooper, A.K., Davey, F.J. and Behrendt, J.C., 1987. Seismic stratigraphy and structure of the Victoria Land Basin, Western Ross Sea, Antarctica. In: Cooper, A.K. and Davey, F.J. (eds.), *The Antarctic Continental Margin: Geology and Geophysics of the Western Ross Sea*. CPCEMR, 5b, Houston, Texas: 27-77.

Crundwell, M.P. and Arnot, M., 2005. A 4-D biostratigraphic approach. *Eastern Taranaki Basin Margin Workshop Proceedings,* Geological & Nuclear Sciences, Lower Hutt.

Davey, F.J. and Brancolini, G., 1995. The Late Mesozoic and Cenozoic structural setting of the Ross Sea Region. In: A.K. Cooper, P.F. Barker and G. Brancolini (eds.), *Geology and seismic stratigraphy of the Antarctic Margin*, Antarctic Research Series, Washington, D.C., 68: 167-183.

Davey, F.J., Barrett, P.J., Cita, M.B., Van der Meer, J.J.M., Tessensohn, F., Thomson, M.R.A., Webb, P.-N. and Woolfe, K.J., 2001. Drilling for Antarctic Cenozoic climate and tectonic history at Cape Roberts, southwestern Ross Sea. EOS, 82: 585 and 589-590.

Dawber, M. and Powell, R.D., 1998. Epifaunal distributions at marine-ending glaciers: influences of ice dynamics and sedimentation. In: Ricci, C.A. (ed.) *The Antarctic Region: Geological Evolution and Processes* (Proceedings VII International Symposium on Antarctic Earth Sciences, Siena, Italy, 1995). Terra Antartica, Siena: 875-884.

Ding, Z.L., Derbyshire, E., Yang, S.L., Yu, Z.W., Xiong, S.F. and Liu, T.S. 2002. Stacked 2.6-Ma grain size record from the Chinese loess based on five sections and correlation with the deep-sea $d^{18}O$ record. Paleoceanography 17(3): 1-21.

Doake, C.S.M., Corr, H.F.J., Rott, H., Skvarca, P. and Young, N.W., 1998. Breakup and conditions for stability of the northern Larsen Ice Shelf, Antarctica. Nature, 391: 778-780.

Doake, C.S.M. and Vaughn, D.G., 1991. Rapid disintegration of the Wordie Ice Shelf in response to atmospheric warming. Nature, 421: 245-249.

Domack, E.W. and Harris, P.T., 1998. A new depositional model for ice shelves, based upon sediment cores from the Ross Sea and the Mac.Robertson shelf, Antarctica. Annals of Glaciology, 27: 281-284.

Domack, E.W., Jacobson, E.A., Shipp, S. and Anderson, J.B., 1999. Late Pleistocene-Holocene retreat of the West Antarctic ice-sheet system in the Ross Sea; Part 2, sedimentologic and stratigraphic signature. Geological Soc. America Bulletin, 111: 1517-1536.

EPICA Community Members, 2004. Eight glacial cycles from an Antarctic ice core, Nature, 429: 623-628.

Esser, R.E., Kyle, P.R. and McIntosh, W.C., 2004. $^{40}Ar/^{39}Ar$ dating of the eruptive history of Mount Erebus, Antarctica: volcano evolution. Bulletin of Volcanology, 66: 671-686.

Fenner, J. M., 1991. Late Pliocene–Quaternary quantitative diatom stratigraphy in the Atlantic sector of the Southern Ocean. Proceedings of the Ocean Drilling Program, Scientific Results, 114: 97–121.

Fielding, C.R., Naish, T. R. and Woolfe, K. J., 2001. Facies architecture of the CRP-3 drillhole, Victoria Land Basin, Antarctica. Studies from the Cape Roberts Project, Ross Sea, Antarctica; scientific report of CRP-3; Part I, Sedimentary environments for CRP-3. Terra Antartica, 8: 217-224.

Fisher, R.V., 1961. Proposed classification of volcaniclastic sediments and rocks: Geol. Soc. America Bull., 72: 1409-1414.

Fisher, R.V. and Schmincke, H., 1984. *Pyroclastic rocks*. Springer-Verlag: Berlin.

Gersonde, R. and Burckle, L. H., 1990. Neogene diatom biostratigraphy of ODP Leg 113, Weddell Sea (Antarctic Ocean). Proceedings of the Ocean Drilling Program Scientific Results, 113: 761–789.

Gillespie, M.R. and Styles, M.T., 1999. BGS Rock Classification scheme: Volume 1, Classification of igneous rocks, British Geological Survey Research Report, (2nd ed.), RR 99-06: Nottingham, UK.

Gombos, A. M. Jr. and Ciesielski, P. F., 1983. Late Eocene to early Miocene diatoms from the southwestern Atlantic. Initial Reports of Deep Sea Drilling Project; 90: 583–634.

Grutzner, J., Rebesco, M. A., Cooper, A. K., Forsberg, C. F., Kryc, K. A. and Wefer, G., 2003. Evidence for orbitally controlled size variations of the East Antarctic ice sheet during the late Miocene. Geology, 31: 777-780.

Hall, I.R., McCave, I.N., Shackleton, N.J., Weedon, G.P. and Harris, S.E., 2001. Glacial intensification of deep Pacific inflow and ventilation. Nature, 412: 809-812.

Hall, B.L. and Denton, G.H., 2000a. Radiocarbon chronology of Ross Sea drift, eastern Taylor Valley, Antarctica: evidence for a grounded ice sheet in the Ross Sea at the last glacial maximum. Geografiska Annaler, 82A: 305–336.

Hall, B.L. and Denton, G.H., 2000b. Extent and chronology of the Ross Sea ice sheet and the Wilson Piedmont Glacier along the Scott Coast at and since the last glacial maximum. Geografiska Annaler, 82A: 337–363.

Hall, J.M., Wilson, T.J., and Henrys, S.A., 2005. Fault architecture within the eastern Terror Rift, Western Ross Sea, Antarctica: EOS Trans. AGU, 86, (52): T43B-1408.

Hall, J.M., 2006. Structural Evolution of the Terror Rift, Western Ross Sea, Antarctica: Interpretation from 2D Reflection Seismic Data. Unpublished M.Sc. Thesis, The Ohio State University, Columbus, OH.

Harwood, D.M. and Bohaty, S.M., 2001. Early Oligocene siliceous microfossil biostratigraphy of Cape Roberts Project CRP-3, Victoria land Basin, Antarctica. Terra Antartica, 8: 315–338.

Harwood, D.M. and Maruyama, T. 1992. Middle Eocene to Pleistocene diatom biostratigraphy of Southern Ocean sediments from the Kerguelen Plateau. Proceedings of the Ocean Drilling Program, Scientific Results, 120: 683–733.

Harwood, D., Lacy, L., Levy, R. (eds), 2003. Future Antarctic margin drilling: Developing a science program plan for McMurdo Sound, report of a workshop, Oxford, UK, April 5-7, 2001. ANDRILL Contribution 1. ANDRILL Science Management Office, University of Nebraska-Lincoln: Lincoln, NE: 302 pp.

Harwood, D.M., Florindo, F., Levy, R.H., Fielding, C.R., Pekar, S.F., Speece, M. and SMS Science Team, 2005. ANDRILL Southern McMurdo Sound Project, Scientific Prospectus. ANDRILL Science Management Office, ANDRILL Contribution 5. University of Nebraska – Lincoln. Lincoln, NE: 29 pp.

Heath, R.A., 1977. Circulation across the ice shelf edge in McMurdo Sound, Antarctica. In: Dunbar, M.J., (ed.). Polar Oceans. Arctic Institute of North America, Calgary: 682 pp.

Henrys, S.A., Bucker, C.J., Bartek, L., Bannister, S., Niessan, F. and Wonik, T., 2000. Correlation of seismic reflections with CRP-2/2A. Terra Antartica, 7: 221-230.

Henrys, S.A., Naish, T., Wilson, G., Gorman, A., Clifford, A.L.J. and Blakemore, H., 2006. ANDRILL 2005 Site Investigations/Seismic Surveys, McMurdo and Southern McMurdo Ice Shelf, McMurdo Sound, Antartctica.: GNS Science Report, 2006/1342: 44 pp.

Holbourn, A., Kuhnt, W. Schulz M. and Erlenkeuser H., 2005. Impacts of orbital forcing and atmospheric carbon dioxide on Miocene Ice Sheet expansion, Nature, 438-487.

Holland, D.M., Jacobs, S.S. and Jenkins, A., 2003. Modelling the ocean circulation beneath the Ross Ice Shelf. Antarctic Science, 15: 13-23.

Horgan, H., Bannister, S., Naish, T., Wilson, G., Pyne, A., Clifford, A. and Finnemore, M., 2003. ANDRILL Site Investigations/Seismic Surveys, McMurdo and Southern McMurdo Ice Shelf, McMurdo Sound, Antarctica. Institute of Geological and Nuclear Sciences, Science Report, 2003/05: 47 pp.

Horgan, H., Naish, T., Bannister, S., Balfour, N. and Wilson, G., 2005. Seismic stratigraphy of the Ross Island flexural moat under the McMurdo-Ross Ice Shelf, Antarctica, and a prognosis for stratigraphic drilling, Global Planetary Change, 45: 83-97.

Houhgton J. and others, 2001. *Climate Change 2001: The Scientific Basis (Third Assessment report from IPCC Working group 1)*. Cambridge University Press, Cambridge, UK: 94 pp.

Hunt, B.M., Hoefling, K. and Cheng, C.C., 2003. Annual warming episodes in seawater temperatures in McMurdo Sound in relationship to endogenous ice in notothenioid fish. Antarctic Science, 15: 333-338.

Huston, M., Gilbert, N. and Newman, J., (eds.), 2006. Final Comprehensive Evaluation (CEE) for ANDRILL McMurdo Sound Portfolio. Antarctica New Zealand. Christchurch, New Zealand, 152 pp.

Huybrechts, P., 2004. Antarctica: modelling. In Bamber, J.L. and Payne, A.J. (eds), 2004. *Mass Balance of the Cryosphere*. Cambridge University Press, Cambridge, UK: 491-523.

Jacobs, S.S., Fairbanks, R.G. and Horibe, Y. 1985. Origin and evolution of water masses near the Antarctic continental margin: evidence from $H_2^{18}O/H_2^{16}O$ ratios in seawater. In: Jacobs, S.S. (ed.) Oceanology of the Antarctic Continental Shelf. Antarctic Research Series: 43, 59-85.

Jacobs, S.S., Gordon, A.L., Ardai, J.L. Jr., 1979. Circulation and melting beneath the Ross Ice Shelf. Science: 203, 439-443.

Jacobs, S.S., 2004. Bottom water production and its links with the thermohaline circulation. Antarctic Science, 16, 427-437.

Joughin, I. and Tulaczyk, S., 2002. Positive mass balance of the Ross ice streams, West Antarctica. Science, 295: 476-480.

Kaharoeddin, and others, 1988. The U.S. Antarctic Research Program in the western Ross Sea, 1979-80; the sediment descriptions. In: Cassidy, D.S., (ed.), Sedimentology Research Laboratory Contribution 53: Florida State University Department of Geology, Tallahassee, FL: 230 pp.

Kemple, W.G., Sadler, P.M., and Strauss, D.J., 1995. Extending graphic correlation to many dimensions: stratigraphic correlation as constrained optimization. In: Mann, K. O., and Lane, H. R. (eds.). Graphic Correlation. SEPM Society for Sedimentary Geology, Special Publication, 53: 65-82.

Kyle, P.R., 1981. Evolution of a basanite phonolite sequence, Hut Point Peninsula, Antarctica. Evidence from Dry Valley Drilling Project Drillholes 1, 2 and 3. Journal of Petrology 22: 451-500.

Kyle, P. R., 1981, Glacial history of the McMurdo Sound area, as indicated by the distribution and nature of the McMurdo Volcanic Group Rocks. In: McGinnis (ed.), Dry Valley Drilling Project: AGU, Antarctic Research Series, Washington, D.C., 33: 403-412.

Kyle, P.R., 1990a. A. 18 Hut Point Peninsula. In: LeMasurier, W.E. and Thomson, J.W., (eds.), *Volcanoes of the Antarctica Plate and Southern Oceans*, Antarctic Research Series, Washington, D.C.: 48: 109-112.

Kyle, P.R., 1990b. A. Erebus volcanic province, in LeMasurier, W.E. and Thomson, J.W., (eds.), *Volcanoes of the Antarctica Plate and Southern Oceans*, Antarctic Research Series, Washington, D.C.: 48: 81-88.

Kyle, P.R., Moore, J.A. and Thirlwall, M.F., 1992. Petrologic evolution of anorthoclase phonolite lavas at Mount Erebus, Ross Island, Antarctica. J. Petrology, 33: 849-875.

Kukla, G.J., 1977. Pleistocene land-sea correlations I. Europe. Earth-Science Reviews, 13: 307-374.

Licht, K.J., Jennings, A.E., Andrews, J.T. and Williams, K.M., 1996. Chronology of Late Wisconsin ice retreat from the western Ross Sea, Antarctica. Geology, 24: 223-226.

Littlepage, J.L., 1965. Oceanographic investigation in McMurdo Sound, AGU, Antarctica. Antarctic Research Series, 15: 1-37.

Mazzullo, J. and Graham, A.G. (eds.), 1988. Handbook for Shipboard Sedimentologists. ODP Tech. Note, 8: 45-67.

MacAyeal, D.R., 1992. Irregular oscillations of the West Antarctic ice sheet. Nature, 359: 29-32.

McGinnis, L.D., Bowen, R.H., Erickson, J.M., Aldred, B.J. and Kreamer, J.L., 1985. East-West Antarctic boundary in McMurdo Sound. Tectonophysics, 14: 341-356.

McKelvey, B.C. and Stephenson, N.C.N., 1990. A geological reconnaissance of the Radok Lake area, Amery Oasis, Prince Charles Mountains. Antarctic Science, 2: 53–66.

McKelvey, B., Hambrey, M., Harwood, D.M., Mabin, M.C.G., Webb, P.-N. and Whitehead, J., 2001. The Pagodroma Group: the Neogene Record in the Northern Prince Charles Mountains of a dynamic Lambert Glacier and East Antarctic Ice Sheet. Antarctic Science, 13: 455–468.

McPhie, J., Doyle, M., and Allen, R., 1993. Volcanic textures: a guide to the interpretation of textures in volcanic rocks. Centre for Ore Deposit and Exploration Studies, University of Tasmania: Hobart, Tasmania: 198 pp.

Melhuish, A., Henrys, S.A., Bannister, S. and Davey, F.J., 1995. Seismic profiling adjacent to Ross Island: constraints on late Cenozoic stratigraphy and tectonics. Terra Antartica, 2: 127-136.

Medina-Elizalde, M. and Lea D.W., 2005. The Mid-Pleistocene Transition in the Tropical Pacific, Science, 310: 1009-1012.

Miller and Smail, 1997. A semi-quantitative field method for evaluating bioturbation on bedding planes: Palaios, 12: 391-396.

Moore, J. A. and Kyle, P.R., 1990. A. 17 Mount Erebus. In: LeMasurier, W.E. and Thomson, J.W., (eds.) *Volcanoes of the Antarctica Plate and Southern Oceans*. AGU, Antarctic Research Series, Washington, D.C.: 103-108.

Moncrieff, A.C.M., 1989. Classification of poorly sorted sedimentary rocks. Sedimentary Geology, 65: 191-194.

Mudelsee, M. and Schulz, M., 1997. The Mid-Pleistocene climate transition: onset of 100 ka cycle lags ice volume build-up by 280 ka. Earth and Planetary Science Letters, 151: 117-123.

Naish, T, Kamp P.J.J, Pillans, B. 1997. Recurring global sea-level changes recorded in shelf deposits near the G/M polarity transition, Wanganui Basin, New Zealand; implications for redefining the Pliocene-Pleistocene boundary, Quaternary International, 40: 61-71.

Naish, T.R., Woolfe, K.J., Barrett, P.J., Wilson, G.S., Atkins, C., Bohaty, S.M., Buckner, C.J., Claps, M., Davey, F.J., Dunbar, G.B., Dunn, A.G., Fielding, C.R., Florindo, F., Hannah, M.J., Harwood, D.M., Henrys, S.A., Krissek, L.A., Lavelle, M.A., van der Meer, J.J.M., McIntosh, W.C., Niessen, F., Passchier, S., Powell, R.D., Roberts, A.P., Sagnotti, L., Scherer, R.P., Strong, C.P., Talarico, F., Verosub, K.L., Villa, G., Watkins, D.K., Webb, P.-N. and Wonik, T., 2001a. Orbitally induced oscillations in the East Antarctic ice sheet at the Oligocene/Miocene boundary. Nature, 413: 719-723.

Naish, T. R., Barrett, P. J., Dunbar, G. B., Woolfe, K. J., Dunn, A. G., Henrys, S. A., Claps, M., Powell, R. D. and Fielding, C. R., 2001b. Sedimentary cyclicity in CRP drillcore, Victoria Land Basin, Antarctica. Terra Antartica, 8: 225-244.

Naish, T., Powell, R., Barrett, P., Horgan, H., Dunbar, G., Wilson, G., Levy, R., Robinson, N., Carter, L., Pyne, A., Neissen, F., Bannister, S., Balfour, N., Damaske, D., Henrys, S., Kyle, P. and Wilson, T., 2005. ANDRILL McMurdo Ice Shelf Project, Scientific Prospectus. ANDRILL Science Management Office, ANDRILL Contribution 4. University of Nebraska – Lincoln. Lincoln, NE: 21 pp.

Neumann, A.C. and Hearty, P.J., 1996. Rapid sea-level changes at the close of the last interglacial (Substage 5e) recorded in Bahamian island geology. Geology, 24: 775-778.

Powell, R.D., Dawber, M., McInnes, J.N. and Pyne, A.R., 1996. Observations of the grounding line area at a floating glacier terminus. Annals of Glaciology, 22: 217-223.

Powell, R.D., Laird, M.G., Naish, T.R., Fielding, C.R., Krissek, L.A. and van der Meer, J.J.M., 2001. Depositional environments for strata cored in CRP-3 (Cape Roberts Project), Victoria Land Basin, Antarctica; palaeoglaciological and palaeoclimatological inferences. Terra Antartica, 8: 207-216.

Prueher, L.M. and Rhea, D.K., 2001. Volcanic triggering of late Pliocene glaciation: evidence from the flux of volcanic glass and ice-rafted debris to the North Pacific Ocean. Palaeogeography, Palaeoclimatology, Palaeoecology, 173: 215-230.

Ramsay, A. T. S. and Baldauf, J. G. 1999. *A reassessment of the Southern Ocean Biochronology*. Geological Society of London Memoir, 18.

Raymo, M. E., Ruddiman, W. F., Backman, J., Clement B. M. and Martinson, D. G. 1989. Late Pliocene variation in Northern Hemisphere ice sheets and North Atlantic deep water circulation, Paleoceanography, 4: 413-446.

Robinson, R.S., Brunelle, B.G. and Sigman, D.M., 2004. Revisiting nutrient utilization in the glacial Antarctic: evidence from a new method for diatom-bound N isotopic analysis. Paleoceanography, 19: PA3001, doi: 10.1029/2003PA000996.

Rott, H., Rack, W., Nagler, T. and Skvarca, P. 1998. Climatically induced retreat and collapse of northern Larsen Ice Shelf, Antarctic Peninsula. Annals of Glaciology, 27: 86-92.

Rott, H., Rack, W., Skvarca, P. and de Angelis, H., 2002. Northern Larsen Ice Shelf – further retreat after the collapse. Annals of Glaciology, 34: 277-282.

Rott, H., Skvarca, P. and Nagler, T., 1996. Rapid collapse of the northern Larsen Ice Shelf, Antarctica. Science, 271: 788-792.

Sadler, P.M., 2001. Constrained optimization approaches to the paleobiologic correlation and seriation problems: A users guide and reference manual to the CONOP program family: Riverside, CA,Peter M. Sadler, 165 pp.

Sadler, P.M., 2004. Quantitative biostratigraphy – achieving finer resolution in global correlation: Annual review of Earth and Planetary Sciences, 32: 187-213.

Schmid, R., 1981. Descriptive nomenclature and classification of pyroclastic deposits and fragments: Recommendations of the IUGS subcommission on the systematics of igneous rocks. Geology, 9: 41-43.

Schmieder, F., von Dobeneck, T. and Bleil, U. 2000. The Mid-Pleistocene climate transition as documented in the deep South Atlantic Ocean: initiation, interim state and terminal event, Earth and Planetary Science Letters, 179: 539-549.

Scherer, R.P., Aldahan, A., Tulaczyk, S., Kamb., B., Engelhardt, H. and Possnert, G., 1998. Pleistocene collapse of the West Antarctic Ice Sheet. Science, 281: 82-85.

Scherer, R. P., 1991. Quaternary and Tertiary microfossils from beneath Ice Stream B: evidence for a dynamic West Antarctic Ice Sheet history. Palaeogeography, Palaeoclimatology, Palaeoecology 90, 395–412.

Scherer, R.P., 1994. A new method for the determination of absolute diatom abundance and other silt-sized sedimentary particles. Journal of Paleolimnology, 12: 171– 179.

Scherer, R.P. and Koc, N., 1996. Late Paleogene diatom biostratigraphy and paleoenvironments of the northern Norwegian-Greenland Sea. *Proceedings of the Ocean Drilling Program, Scientific Results.* 151: 75-100.

Scherer, R. P., Bohaty, S. M. and Harwood, D. M., 2000. Oligocene and Lower Miocene siliceous microfossil biostratigraphy of Cape Roberts Project Core CRP-2/2A, Victoria Land Basin, Antarctica. Terra Antartica 7: 417–442.

Scherer, R., Sjunneskog, C., Iversen, N., Hooyer, T., 2004. Assessing sub-glacial processes from diatom fragmentation patterns. Geology, 32 (7): 557–560.

Sigman, D.M., Altabet, M.A., Francois, R., McCorkle, D.C., and Gaillard, J.-F., 1999. The isotopic composition of diatom-bound nitrogen in Southern Ocean Sediments. Paleoceanography, 14(2): 118-134, doi: 0883-8305/99/1998PA900018.

Sjunneskog, C. and Scherer, R., 2005. Mixed diatom assemblages in glacigenic sediment from the central Ross Sea, Antarctica. Palaeogeography, Palaeoclimatology, Palaeoecology, 218: 287– 300.

Skvarca, P., 1993. Fast recession of the northern Larsen Ice Shelf, monitored by space images. Annals of Glaciology, 17: 317- 321.

Skvarca, P., Rack, W., Rott, H. and Ibarzábal-Donángelo, T., 1999. Climatic trend and the retreat and disintegration of ice shelves on the Antarctic Peninsula: an overview. Polar Research, 18: 151-157.

Shackleton, N.J., Crowhurst, S., Hagelberg, T., Pisias, N.G. and Schneider, D.A., 1995. A new late Neogene time scale; application to Leg 138 sites. Proceedings of the Ocean Drilling Program, Scientific Results, 138: 73-101.

Shackleton, N.J., 2000. The 100,000 year ice-age cycle identified and found to lag temperature, carbon dioxide, and orbital eccentricity. Science, 289: 1897-1902.

Slater, L., Jull, M., McKenzie, D. and Gronvold, K., 1998. Deglaciation effects on mantle melting under Iceland: results from the northern volcanic zone. Earth and Planetary Science Letters, 164: 151-164.

Stern, T.A., Davey, F.J. and Delisle, G., 1991. Lithospheric flexure induced by the load of the Ross Archipelago, southern Victoria land, Antarctica. In Thomson, M.R.A., Crame, A., and Thomson, J.W. (eds.), *Geological Evolution of Antarctica*, Cambridge University Press, Cambridge, UK: 323-328.

Taviani, M. and Beu, A.G., 2003. The paleoclimatic significance of Cenozoic marine macrofossil assemblages from Cape Roberts Project drillholes, McMurdo Sound, Victoria Land Basin, East Antarctica. Palaeogeography, Palaeoclimatology, Palaeoecology, 198: 131-143.

Taviani, M. and Claps, M., 1998. Biogenic Quaternary carbonates in the CRP-1 drillhole, Victoria Land Basin, Antarctica. *Studies from the Cape Roberts Project, Ross Sea, Antarctica, Scientific Report on CRP-1,* Terra Antartica, 5 (3): 411-418.

Taviani, M. and Zahn, R., 1998. The stable oxygen isotope record of Pleistocene and Miocene bivalves in the CRP-1 drillhole, Victoria Land Basin, Antarctica. *Studies from the Cape Roberts Project, Ross Sea, Antarctica, Scientific Report on CRP-1.* Terra Antartica, 5 (3): 419-424.

Taviani, M., Beu A. and Lombardo, C., 1998. Pleistocene macrofossils from CRP-1 drillhole, Victoria Land Basin, Antarctica. *Studies from the Cape Roberts Project, Ross Sea, Antarctica, Scientific Report on CRP-1.* Terra Antartica, 5 (3): 485-492.

Taviani, M., Montagna, P., McCulloch, M., Remia, A. and Schiaparelli, S., 2006. Deep-water corals as proxy of variability in the formation of Southern Ocean masses: a pilot study. Journal of Marine Systems (submitted April 2006).

Stocker, T.F., 2003. South dials the north. Nature, 424: 496-497.

Tauxe, L., Gans. P. and Mankinen, E.A., 2004. Paleomagnetism and $^{40}Ar/^{39}Ar$ ages from volcanics extruded during the Matuyama and Brunhes Chrons near McMurdo Sound, Antarctica. Geochemistry, Geophysics, Geosystems, 5 Q06H12, doi:10,1029/2003GC000656.

ten Brink, U.S., Hackney, R.I., Bannister, S., Stern, T.A. and Makosvsky, Y., 1997. Uplift of the Transantarctic Mountains and the bedrock beneath the East Antarctic Ice Sheet. J. Geophysical Research, 102: 27603-27621.

Vaughn, D.G. and Doake, C.S.M., 1996. Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula. Nature, 379: 328-331.

Villa, G. et al. in prep. The Pleistocene evolution of the East Antarctic Ice Sheet in the Prydz Bay region: calcareous nannofossil and environmental magnetism evidences from ODP Site 1165.

Villa, G., Palandri, S. and Wise, S.W. Jr., 2005. Quaternary calcareous nannofossils from Periantarctic basins: Paleoecological and paleoclimatic implication. Marine Micropaleontology, 56: 103-121.

Villa, G., Persico, D., Bonci, M.C., Lucchi, R.G., Morigi, C. and Rebesco, M., 2003. Biostratigraphic characterization and Quaternary microfossil palaeoecology in sediment drifts west of the Antarctic Penisula – implications for cyclic glacial-interglacial deposition. Palaeogeography Palaeoclimatology Palaeoecology, 198: 237-263.

Villa, G. and Wise, S.W. Jr., 1998. Quaternary calcareous nannofossil from the Antarctic region. Terra Antartica, 5 (3): 479-484.

Webb, P.-N. and Strong, C.P., 1998: Occurrence, stratigraphic distribution and palaeoecology of Quaternary foraminifera from CRP-1. Terra Antartica *5(3):* 455-472.

Weaver, A.J., Saenko, O.A., Clark, P.U. and Mitrovica, J.X., 2003. Meltwater pulse 1A from Antarctica as a trigger of the Bolling-Allerod warm interval. Science, 299: 1709-1713.

Whitehead, J.M. and Bohaty, S.M., 2003. Data report: Quaternary–Pliocene diatom biostratigraphy of ODP Sites 1165 and 1166, Cooperation Sea and Prydz Bay. In: Cooper, A.K., O'Brien, P.E., and Richter, C. (eds.). *Proc. ODP, Sci. Results,* 188, 1–25 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/188_SR/VOLUME/CHAPTERS/ 008.PDF>. [Cited 2006-03-30].

Whitehead, J.M., Harwood, D.M., McKelvey, B.C., Hambrey, M.J. and McMinn, A., 2004. Diatom biostratigraphy of the Cenozoic glaciomarine Pagodroma Group, northern Prince Charles Mountains, East Antarctica. Australian Journal of Earth Sciences, 51: 521-547.

Whittaker, J., 2005. Cenozoic Structural and Stratigraphic History of McMurdo Sound, Antarctica [M.Sc. thesis]: Wellington, New Zealand, Victoria University of Wellington.

Wilson, G., Naish, T., Jordon, T., Damaske, D., Ali, M., Horgan, H., Balfour, N., Watts, A., Bannister, S. and the ANDRILL site survey team, 2003. Using flexural modeling and geophysical data to define Neogene stratigraphic drilling targets in moat basins beneath the McMurdo Ice Shelf. European Geophysical Society, Geophysical Research Abstracts, 5,: art. no. 05682.

Wilson, G.S., and others, 2002. Integrated chronostratigraphic calibration of the Oligocene-Miocene boundary at 24.0± 0.1 Ma from the CRP-2A drill core, Ross Sea, Antarctica. Geology, 30: 1043-1046.

Wilson, T.J., Lawver, L.A., Henrys, S., Lowe, A., Watson, Capt. M., 2004. Cruise Report NBP04_01 19 January to 18 February 2004 – McMurdo Station to McMurdo Station, Ross Sea, Antarctica. Institute of Geological & Nuclear Sciences, Science Report 2004/03: 85 pp.

Winter, D.M. and Harwood, D.M., 1997. Integrated diatom biostratigraphy of late Neogene drillholes in Southern Victoria Land and correlation to Southern Ocean records. In: Ricci C. A. (ed.). *The Antarctic Region; Geological Evolution and Processes; Proceedings of the VII International Symposium on Antarctic Earth Sciences*, Terra Antartica Publishers, Siena: 985–992.

Winter, D. and Iwai, M., 2002. Data report: Neogene diatom biostratigraphy, Antarctic Peninsula Pacific margin, ODP Leg 178 rise sites. Proceedings of the Ocean Drilling Program, Scientific Results, 178 <http://www-Odp.Tamu.Edu/Publications/178_SR/Chap_29/Chap_29.htm> [Cited 2006-03-30].

Wright, A.C. and Kyle, P.R., 1990a. A.15 Mount Bird, in Le Masurier, W.E., and Thomson, J.W., (eds.), *Volcanoes of the Antarctica Plate and Southern Oceans*, Antarctic Research Series, Washington, D.C. 48: 97-98.

Wright, A.C. and Kyle, P.R., 1990b. A.16 Mount Terror, in Le Masurier, W.E., and Thomson, J.W., (eds.), *Volcanoes of the Antarctica Plate and Southern Oceans*, Antarctic Research Series, Washington, D.C. 48: 99-102.

Yanagisawa, Y. and Akiba, F., 1998. Refined Neogene diatom biostratigraphy for the Northwest Pacific around Japan, with an introduction of code numbers for selected diatom biohorizons. Journal of the Geological Society of Japan 104: 395–414.

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E. and Billups, K., 2001a. Trends, rhythms, and aberrations in global climate 65 Ma to present, Science, 292: 686-693.

Zachos, J.C., Shackleton, N.J., Ravenaugh, J.S., Palike, H. and Flower, B.P.. 2001b. Climate response to orbital forcing across the oligocene-Miocene boundary, Science, 292: 274-278.

Zielinski, U. and Gersonde, R., 2002. Plio-Pleistocene diatom biostratigraphy from ODP Leg 177, Atlantic sector of the Southern Ocean. Marine Micropaleontology, 45: 225–268.

Zotikov, I.A., Zagorodnov, V.S. and Raikovsky, J.V, 1980. Core drilling through the Ross Ice Shelf (Antarctica) confirmed basal freezing. Science, 207: 1463-1465.

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TABLE 2

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Tim Naish (NZ) | Co Chief Scientist | Overall leadership and management of MIS science activities, Co-ordination of post-drilling workshop, publication of initial science report, co-ordination of science integration workshop, publication of science results volumes. Co-ordinate synthesis papers and the production of popular articles. Promote the successes of the project through conference | | | | |
| Ross Powell (US) | Co Chief Scientist | Overall leadership and management of MIS science activities, Co-ordination of post-drilling workshop, publication of initial science report, co-ordination of science integration workshop, publication of science results volumes. Co-ordinate synthesis papers and the production of popular articles. Promote the successes of the project through conference | | | | |
| Richard Levy (SMO) | Staff Scientist | Responsible for ensuring the effective implementation of the MIS science plan by helping co-ordinate the post-ice core workshop, and the science integration workshop | Work with Crampton and Harwood and PhD student on quantitative stratigraphic correlation of MIS and other high-latitude records | | | |
| TBA (US) | EPO Co-ordinator | Leadership and co-ordination of the ARISE Programme educators and facilitate successful completion of MIS ARISE | | | | |
| Laura Lacy (SMO) | Research Support Coordinator | SMO research support co-ordinator for MIS workshops and publication of materials | | | | |
| Megan Berg (SMO) | Graphics and web | Web site management and graphics. | | | | |
| Josh Reed (CHRONOS) | Database Coordinator | Ongoing support of data management and visualisation systems. | | | | |
| Matt Olney (US) | Head Curator | Co-ordinate core viewing and sampling at post drilling core workshop, ongoing support of core studies. | | | | |
| Matt Curren (US) | Assistant Curator | Co-ordinate core viewing and sampling at post drilling core workshop, ongoing support of core studies. | | | | |
| Betty Trummel (US) | ARISE | | | | | |
| LuAnn Dahlman (US) | ARISE | | | | | |
| Vanessa Miller (US) | ARISE | | | | | |
| Julian Thompson (NZ) | ARISE | | | | | |
| Alexander Siegmund (DE) | ARISE | | | | | |
| Matteo Cattadori (IT) | ARISE | | | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| | **Sedimentology** | | | | | |
| Larry Krissek (US) | Discipline Team Leader/ sedimentology | Leadership and co-ordination of the sedimentology/stratigraphy team. Responsible for co-ordinating the sedimentology group at post-drilling workshop and identifying key areas of scientific interest for further work and publication. Help co-chiefs with the production and editing of science results volumes and the initial reports | Major contributor and compiler for the initial report. Attend and help facilitate core workshop. Ensure co-ordination of post-ice scientific investigations, interpretations and syntheses. Help co-ordinate and edit thematic issues and science report papers for the Sedimentology/stratigraphy group. Analyze a limited number of mudrock samples for bulk and clay mineralogy using XRD to infer temporal variations in weathering conditions and provenance. | 2-5m | 20cc | 400-600 |
| Robert McKay (NZ) | Sedimentary petrology | Contribute to initial report. Attend core workshop. Sediment textural analyses and contribution to facies analysis, depositional and provenance history. PhD student | Sample diamictites for clast analysis, shape, orientation and glacial features. | facies dependent | 25cm whole core | facies dependent |
| Lionel Carter (NZ) | Marine sedimentology | Contribute to initial report. Attend core workshop. Continue general sedimentological interpretation in the context of oceanographic and glacimarine processes. | Based on core characterisation phase, undertake high-resolution sedimentological and geochemical analyses (Mg/Ca on forams) and contribute to integration of multidisciplinary datasets. Integrate with far-field coeval oceanographic data. | intense sampling over limited intervals | 20cc | ? |
| Ellen Cowan (US) | Glacial sedimentology | Contribute to initial report. Attend core workshop.Continue the characterisation and interpretation of glacial facies and integrate with sedimentology team | If necessary continue sampling for thin-section microscopic analyses of glacial | all facies | thin section block or 10cc in unconsolidated sediments | ? |
| Gavin Dunbar (NZ) | Facies analysis | Contribution to initial report. Attend core workshop. Sediment textural analyses and contribution to facies analysis and depositional and environmental history. | Grainsize analysis (laser). Possible sampling of diatomaceous intervals for geochemical analysis of sea-ice proximity | diatomaceous facies | 10cc | limited number of diatomaceous facies |
| Thom Wilch (US) | Volcaniclastic sedimentology | Contribution to initial report. Attend core workshop .Further characterization and interpretation of the mode of emplacement of volcaniclastic deposits. Contribute to volcanic history and age assessment | Additional sampling of volcaniclastic intervals | dependent on occurrence | 1-2cc | dependent on occurrence |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Linda Hinnov (US) | Spectral analysis | Await data produced by the sedimentology and chronstratigraphic teams. There may not be a need at this stage to be engaged. Contribute to initial report. Attend core | Contribute to cyclostratigraphic analysis of proxy datasets as required | | | |
| Giovanna Georgetti (IT) | Sedimentology/mineralogy | Contribute to sediment geochemistry in collaboration with Larry Krissek and the sedimentology team and also the petrology team (Kuhn, Bellanca). Specifically, sand XRD, bulk XRF and ICPMS analyses. | Mineralogical and geochemical characterisation | 1 sample/1 kyr | 5-10cc | sedimentation rate dependent |
| Molly Miller (US) | Ichnology | Await appropriate samples from the on-ice sedimentology team for analysis. Depending on need for interpretive data and core quality, this may be required at during drilling. Contribute to initial report if necessary and attend core workshop. | Conduct study on the trace fossil component of the core, from visual inspection, x-ray and slabs | where appropriate material occurs | whole core slabs - non-destructive | <10 |
| | **Paleontology/biostratigraphy** | | | | | |
| Reed Scherer (US) | Discipline Team Leader/ diatom | Leadership and co-ordination of the paleontology/biostratigraphy team. Responsible for co-ordinating the group at post-drilling workshop and identifying key areas of scientific interest for further work and publication. Help co-chiefs with the production and editing of science results volumes and the initial reports | Major contributor and compiler for the initial report. Attend and help facilitate core workshop. Ensure co-ordination of post-ice scientific investigations, interpretations and syntheses. Help co-ordinate and edit thematic issues and science report papers for the Paleontology group. Review core material at the workshop and determine further sampling intervals. Further characterization and interpretation of the biostratigraphy and paleoenvironmental history. Work with the Chronostratigraphic Team to determine reliable age-depth | | | |
| Erica Crouch (NZ) | Marine palynology | Contribute to initial report. Continue analysis of marine palynomorphs in collaboration with the paleontology and sedimentology group. | Undertake biostratigraphic and environmental analysis and interpretations. Additional sampling if required. | | | |
| Martin Crundwell (NZ) | Foraminifera | If significant numbers of forams are encountered work with Percy Strong to undertake foraminiferal census work for palaeoecological reconstructions and biostratigraphy. | | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Tim Naish (NZ) | Co Chief Scientist | Overall leadership and management of MIS science activities, Co-ordination of post-drilling workshop, publication of initial science report, co-ordination of science integration workshop, publication of science results volumes. Co-ordinate synthesis papers and the production of popular articles. Promote the successes of the project through conference | | | | |
| Ross Powell (US) | Co Chief Scientist | Overall leadership and management of MIS science activities, Co-ordination of post-drilling workshop, publication of initial science report, co-ordination of science integration workshop, publication of science results volumes. Co-ordinate synthesis papers and the production of popular articles. Promote the successes of the project through conference | | | | |
| Richard Levy (SMO) | Staff Scientist | Responsible for ensuring the effective implementation of the MIS science plan by helping co-ordinate the post-ice core workshop, and the science integration workshop | Work with Crampton and Harwood and PhD student on quantitative stratigraphic correlation of MIS and other high-latitude records | | | |
| TBA (US) | EPO Co-ordinator | Leadership and co-ordination of the ARISE Programme educators and facilitate successful completion of MIS ARISE | | | | |
| Laura Lacy (SMO) | Research Support Coordinator | SMO research support co-ordinator for MIS workshops and publication of materials | | | | |
| Megan Berg (SMO) | Graphics and web | Web site management and graphics. | | | | |
| Josh Reed (CHRONOS) | Database Coordinator | Ongoing support of data management and visualisation systems. | | | | |
| Matt Olney (US) | Head Curator | Co-ordinate core viewing and sampling at post drilling core workshop, ongoing support of core studies. | | | | |
| Matt Curren (US) | Assistant Curator | Co-ordinate core viewing and sampling at post drilling core workshop, ongoing support of core studies. | | | | |
| Betty Trummel (US) | ARISE | | | | | |
| LuAnn Dahlman (US) | ARISE | | | | | |
| Vanessa Miller (US) | ARISE | | | | | |
| Julian Thompson (NZ) | ARISE | | | | | |
| Alexander Siegmund (DE) | ARISE | | | | | |
| Matteo Cattadori (IT) | ARISE | | | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Diane Winter (US) | Diatom biostratigraphy | Review core material at the workshop and determine further sampling intervals. Further characterization and interpretation of the biostratigraphy and paleoevironmental history. Work with the Chronostratigraphic Team to determine reliable age-depth model for the cored section. | Undertake biostratigraphic and environmental analysis and interpretations. Additional sampling if required. | | | |
| Woody Wise (US) | Nannofossil biostratigraphy | Contribute to initial report. Attend core workshop. Help co-ordinate core workshop. If appropriate material undertake analysis of nannofossils for palaeoecology and biostratigraphy. Collaborate with paleontology group and the ANDRILL science team as appropriate | Sampling for nannofossil biostratigraphy. Undertake biostratigraphic and environmental analysis and interpretations. | every c. 10 cm in each fine-grained lithology | 2cc | |
| | **Physical properties** | | | | | |
| Frank Niessen (DE) | Discipline Team Leader/ MST scanning | Leadership and co-ordination of the physical properties team. Responsible for co-ordinating the this group at post-drilling workshop and identifying key areas of scientific interest for further work and publication. Help co-chiefs with the production and editing of science results volumes and the initial reports | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. Major contributor and compiler for the initial report. Attend and help facilitate core workshop. Ensure co-ordination of post-ice scientific investigations, interpretations and syntheses. Help co-ordinate and edit thematic issues and science report papers for the Physical Properties group. | | | |
| Andrea Catalina Gebhardt (DE) | MST Tech | | | | | |
| Rich Jarrard (US) | Downhole logging | Contribute to initial report. Attend core workshop. Receive data from on-ice downhole logging team and process the data in a preliminary, but timely way for the on-ice report. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Stuart Henrys (NZ) | VSP - seismic stratigraphy | Contribute to the integration of the borehole and core data with more regional seismic stratigraphic architecture of the Victoria Land Basin. Contribute to the Neogene tectonic evolution of the basin with collaborators. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Dhiresh Hansaraj (NZ) | VSP - seismic stratigraphy | MSc student with Henrys and Naish. Thesis will involve seismic well correlations and interpretations. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Diana Magens (DE) | MST Tech | ? | | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Andreas Laeufer (DE) | Whole core fractures | Contribute to initial report. Attend core workshop. Contribute with US collaborators to the investigation the kinematics and dynamics of rifting, the related faulting history and palaeostress states in the western Ross Sea during the Neogene-Recent. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Roger Morin (US) | Down hole logging | Contribute to initial report. Attend core workshop. Once all data have been collected, produce documentation of | Further analysis of data, interpretation synthesis and | | | |
| Tim Paulsen (US) | Whole core fractures | Contribute to initial report. Attend core workshop. Before the core sampling workshop process data on fracture type, dip direction, dip angle, and depth for intact core intervals, make thin sections and begin petrographic microstructural analyses for palaeostress analysis. Submit a supplementary research proposal for Science Documentation Phase for data sorting, orientation analysis, palaeostress analysis, interpretation, and preparation of manuscripts for publication. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Trevor Williams (US) | Down hole logging | Contribute to initial report. Attend core workshop. Continue to work on and analyze data. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Cristina Milan-Martinez (US) | Whole core fractures | Contribute to initial report. Attend core workshop. Make thin sections and begin petrographic microstructural analyses focused on description, classification, and interpretation of clastic dykes, veins, and microfaults. Create digital whole-core intervals for core orientation. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Travis Crosby (US) | Down hole logging | Contribute to initial report. Attend core workshop. Continue to work on and analyze data. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |
| Terry Wilson (US) | Whole core fractures/hydrofracture | Contribute to initial report. Attend core workshop. Before the core sampling workshop process data on fracture type, dip direction, dip angle, and depth for intact core intervals, make thin sections and begin petrographic microstructural analyses focused on description, classification, and interpretation of clastic dykes, veins, and microfaults. Submit a supplementary research proposal for Science Documentation Phase for data sorting, orientation analysis, palaeostress analysis, contemporary stress analysis, interpretation, and preparation of manuscripts for publication. | Further analysis of data, interpretation synthesis and integration with other teams. | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| | **Geochronology/Chronostratigraphy** | | | | | |
| Gary Wilson (NZ) | Discipline Team Leader/ paleomagnetism | Leadership and co-ordination of the geochronology/chronostratigraphy team. Responsible for co-ordinating the group at post-drilling workshop and identifying key areas of scientific interest for further work and publication. Help co-chiefs with the production and editing of science results volumes and the initial reports. Lead the development of the age model | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. Major contributor and compiler for the initial report. Attend and help facilitate core workshop. Ensure co-ordination of post-ice scientific investigations, interpretations and syntheses. Help co-ordinate and edit thematic issues and science report papers for the Chronostratigraphy/ Geochronology group. | see Wilson G | | |
| Fabio Florindo (IT) | Paleomagnetism | Contribute to initial report. Attend core workshop. Contribute to paleomagnetic analysis of the MIS core with other members of the paleomagnetic team. Also contribute to the integrated chronostratigraphic framework for the MIS drillcore and correlation to other Antarctic and Southern Ocean drillcores. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | see Wilson G | | |
| Christian Ohneiser (NZ) | Paleomag Tech | Contribute to initial report. Attend core workshop. Contribution to the analysis, interpretation of the paleomagnetic data under the supervision of Gary Wilson. Production of a PhD thesis using MIS paleomagnetic data. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | | | |
| Glenn Berger (US) | Luminescence dating of quartz | Contribute to initial report. Attend core workshop. Grain-quartz luminescence dating of selected Pleistocene-Holocene horizons. May receive samples for laboratory analysis if any appropriate material is found and it is deemed useful to obtain a date at that particular interval. | Thermoluminescence dating | only fine-sand dominant horizons | 1 2-oz cylindrical tin (60 ml: 51mm diam. x 32mm deep) and 2 15-ml tins (34 mm diam. x 15 mm deep) | 3 through all of core |
| Stefanie Brachfield (US) | Paleomagnetism | Contribute to initial report. Attend core workshop. Processing samples sent by the on-ice paleomagnetic's team for establishing magnetostratigraphy during drilling. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | see Wilson G | | |
| James Crampton (NZ) | Quantitative stratigraphic correlation (CONOP) | Contribute to quantitative stratigraphic analysis and correlation of the MIS drillcore record with other Ross Sea and Southern Ocean drill sequences using CONOP. Contribute to an integrated chronostratigraphy for the MIS drill core. Collaborations will be most closely with Richard Levy, but will also involve the paleontology, sedimentology and geochronology teams. | Further analysis of data, interpretation synthesis and integration with other teams. Support PhD student and work with Harwood and Levy | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Ian Graham (NZ) | Sr Chronology | Contribute to initial report. Attend core workshop. Receive and prepare carbonate material (if suitable) at GNS Science for Sr geochronology. Co-ordinate analyses and interpret results. Marco Taviani (micropaleontology's) will identify and sample material on-ice. Attend core workshop and contribute to the integrated chronostratigraphy of the ANDRILL MIS core. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | fossiliferous material for Sr dating depending on occurrence | | |
| Leah Joseph (US) | Paleomagnetism | Contribute to initial report. Attend core workshop. Further process the data and provide interpretations that integrate with other sedimentological/stratigraphic/structural data and interpretations | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | see Wilson G | | |
| Bill Mackintosh (US) | Ar/Ar chronology | Perform Ar/Ar dating of tephra and volcanic rocks sent off-ice by the on-ice Petrology/Geochemistry Team, and provide results to the MIS team in a timely manner. Contribute to initial report. Attend core workshop. | Continue sampling and analysis of tephra for Ar chronology and contribute to the MIS age model | See Wilch and Kyle | | |
| Jaakko Putkonnin | 10Be cosmogenic chronology | Contribute to initial report. Attend core workshop. Work with on-ice sampling team to supply samples for dating analysis and perform preliminary dating on the samples as a test of the potential of this technique to constrain sediment age and history of the size of the ice sheet. Work in collaboration with Albert Zondervan of New Zealand. | If successful continue analysis and additional sampling if required. Contribute to MIS Age model. | | | |
| Leonardo Sagnotti (IT) | Paleomagnetism | Contribute to paleomagnetic analysis of the MIS core with other members of the paleomagnetic team. Also contribute to the integrated chronostratigraphic framework for the MIS drillcore and correlation to other Antarctic and Southern Ocean drillcores. Contribute to the development of environmental magnetic records and integrate with other proxies to address paleoclimatic and tectonic/provenance questions. Contribute to initial report. Attend core workshop. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | see Wilson G | | |
| Albert Zondervan (NZ) | 10Be cosmogenic chronology | Contribute to initial report. Attend core workshop. Contribute to the development of a Be-chronology for the drillcore and/or use Be/Al cosmogonic isotopic analysis of sediments as a paleoclimatic proxy. If suitable sediments can be identified. Attend the core workshop and collaborate with Jaakko Putkonen (US) who will also do Be-chronology. Contribute to the integrated chronostratigraphy with other MIS ANDRILL scientists. | If successful continue analysis and additional sampling if required. Contribute to MIS Age model. | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| | **Geochemistry/Petrology** | | | | | |
| Massimo Pompilio (IT) | Discipline Team Leader/Igneous petrology and Volcanology | Leadership and co-ordination of the petrology/geochemistry team. Responsible for co-ordinating the group at post-drilling workshop and identifying key areas of scientific interest for further work and publication. Help co-chiefs with the production and editing of science results volumes and the initial reports. Lead the development of the age model. Individual research interests include volcanic petrology and geochemical characterisation and interpretation of primary volcanic material Collaborate with a the volcanic petrology group that comprises Phil Kyle, Nelia Dunbar , Thom Wilch, Riccardo Vannucci, Roberto Udisti and Andreas Veit. | Major contributor and compiler for the initial report. Attend and help facilitate core works. Ensure co-ordination of post- ice scientific investigations, interpretations and syntheses. Help co-ordinate and edit thematic issues and science report papers for the petrology and geochemistry group. Ensure that the group contributes to the understanding of the diagenetic processes represented by the core, sediment provenance (glacial history), uplift and erosion of the TAM, and the magmatic evolution and volcanic history of the Victoria land Basin. | | | |
| Gerhard Kuhn (DE) | Sediment geochemistry-XRF core scanning | Attend core workshop. Continue work on whole rock bulk XRF calibration of XRF scan data with Lothar Viereck-Goette and contribute to the provenance, erosional history and paleoclimatic interpretation of the core. XRF data will form a key component of the integrated dataset that will be of interest to many of the MIS ANDRILL Science Team | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | | | |
| Donata Helling (DE) | Sediment geochemistry-XRF core scanning | Collaborate with Gerhard Kuhn and Lothar Viereck-Goette | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | | | |
| Phil Kyle (US) | Igneous petrology and Volcanology | Attend core workshop. Contribute to initial report. Assist with volcanic examination of cores, select samples Ar dating, select samples for off-ice geochemistry. | Review core material at the workshop for further characterization and interpretation of the mode of emplacement of volcanic rocks. Contribute to volcanic history and age of the core. Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Franco Talarico (IT) | Clast petrology | Attend core workshop. Contribute to initial report. Contribute to petrographical and compositional characterisation of clasts to infer provenance. Collaborative with Alan Cooper and Sonia Sandroni and sedimentology team. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | | | |
| Stefan Vogel (US) | Porewater geochemistry | Attend core workshop. Contribute to initial report. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | | | |
| Fulvia Aghib (IT) | Sediment diagenesis | Attend core workshop. Contribute to the study of diagenetic features of the core. Specifically characterisation of the preservation of biogenic opal, documentation of fabrics, microstructures of diagenetic features, investigation of the origin of carbonate cement using cathodluminscence. Collaborate with Adriana Bellanca and Stefan Vogel. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | 1 sample/every 5-10 meters, | 10 cc | 100 |
| Joel Baker (NZ) | Isotope geochemistry and sediment provenance | Contribute to high precision isotopic analysis of bulk sediments and single grain detrital feldspar and zircon using Pb, Nd, Hf isotopes and Pb-Pb and Lu-Hf age determination. Contribute to crustal provenance studies. Working with Dickinson, Bakers lab | High precision Pb, Nd, Hf isotopic analyses of bulk samples and Pb-Pb and Lu-Hf age determination of single grain feldspar and zircon. | where appropriate | (i) 1 g of bulk sediment (mud or sand) for bulk isotopic analysis; (ii) up to several grams of bulk sediment (sand-sized) for extraction of feldspar and zircon separates | |
| Adriana Bellanca (IT) | Sediment geochemistry and diagenesis | Attend core workshop. Contribute to characterisation of major and trace element composition of sediment whole rock samples (sand) using XRF for provenance and erosional history. Collaborate with Gerhard Kuhn's group using XRF scanning. Collaborate with Fulvia Aghib and the pore water geochemistry group (Vogel and Tulaczyk) .Contribute to the analysis of carbonate cements in order to understand their evolution using stable isotope analyses, and bulk geochemical techniques. | Further analysis of data, interpretation synthesis and integration with other teams. | where appropriate | 5 -10 g | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Barry Cameron (US) | Geochemistry of volcanic glasses | Attend core workshop if suitable material is cored. Can use the geochemistry of glass in hyloclastites to estimate ice cover. As yet it is unknown if appropriate sample material will be recovered. May receive samples for laboratory analysis if any appropriate material is found and it is deemed useful to assess this procedure for interpreting the | Volatile analyses in volcanic glasses by micro FT-IR . Stable isotopes in volcanic glasses. Integration with other teams. More sampling may be required . | where appropriat e material occurs | 100 mg of glass material | ideally about 36 depending on types of materials recovered |
| Alan Cooper (NZ) | Clast petrology | Attend core workshop. Contribute to petrographical and compositional characterisation of clasts to infer provenance. Collaborative with Sonia Sandroni and Franco Talarico and sedimentology team. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | where appropriat e | thin section of clasts | |
| Nelia Dunbar (US) | Geochemistry and petrology of volcaniclastics rocks | Attend core workshop. Contribute to initial report. Will receive samples for laboratory analysis if any appropriate material is found for Ar-dating and it is deemed useful for a particular interval. Carry out preliminary basic petrological and mineralogical observations that include backscattered-electron (BSE) imaging and EMP determination to select particles for successive quantitative analysis and dating. | Further analysis of data, interpretation synthesis and integration with other teams in particular with B. Mackintosh (Geochronology) for characterising and dating tephra | occurrence dependent | 10 <1g samples from each sample interval | 30-40 |
| Rob Dunbar (US) | Diatom biogeochemistry | Attend core workshop, Contribute to the dating of carbonates with C14, U/Th by ICPMS-ID. Measure sedimentary C13/N15. Collaborate with Christina Riesselman | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | 2 cm in diatoms | 2 cc | |
| Warren Dickinson (NZ) | Isotope geochemistry and sediment provenance | Attend core workshop.Contribute to high precision isotopic analysis of bulk sediments and single grain detrital feldspar and zircon using Pb, Nd, Hf isotopes and Pb-Pb and Lu-Hf age determination. Contribute to crustal provenance studies. | High precision Pb, Nd, Hf isotopic analyses of bulk samples and Pb-Pb and Lu-Hf age determination of single grain feldspar and zircon. | where appropriat e | (i) 1 g of bulk sediment (mud or sand) for bulk isotopic analysis; (ii) up to several grams of bulk sediment (sand-sized) for extraction | |
| Kevin Mandernack (US) | Microbiology | Review core at the workshop to determine if there is any appropriate material for further analysis deeper in the core. Further characterization and interpretation of the geomicrobioligcal data if there is sufficient material recovered and it is appropriate. Contribute to the paleontological and biological characterization of the core in reports and papers. | Continue analysis of lipids, DNA and pore water geochemistry. | | | |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Christina Riesselman (US) | Diatom biogeochemistry | Attend core workshop. Contribute to initial report. Sample for geochemical analysis of diatoms for sea-ice proximity (work with Rob Dunbar) and productivity. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | from 3.2 - 1.7 Ma with one sample per ~ 5 kyr | 5-10cc | |
| Sonia Sandroni (IT) | Clast petrology | Attend core workshop. Contribute to petrographical and compositional characterisation of clasts to infer provenance. Collaborative with Alan Cooper and Franco Talarico | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required . | see Talarico | see Talarico | |
| Slawek TulaczyK (US) | Pore water geochemistry and glacial evolution | Attend core workshop. Collaborate with Stefan Vogel, Kevin Mandernack. | see Vogel, Mandernack on-ice sampling plans. Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. Analyse on ice pore water samples by Vogel for stable isotope geochemistry, chlorinity and sulphate concentration together with other standard pore water analytical measurements (pH, alkalinity, major cation and anion, trace elements.) | | | |
| Robert Udisti (IT) | Sediment and volcaniclastic rocks geochemistry | Attend core workshop. May contribute to the Initial report. Contribute trace element characterisation (using HR-ICP-MS) and isotopes (Sr-Nd) of sediments and bulk volcaniclastic rocks . Possible collaboration with Adriana Bellanca (bulk XRF), Gerhard Kuhn, Lother Viereck-Goette (XRF scanning) and volcanic petrology group. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | 5m | 20cc | 240 |
| Riccardo Vannucci (IT) | Geochemistry and petrology of volcaniclastics rocks | Attend core workshop. May contribute to the Initial report. Contribute to the geochemical characterisation (using LA-ICP-MS and Ion beam analysis) of the glass shards and minerals in volcaniclastic rocks in collaboration with Massimo Pompilio and the wider volcanic petrology group. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. | where appropriat e | 100-200cc | 80-100 |
| Andreas Veit (DE) | Geochemistry and petrology of volcaniclastics rocks | Attend core workshop. May contribute to the Initial report. Undertake geochemical characterisation of primary volcanic material (glass using EMP and LA-ICPMS). Collaborate with large volcanic petrology group. | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. Attend core workshop. | where appropriat e | 5g | 80 |

TABLE 2 cont'd

| Name | Discipline | Post-ice research responsibilities | Post-ice analyses | Sampling interval | Sample size | Number of samples |
|---|---|---|---|---|---|---|
| Lothar Viereck-Goette (DE) | Sediment geochemistry-XRF core scanning | Attend core workshop. Continue work on whole rock bulk XRF calibration of XRF scan data with Gerhard Kuhn and contribute to the provenance, erosional history and paleoclimatic interpretation of the core. XRF data will form a key component of the integrated dataset that will be of interest to many of the MIS ANDRILL Science Team | Further analysis of data, interpretation synthesis and integration with other teams. More sampling may be required. Attend core workshop. | see Kuhn | | |

TABLE 3

| | Name | Discipline | On-ice research responsibilities | Primary work location | Shift |
|---|---|---|---|---|---|
| **TOTAL PERS** | **Name** | | | | |
| 1 | Tim Naish (NZ) | Co Chief Scientist | Overall leadership and management of MIS science activities. | CSEC/Drill Site | Flexible |
| 2 | Ross Powell (US) | Co Chief Scientist | Overall leadership and management of MIS science activities. | CSEC/Drill Site | Flexible |
| 3 | Richard Levy (SMO) | Staff Scientist | Responsible for ensuring the effective implementation of the MIS science plan by managing and supporting science operations. Management of DTLs, EPO Coordinator, Curator, Research Support Coordinator, Database Coordinator. Reports to Co-Chief Scientists. | CSEC | Flexible |
| 4 | John Jackson (SMO) | EPO Co-ordinator | Leadership of the ARISE Programme educators and coordinator of ANDRILL's EPO efforts and affiliated EPO projects. Reports to the Staff Scientist. | CSEC | Day |
| 5 | Laura Lacy (SMO) | Research Support Coordinator | Coordinates all research support. Works with Crary Lab manager, RSPC, USAP. Reports to Staff Scientist. | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 6 | Megan Berg (SMO) | Graphics and web | Web site management and graphics. Reports to Staff Scientist. | CSEC | Day |
| 7 | Josh Reed (CHRONOS) | Database Coordinator | Coordinates data management and visualisation systems. Reports to Staff Scientist. | CSEC | Flexible/Night |
| 8 | Matt Olney (US) | Head Curator | Manages curatorial team. Night-shift curator. Reports to Staff Scientist. | CSEC | Night |
| 9 | Matt Curren (US) | Assistant Curator | Day-shift curator. Reports to Head Curator. | CSEC | Day |
| 10 | Charlene King (US) | Core processor | Core splitting and sampling. | CSEC | Day |
| 11 | Kelly Jemison (US) | Core processor | Core splitting and sampling. | CSEC | Day |
| 12 | Steve Petrushak (US) | Core processor | Core splitting and sampling. | CSEC | Night |
| 13 | Davide Persico (IT) | Core processor | Core splitting and sampling. | CSEC | Night |
| 14 | Betty Trummel (US) | ARISE | Micropaleontology, porewater and curatorial | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 15 | LuAnn Dahlman (US) | ARISE | Porewater microbiology, XRF spectrophotometry | CSEC | Day |
| 16 | Vanessa Miller (US) | ARISE | Sedimentology, micropaleontology | CSEC | Day |
| 17 | Julian Thomson (NZ) | ARISE | Paleomagnetic sampling, sedimentology, smear slides | CSEC | Day |
| 18 | Alexander Siegmund (DE) | ARISE | XRF spectrophotometry | CSEC | Day |
| 19 | Matteo Cattadori (IT) | ARISE | Paleomagnetic sampling, clastology | CSEC | Day |
| | | **Sedimentology** | | | |
| 20 | Larry Krissek (US) | Discipline Team Leader/ sedimentology | Leadership and coordination of the sedimentology/stratigraphy team. Responsible for the sedimentology sections of the On-Ice and Initial Science Reports. Reports to Staff Scientist and Co-chiefs. | CSEC | Night |
| 21 | Robert McKay (NZ) | Sedimentary petrology | Thin section description and smear slides. | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 22 | Lionel Carter (NZ) | Marine sedimentology | Day-shift lead sedimentologist. Check core description. Co-ordinate summary logs and interpretation. Discipline integration (until late Nov). | CSEC | Day |
| 22 | Greg Browne (NZ) | Sequence stratigraphy | Day-shift lead sedimentologist. Check core description. Co-ordinate summary logs and interpretation. Discipline integration (after late Nov). | CSEC | Day |
| 23 | Ellen Cowan (US) | Glacial sedimentology | Core description team. | CSEC | Night |
| 24 | Gavin Dunbar (NZ) | Facies analysis | Core description team. | CSEC | Night |
| 25 | Thom Wilch (US) | Volcaniclastic sedimentology | Core description team. | CSEC | Night |
| | | **Paleontology/biostratigraphy** | | | |
| 26 | Reed Scherer (US) | Discipline Team Leader/ diatom | Leadership and coordination of the paleontology and biostratigraphy team. Responsible for the paleontology/biostratigraphy sections of the On-Ice and Initial Science Reports. Reports to Staff Scientist and Co-Chiefs. | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 27 | Mike Hannah (NZ) | Marine palynology | Marine palynological analysis, paleontology support. | CSEC | Day |
| 28 | Paola Maffioli (IT) | Paleontology Tech | Diatom and foraminifera sample preparation. | CSEC | Day |
| 29 | Kevin Mandernack (US) | Microbiology | Microbiological sampling of unlithified section of the core and preparation of samples. | Drill site/CSEC | Flexible |
| 30 | Charlotte Sjunneskog (US) | Diatom biostratigraphy | Diatom biostratigraphy and paleontology. | CSEC | Day |
| 31 | Percy Strong (NZ) | Foraminifera | Foraminiferal biostratigraphy and paleontology. | CSEC | Day |
| 32 | Marco Taviani (IT) | Macropaleontology | Macropaleontology and samples for strontium dating. | CSEC | Day |
| 33 | Diane Winter (US) | Diatom biostratigraphy | Diatom biostratigraphy and paleontology. | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| | | **Physical properties** | | | |
| 34 | Frank Niessen (DE) | Discipline Team Leader/ MST scanning | Leadership and coordination of the physical properties team. Science Leader at the drillsite. Responsible for the physical properties sections of the On-Ice and Initial Science Reports. Reports to Staff Scientist and Co-Chiefs. | Drill site | Day |
| 35 | Andrea Catalina Gebhardt (DE) | MST Tech | Technical assistant for MST scanning. | Drill site | Night |
| 36 | Stuart Henrys (NZ) | VSP - seismic stratigraphy | Run VSP experiment and borehole/core seismic correlation. | Drill site/CSEC | Day |
| 37 | Dhiresh Hansaraj (NZ) | VSP - seismic stratigraphy | Assist with VSP experiment and borehole/core seismic correlation. | Drill site/CSEC | Day |
| 38 | Diana Magens (DE) | MST Tech | Technical assistant for MST scanning. | Drill site | Day |
| 39 | Andreas Laeufer (DE) | Whole core fractures | Technical support for whole core scanning and fracture analysis. Contribute to structural analysis of natural fractures in the MIS ANDRILL core. | Drill site | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 40 | Roger Morin (US) | Down hole logging | Acquisition, processing and interpretation of geophysical borehole logs. | Drill site/CSEC | Flexible |
| 41 | Tim Paulsen (US) | Whole core fractures | Examine whole core fractures. | Drill site | Day |
| 42 | Trevor Williams (US) | Down hole logging | Acquisition, processing and interpretation of geophysical borehole logs. | Drill site/CSEC | Flexible |
| 43 | Cristina Milan-Martinez (US) | Whole core fractures | Technical assistant on whole core scanning and fracture analysis. | Drill site | Night |
| 44 | Travis Crosby (US) | Down hole logging | Acquisition, processing and interpretation of geophysical borehole logs and VSP. | Drill site/CSEC | Flexible |
| 45 | Erich Scholz (US) | Hydrofracture/Down hole logging | Manage downhole logging equipment and run hydrofracture experiment. | Drill site/CSEC | Flexible |
| 46 | Terry Wilson (US) | Whole core fractures/hydrofracture | Leader of whole core scanning and fracture studies. Hydrofracture experiment. | Drill site | Night |
| | | **Geochronology/Chronostratigraphy** | | | |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 47 | Gary Wilson (NZ) | Discipline Team Leader/ paleomagnetism | Leadership and coordination of the Geochronology/Chronostratigraphy team. Responsible for the chronostratigraphy sections of the On-Ice and Initial Science Reports. Some members of the biostratigraphy team will also contribute to this team. Reports to Staff Scientist and Co-chiefs. | CSEC | Day |
| 48 | Fabio Florindo (IT) | Paleomagnetism | Sampling oriented core plugs for paleomagnetic analysis and measuring NRM. | CSEC | Day |
| 49 | Christian Ohneiser (NZ) | Paleomag Tech | Assistance with sampling oriented core plugs for paleomagnetic analysis and measuring NRM. | CSEC | Day |
| | | **Geochemistry/Petrology** | | | |
| 50 | Massimo Pompilio (IT) | Discipline Team Leader/ igneous petrology | Leadership and coordination of the Geochemistry/Petrology team. Responsible for the geochemistry/petrology sections of the On-Ice and Initial Science Reports. Reports to Staff Scientist and Co-Chiefs. | CSEC | Day |

TABLE 3 cont'd

| | | | | | |
|---|---|---|---|---|---|
| 51 | Gerhard Kuhn (DE) | XRF core scanning | Lead XRF scanning of the split core. | CSEC | Day |
| 52 | Donata Helling (DE) | XRF core scanning | Assist with XRF scanning of the split core. | CSEC | Night |
| 53 | Phil Kyle (US) | Igneous petrology | Assist with volcanic examination of cores, select samples Ar dating, select samples for off-ice geochemistry. | CSEC | Day |
| 54 | Brent Pooley (NZ) | Petrology tech | Make thin sections and detrital grain mounts for both sedimentary and igneous petrologists. | CSEC | Day |
| 55 | Franco Talarico (IT) | Clast petrology | Clast characterisation through physical description and identification of composition of clasts. Integrated with the sedimentology team. | CSEC | Night |
| 56 | Stefan Vogel (US) | Porewater geochemistry | Squeeze pore water samples for isotope geochemistry and diagenetic processes. Sample carbonate nodules, pebble coatings etc. Total organic carbon measurement, pH, alkalinity | CSEC | Day |